CHAPTER ONE

Consequences of living in an industrial world

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Introduction

One of the first questions that faced us when preparing this introductory chapter was 'what do we mean by industry?' In modern terms, one often refers to the industrial revolution that began in the latter half of the eighteenth century, which circumscribes the change from an agriculturally based economy to one dominated by manufacturing. However, industrial processes have a history far longer than this, and can be traced back to the Bronze Age and even before, particularly the extraction of minerals. We could also consider agriculture to be an industry as it is the extraction of raw resources albeit in a rather different form. Therefore when we refer to industry, we are actually considering a very wide range of processes and activities. Common to all these, however, is the fact that the production of goods from raw resources creates by-products that can pollute the environment and adversely affect ecosystems.

The industrial pollutants produced and their impacts are potentially as varied as the sources from which they derive, and there has been extensive research into specific effects of individual contaminants on specific organisms or communities. The problem with this approach is that the resulting view is one that can be rather blinkered. It is becoming increasingly clear that, rather than simply causing deterioration of ecosystems, contaminated sites may well be sources of biodiversity. Organisms living on such sites can show great genetic adaptation and may prove useful in the remediation of other contaminated sites. In addition, the limitations of ecological monitoring have potentially caused problems in the assessment of impacts, and the detachment of research into remediation from that of ecotoxicology has resulted in inappropriate application of technologies and poor results in terms of restoration or remediation. Within this volume, we have tried to select a number of different types of industry in order to illustrate these general themes. It should be noted that, although many industrial processes release(d) carbon dioxide and other greenhouse gases into the atmosphere, we

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have chosen not to cover this topic within this volume. Climate change is linked to many different causes (not just industry) and the discussions surrounding this area are sufficiently complex to merit their own substantial volume. However, it may be said that many of the key processes that result in impacts on ecological systems and the limits to restoration ecology could be extremely important in predicting responses and adaptation to climate change.

Impacts of industry

It is interesting to note the changing attitudes to industrial activity over the years as nations develop. A good example of this is the activities associated with the Parys Mountain copper mine on Anglesey, UK. In letters written in the late eighteenth century by a professor studying the mining around the area, it is reported that the copper is sent to factories in Flintshire where '…the view of the valley…is particularly charming because the cotton spinning mills are lit up from top to bottom and reflected in the ponds…' and '… I think this is the prettiest valley that I have ever seen…. Poverty and misery are not to be found' (Rothwell 2007). In contrast, Greenly (1919), when commenting on the mining area itself reports that the '…higher and central portions are of the most utter desolation imaginable'. It is easy to forget that the industrial revolution led to great improvements in the wealth of many nations and did indeed have positive impacts on human health (as well as the more widely reported negative impacts). However, over the last decades the negative view of industry as a major source of contamination to the environment has increased in volume, particularly in recent years with the issue of climate change. If we examine the effects of industry upon the ecological environment, then typically reports are of reduced biodiversity either through the direct toxic effects of pollutants or through indirect effects on habitat quality and food webs. In this volume, Purvis et al. (Chapter 3) and Batty et al. (Chapter 4) provide examples of this as a result of air and water pollution, respectively.

It is the recognition of these negative impacts of industrial pollutants on the environment that led to significant advances in the protection of both human health and environmental health from the effects of pollution since the industrial revolution. If we take air pollution as an example, then we can see that over time changes in legislation and critically the Clean Air Act of 1956 have acted to both reduce the incidences of respiratory illness and to significantly reduce the concentrations of sulphur in the air, resulting in re-establishment of clean air ecology (particularly lichens) in many previously affected areas (Chapter 3). Equivalent legislative changes for freshwaters and soils have also been implemented with the focus mainly on the protection of human health. However, in recent years there has been a change in emphasis within developed countries to also consider ecological health, as the importance of the function of ecosystems in the health of the human environment has been recognised. The EU Water Framework Directive (WFD) is a key example where it is not simply the chemical environment that is considered, but a healthy ecological status is also a key objective.

Through changes in legislation there has gradually been an improvement in the quality of many environmental compartments within the landscape. However, in many parts of the world, legislation is underdeveloped, or not sufficiently implemented, resulting in continuing threats to the ecological health of the receiving environment. In addition continuing advances in technology result in new pollutants such as those from the nanotechnology and pharmaceutical industries (Chapter 5), and critically the effects of these on organisms are largely unknown.

The long history of global industrial activity has led to the accumulation of contaminants within the environment, especially where the pollutants in question are persistent. It is therefore extremely important that, when considering the impacts of industry, we also recognise the potential contribution of these historical sources to the impacts on current ecological communities. Floodplain deposits, in-river sediments and ancient mine workings are a few examples where old contamination can still affect present day ecosystems (Chapter 2, Chapter 13 and Chapter 14, respectively).

It is a clear ecological concept that environmental heterogeneity within a landscape can drive biological diversity (e.g., see Hutchings *et al.* 2000), but this can also be true within polluted environments (Chapter 2). The presence of highly metalliferous soils upon naturally occurring outcrops of metal ores has led to the adaptation of a number of species (particularly plants, lichens and bacteria) to these conditions, and indeed some may only survive where metal concentrations are high. The exploitation of these resources by man has led to these communities being extremely rare, but they can often survive and proliferate on abandoned sites. The lead rakes of the Peak District are a prime example of this, where calminarian grasslands can be found (Barnatt & Penny 2004). However, changing environmental legislation, the decline of industrial activity and potentially also environmental change now pose a significant threat to these highly biodiverse areas. For example, the requirement to meet the objectives of the Water Framework Directive may result in the removal or remediation of metal sources, such as spoil heaps from the environment. A number of different threats to these unique communities are identified by Baker *et al.* (Chapter 2).

More modern remains of industry are also proving to be valuable as refuges for threatened species. The move from a manufacturing based economy to one based largely on service industry within many countries in the developed world has led to large areas of so-called brownfield land, which are often contaminated by a mixture of pollutants. The lack of human access, together with particular environmental conditions has allowed the colonisation of these areas with a range of species. Although this has not been dealt with in this volume, readers are directed to Chapter 3 of Natural England's Report on the State of the Natural Environment (2008).

Monitoring ecological response to pollution

If we are to determine the impacts of pollutants upon ecosystems and their recovery following remediation, it is absolutely essential that we have a robust method of monitoring. There have been significant advances in the methods of monitoring freshwater systems, details of which are provided in Jones *et al.* (Chapter 6); however, it is clear that there are several challenges to be met. The first of these is to define what is meant by the term 'reference condition'. It is a term used in many key pieces of legislation (including the WFD) to assess an ecological community in relation to the community that is expected to be present based on 'reference conditions'. However, due to the extent of human impact both on a temporal and spatial scale it is difficult to find a 'real' example of this, or to model one. It is the general consensus that, when tackling pollution within the environment, the aim is not to attain a reference condition that reflects pre-industrial conditions (Chapter 6) but rather to achieve high quality and sustainable water resources. However, as Gell points out (Chapter 8), it may be preferable to have pre-industrial baseline targets due to future risks from pollutants (in the form of sediments) on the longevity of a system (current evaluation of status shows little divergence from a standard reference condition). The relative value of monitoring against some ideal ecological community is a concept that is clearly questionable.

There has been far less progress in the ecological monitoring of either land or marine environments in terms of ecological impacts. It is suggested that, rather than using a similar system used for freshwaters where the physical environment is very different, for marine environments sediment toxicity testing to monitor lethal and more importantly sub-lethal effects would be more beneficial (Chapter 7). This idea that sub-lethal effects may be of critical importance is also highlighted in other systems where there is a need for new toxicity tests for emerging contaminants due to the inappropriate nature of existing tests that lack subtle endpoints (Chapter 5). The assessment of land contamination is notoriously difficult due to the extremely heterogeneous nature of soils which strongly control the bioavailability of contaminants. There has been some attempt to assess contamination using chemical approaches (production of Soil Guideline Values for a number of contaminants), but the limitations of these are extensive, and there is little if any link to the ecology of the area. Recent work has made progress in providing a much clearer link between land contamination and associated communities using a risk-based approach (Chapter 9), and the success of this approach will be monitored in forthcoming years.

Remediation and ecological recovery

We now return to the previous question of 'reference conditions'. Whenever the remediation of a contaminated site and its associated ecological recovery is considered, a 'target' must be defined by which the remediation activity can be deemed a success. However, as we have previously highlighted, there is a question as to where this point should lie. Is the aim to return an environment to its pre-contaminated conditions, or alternatively should the target be a particular community composition, such as the presence of a rare species, or more generally a sustainable water resource? It appears that returning a particular habitat to its pre-industrial conditions is an unrealistic goal for two main reasons. The first of these is a lack of good quality data that provide a detailed characterisation of the abiotic and biotic components of any environment. Although there has been some attempt to use palaeoecological data (Chapter 8), this is limited in many environments due to preservation, and the lack of consistency in methods and data analysis has been highlighted (Chapter 6). The second is that, even where more recent data are available, it is evident that the community does not return to its previous state even when given sufficient time. Tibbett, Williams *et al.*, Langford *et al.*, Batty *et al.* and Purvis (Chapters 15, 14, 13, 4 and 3, respectively) all report that, despite improvements in the physico-chemical environment, either through a decline in industry or active remediation activities, the community does not return to its pre-contaminated state (or other target condition). This constraint to recovery is probably due to the lack of sources of colonising organisms, lack of physical habitat (although chemical conditions may improve), the impact of other pollutants in the environment (other than those directly targeted by remediation) and transfer of industrial pollutants from long-term sources (such as sediments) not tackled by remediation. In addition, ecological function may continue to be impaired as a result of the changes in community structure, although there is little information on the causes of ecological dysfunction in recovering communities (Chapter 15).

The presence of adapted organisms on industrially contaminated sites provides a potential opportunity to exploit these organisms for either the stabilisation of such sites or active remediation. The potential for using metallophyte plants in the remediation of metalliferous soils has been postulated for a number of years and successfully applied in some cases; however, this potential is rather under-exploited due to a lack of knowledge of the mechanisms of adaptation and metabolic and genetic responses to pollutants (Chapter 2). Rather more progress has been made in the use of bacteria in remediation activities, particularly where the land is contaminated by organic pollutants or radionuclides (Chapters 12 and 11, respectively). Advances in knowledge of the genetics involved in adaptation of microorganisms and mechanisms of action in remediation processes (Chapter 10) provides great potential for these organisms to be applied in many situations, particularly where there are problems of mixed contaminants.

Conclusions

This volume provides an overview of the impacts of industrial pollution, ways of monitoring and remediation and recovery of such systems. It is clear that, although in many countries the main polluting industries have now declined or in fact ceased, the legacy of industrial activity continues to affect ecological communities, and changes in industrial processes now provide new potentially harmful substances within the environment. The need therefore to understand the links between the contaminating substances and the ecological responses both on an individual organism and whole ecosystem level is vital. Only when this is achieved will we be able to appreciate the full extent of the impacts, provide appropriate monitoring schemes and design remediation strategies that best tackle the specific problems. A number of key questions arise within this volume:

How important is pollution in driving diversification in communities?
To what extent do polluted areas constitute a valuable habitat for rare species?
What are the limitations of resilience and/or functional redundancy within an impacted community?
Is biomonitoring effective and accurate in assessing the extent of contamination within an environment?
Are 'reference conditions' helpful in either monitoring or restoration/remediation?
Can adapted organisms effectively be used in remediation technologies and how can this potential be maximised?

Although significant progress has been made in all these areas, there is clearly the need for further research in order to create more integrated and sustainable management of our industrial areas (Chapter 16).

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CHAPTER TWO

Metallophytes: the unique biological resource, its ecology and conservational status in Europe, central Africa and Latin America

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Introduction

Metalliferous soils provide very restrictive habitats for plants due to phytotoxicity, resulting in severe selection pressures. Species comprising heavy-metal plant communities are genetically altered ecotypes with specific tolerances to, e.g., cadmium, copper, lead, nickel, zinc and arsenic, adapted through micro-evolutionary processes. Evolution of metal tolerance takes place at each specific site (Ernst 2006). A high degree of metal tolerance depends on the bioavailable fraction of the metal(loids) in the soil and the type of mineralization. At extremely high soil metal concentrations, especially on polymetallic soils, even metal-tolerant genotypes are not able to evolve extreme tolerances to several heavy metals simultaneously. Adapted genotypes are the result of the Darwinian natural selection of metal-tolerant individuals selected from surrounding non-metalliferous populations (Antonovics *et al.* 1971; Baker 1987; Ernst 2006). Such selection can lead ultimately to speciation and the evolution of endemic taxa. Heavy-metal tolerance was first reported by Prat (1934) in *Silene dioica* and demonstrated experimentally in grasses by Bradshaw and co-workers in *Agrostis* spp. and by Wilkins in *Festuca ovina* in the late 1950s and 1960s (see Antonovics *et al*. 1971) and from the early 1950s onwards in the herb *Silene vulgaris* by Baumeister and co-workers (see Ernst 1974). Metal-tolerant plants avoid intoxication by an excess of heavy metals by means of special cellular mechanisms, as long as the soil metal levels do not exceed the levels of metal tolerance (Ernst 1974; Ernst *et al.* 2004). They can thus thrive on soils that are too toxic for non-adapted species and ecotypes. These unique plants with an ability to tolerate metal toxicities and survive and reproduce on metalliferous soils are called *metallophytes*.

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(a)

(b)

Figure 2.1. Metallophyte vegetation on ancient lead-mining sites in the UK. (a) Sparse cover of *Agrostis capilliaris* and *Silene uniflora* on acidic wastes at Goginan lead mine, central Wales; (b) Continuous metallophyte turf colonising superficial mine workings at Gang mines, near Matlock, Peak District. The calcareous substrate here and mosaic of metal contamination levels produce a rich assemblage of metallophytes including *Minuartia verna* in the most metal-contaminated areas. Photos: A. J. M. Baker. See colour plate section.

Heavy-metal sites and their vegetation in Europe

Evolution and distribution of metallophytes

After the last Quaternary Ice Age, forest developed on nearly all soils in Europe, except on those with extreme climatic or edaphic conditions. In the latter group are soils with elevated concentrations of heavy metals, too toxic for trees. In such situations, shadow-sensitive xerophytes were able to survive when they had the genetic advantages in metal tolerance (Ernst *et al.* 1992). Heavy-metal-tolerant vegetation was originally restricted to natural outcrops of metal ores, scattered as a relic of the Late Glacial epoch over Europe. Most of these habitats were destroyed or modified by mining activities from the Bronze Age onwards. However, metal mining has considerably enlarged the potential habitat range by creating further areas of metal-contaminated soils (Ernst 1990; Ernst *et al*. 2004). In Europe, sparsely distributed sites with metal-enriched soils form residual sanctuaries for metallophyte communities. Most sites are disconnected spatially and are of very limited extent. The UK has many sites in Wales (Davies & Roberts 1978), the Peak District (Barnatt & Penny 2004) and the North Pennines, and some isolated sites in Cornwall and in the Mendips (Ernst 1974; JNCC 2002). The central part of Germany is well-known for its heavy-metal vegetation (Schubert 1953, 1954; Ernst 1964, 1974; Becker *et al.* 2007). Alluvial heavy-metal vegetation occurs along the rivers Innerste and Oker in the Harz Mountains. In the Mansfeld area, several hundreds of large Cu-Pb-Zn-mine spoil heaps are scattered with metallophyte communities (Schubert 1953; Ernst & Nelissen 2000). In the European Alps in Austria, Slovenia and Italy, in the French Pyrenees, and several small sites are known in the Spanish Picos de Europa. The most studied and extensive communities are those of the three-border area of Belgium, the Netherlands and Germany, the Harz Mountains area and the Pennine orefield in the UK. Metallophyte vegetation makes up an important component of the biodiversity of Europe (Whiting *et al*. 2004).

Thalius (1588) was the first to recognise a relationship between the plant *Minuartia verna* and heavy-metal-enriched soils in the Harz Mountains, Germany. Subsequently, the association of the plant with lead-mine wastes in the Pennine orefield, UK, gave rise to its local name 'leadwort'. Schulz (1912) speculated that *M. verna* is in fact a glacial relict species surviving on heavy-metal soils as an isolated population; this was later confirmed by genetic analysis (Baumbach 2005). Libbert (1930) then defined the *Armerietum halleri* as a plant association specific to metalliferous soils, and the *Violetum calaminariae* was described from the Breiniger Berg near Aachen by Schwickerath in 1931. Plant associations specific to metal-enriched soils were thus recognised.

Types of heavy-metal sites

The history of metal sites determines the species composition of the vegetation. Three types of heavy-metal vegetation can be distinguished on syntaxonomy and on their occurrence: primary, secondary and tertiary.

Primary sites

Primary sites are those with metallophytes where elevated concentrations of metals are due to natural mineralisation or ore outcropping, and not that which is anthropogenically influenced. Primary sites in Europe are therefore extremely rare today and mostly found as very patchy small sites in Central Europe, in the Pyrenees and in the Alps (Ernst 1974). Virgin sites like those in tropical woodlands and rainforests (Duvigneaud 1958; Brooks *et al.* 1985) are virtually non-existent, although many of the African sites are also threatened by mining activities (Leteinturier *et al*. 1999). Besides a high concentration of metals like zinc, lead, cadmium or copper in soil, heavy-metal vegetation types are characterised by a low nutrient availability. Hence, these plant communities are of very low productivity.

Secondary sites

Almost all primary metal-enriched sites in Europe have been anthropologically influenced by mining activities. These secondary sites result from mining activities, e.g., disturbed primary sites, spoil and slag heaps, ore processing and concentration (beneficiation) areas. The distinction between primary and secondary is often difficult to elaborate especially with ancient sites. Early mining has diminished most primary occurrences of metallophytes. From the Bronze Age to the late Middle Ages mining had a relatively low impact on the local environment. Metallophytes occurred locally on primary sites, and superficial mining created secondary habitats. Both habitat types were ecologically very similar. At that time mining was restricted to areas with metals outcropping. After the Middle Ages, much larger secondary habitats were created, often far away from areas with primary habitats, by deep underground mining or by metal refining on site. Exceptionally high concentrations of metals in soils at primary habitats result from weathering of natural mineralisation on well-developed soils. Modern secondary habitats, however, have a totally different substratum; mining has created soils with altered metal composition, depleted phosphorus and organic matter concentrations and low water retention capacity. Besides evolving metal tolerance, plants growing on these wastes were co-selected for tolerance to P-deficiency, resistance to drought and an ability to grow on loose substrates (Ernst 2000). This has affected the edaphic conditions and is a major cause of differences between primary and early secondary habitats.

Tertiary sites

Tertiary metal vegetation types can be subdivided into those communities whose genesis is a result of atmospheric deposition in the vicinity of metal smelters or alluvial deposition of metal-enriched substrates by sedimentation