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Global Use of Bioremediation Technologies for Decontamination of Ecosystems

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problems has been carried out. There were respondents from all continents (except Antarctica), though North America was comparatively over-represented. Despite a high aspiration to apply bioremediation techniques, this was not borne out in current practice. Air pollution was the lowest priority. Otherwise, a clear association was seen between the per capita income of a region and the concerns, remediation techniques and research practice adopted. For example, contamination of groundwater had higher priority in developed countries/regions. Toxic metals and aromatic hydrocarbons were the most common concern, while alkyl halides were of greater concern in North temperate (comparatively economically developed) countries than elsewhere. Only 15-35% of respondents used online databases to guide the design of their experiments, and these were largely restricted to North America and Europe, three quarters of US respondents used modelling software compared with about a third elsewhere. Consequently, while the developed economies made higher use of low-cost in situ bioremediation technologies (e.g. Monitored Natural Attenuation), their developing counterparts appeared to focus on the more expensive, sometimes ex situ, technologies. Despite the significant investment in and widespread availability of online resources, their limited use emphasizes the need to explore avenues for improved training and the development of more user-friendly resources. In this regard, this survey has produced a bioremediation research wish list to guide such developments. The data from this survey may also contribute to policy-decision making worldwide.

Keywords: Microbial bioremediation; Phytoremediation; Xenobiotics; Bioinformatics; Mathematical modelling; Global survey

Introduction

Contamination of ecosystems by xenobiotic compounds (including various organic petroleum hydrocarbons, pesticides and other agrochemicals, pharmaceutical products and heavy metals) causes ecological problems leading to serious environmental problems [1-5]. Attempts at remediating contaminated sites have used conventional but often costly approaches, such as 'pump and treat', excavation and removal, soil vapour extraction, and other chemical treatments [6]. These methods are time consuming, invasive, disruptive to natural habitats and usually result in a rearrangement of the problem [3]. Using these methods, it is estimated that the cost of reinstatement of all contaminated sites in the United States alone is approximately US $1.7 trillion [7]. Lately however, bioremediation has proven to be a safe, effective, low-cost and environmentally friendly alternative for sustainable remediation of environments contaminated by hazardous and recalcitrant pollutants [3,8-11]. Bioremediation uses biological processes and naturally occurring microbial catabolic activity to eliminate, attenuate or transform contaminants to less hazardous products such as carbon dioxide, water, inorganic salts, and microbial biomass [10,12-14].

Bioremediation generally has high public acceptance and can be carried out in various environmental media for a wide variety of organic and inorganic compounds [14]. However, bioremediation research and practice are currently still hampered by an incomplete understanding of the genetics and genome-level characteristics of the

in situ techniques [14,15,21].

There have been various reports of biodegradation and bioremediation activities utilizing particul ę
have implemented strategies for clean-up of soils and groundwater, comparing clean-up costs, and related opinions on the use of non-

sufficiently high [2,44,46,47] to be judged a good estimate of the wider population and provides relevant data to prioritize R&D within the sector.

Table 1 shows the geographic distribution of the responses, which included all continents except Antarctica. The majority of the respondents were from North America. Using the number of research publications and citations as an estimate a country's research base, the observed profile might reflect the relative size of the research bases of the countries represented. It appears to agree with national rankings extracted from the Essential Science Indicators database of Thomas

were clearly of greatest concern in all climatic zones. There were however marked differences in the distributions, for chlorinated solvents, particularly TCE (Trichloroethane) and PCE (Perchloroethane). Only 33% of respondents from Africa and 22-28% from Asia highlighted TCE and PCE as highly important, while 45-60% from Europe and 62-75% of respondents from North America (both in the North temperate region) were concerned about these.

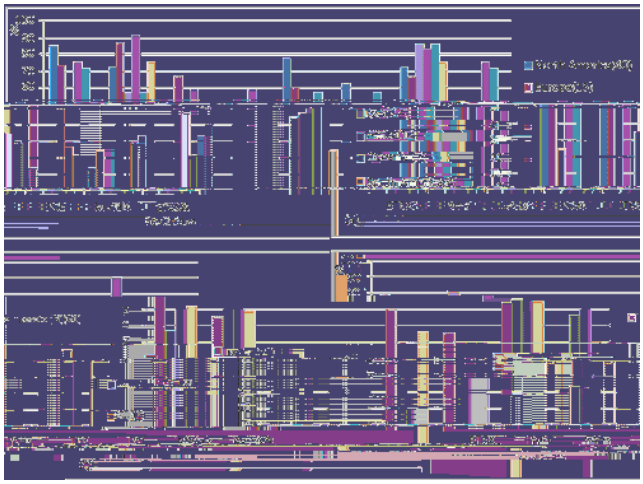

Figure 2: Major contaminants encountered, distributed according to (a) continents and (b) climatic zones. All results expressed as percentages of total respondents in each category: **BTEX**: Benzen_ γp

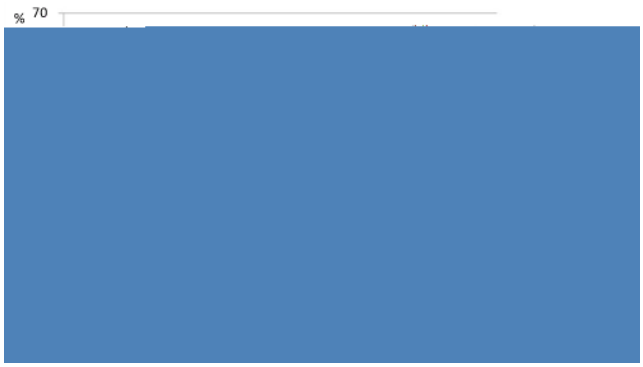

Figure 4: Methods for identifying candidate microbes, expressed as percentages of the total number of respondents in each category, shown in parenthesis

It is remarkable that only half of the respondents sought information from published literature, given the vast amount of information available in both print and online repositories like PubMed, Web of Science, Scopus and Web of Knowledge. This could be because the information is currently not in a form that can be easily accessed and used, or that wading through copious textual output is time-consuming and discouraging, or even that it is difficult to easily detect general trends and patterns from reading individual articles. It may also be that the process conventionally requires submission of multiple queries in order to glean useful information. This finding is particularly pertinent, given the recent advances and improvements in text/data mining software [61] and point to a potential area for the application of bioinformatics/computational biology techniques to bioremediation research.

Use of information resources and modelling software for guidance

The survey also sought to find out the extent of use of biochemical, enzyme and pathway databases, and the usage of existing

specific techniques employed under each of the broad headings. The use of low-cost *in situ* technologies (like MNA) featured quite

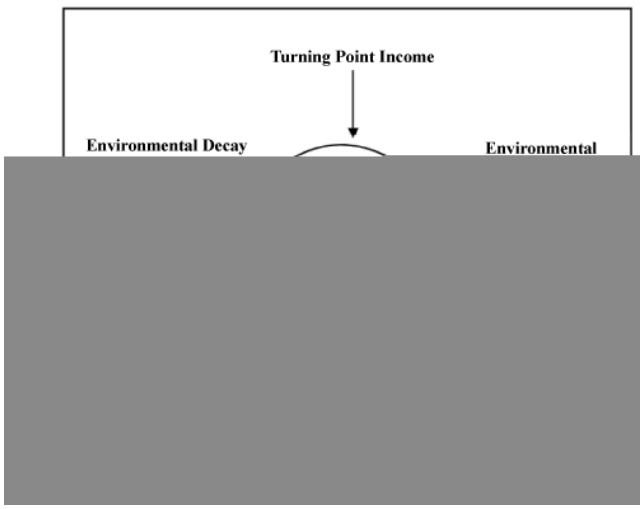

Figure 8: Graphical representation of Environmental Kuznets Curve. Source: Yandle et al. [81]

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