Biopollution

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Biopollution describes the biological pollution caused by the introduction of non-indigenous species into biogeographic regions where they were not present before. It is considered one of the main threats to environmental health, and it is a factor of disturbance that can be consistently viewed as a pollution agent, albeit of a different nature if compared with physical and chemical factors. Ecosystem deterioration may be induced by the development of massive alien population outbreaks following introduction events. Biopollution assessment procedures have been proposed, adopting criteria already used for xenochemical compounds. Also prevention and mitigation measures to reduce biopollution impact have been developed in a similar way as for chemical pollution.

biological invasions | pollution management | global change

1. Introduction

Non-indigenous species (NIS) (synonyms: alien, exotic, non-native, allochthonous, and introduced) are species, or lower taxa, occurring outside their natural range (past or present) and dispersal potential. This includes any part, gamete, or propagule of such species that might survive and subsequently reproduce.

The idea of translating definitions and concepts used in marine pollution assessment and control into the field of biological invasions was proposed under the name of biopollution [1].

The presence of NIS in a given region is either due to an intentional or unintentional introduction, resulting from human activities, or due to their arrival without human assistance from an area where they are alien. Human action transports species across environmental barriers that include land masses or hydrographic separation. It should be noted that in the case of climate altering the distribution of species, these should not be qualified as NIS, unless there is evidence that these species have been spread by humans. A species is defined as cryptogenic, when it cannot be reliably demonstrated as being either introduced or native (because of insufficient taxonomic knowledge or due to a lack of records) [2].

The distinction between “biological introductions” and “biological invasions” is an important one, because the two terms are often used interchangeably. Not all introductions of NIS result in large effects such as those experienced by bioinvasions. Moreover, an invasion may be caused by either natural or human activities, while an introduction is always human mediated, either intentionally or unintentionally. The sharp increase in the frequency, magnitude, and geographic span of biological invasions is almost entirely due to human activities. Invasive alien species (IAS) are a subset of established NIS that have spread, are spreading, or have demonstrated to be able to spread elsewhere, causing adverse effects within invaded regions [3]. Cryptogenic species may demonstrate invasive characteristics and so may be included in IAS assessments. It should be noted that invasive species that cause harmful effects are not necessarily alien. Native organisms can also attain high levels of abundance and so interfere with human activities, impacting the environment or modifying local biodiversity

The number of records of aquatic NIS is steadily growing since the last 50 years [4]. Detection rates, however, are variable within and across regions and ecological domains through time. The knowledge-base on NIS continuously expands and many databases are collecting information on NIS. Currently, there are more than 250 websites on NIS, along different geographical ranges (a few examples are reported in Table 1). Besides inventories of NIS, information on NIS origin, introduction history, pathways, vectors, actual distribution, and more are provided by most databases. The databases have been used increasingly for scientific analyses, though key information required for bioinvasion management and research are only partially reported.

Table 1. Examples of data bases containing information on introduced species at the global and regional level.

Data Base	Web Address (accessed on 11 May 2021)
GISD-Global Invasive Species Database	http://www.iucngisd.org/gisd/
CABI Invasive Species Compendium	http://www.cabi.org/isc/
WRiMS-World Register of Introduced Marine Species	http://www.marinespecies.org/introduced/
Invasive and exotic species of North America	https://www.invasive.org/
National Invasive Species Information Center - US Department of Agriculture	https://www.invasivespeciesinfo.gov/
NAS-Nonindigenous Aquatic Species - US Geological Service	https://nas.er.usgs.gov/
EASIN-European Alien Species Information Network	https://easin.jrc.ec.europa.eu/easin
AquaNIS-Information system on aquatic non-indigenous and cryptogenic species	http://www.corpi.ku.lt/databases/index.php/aquanis/
NOBANIS North European and Baltic Network on Invasive Alien Species	https://www.nobanis.org/about-nobanis/
Invasive species in Belgium	http://ias.biodiversity.be/

Biopollution is a dynamic process: for instance, the spread of a species within a biogeographical region after having been introduced from elsewhere has raised special interest. In this case, the primary inoculation consists of an arrival from a distant source. Secondary spread is defined as the transport to new regions within the same biogeographical area following establishment. Secondary spread may disperse alien biota more efficiently and so could compromise the ability to manage the invasion. The establishment and spread of NIS seem directly linked to propagule pressure, which has been recognised as the major factor in the success of an invasion and depends on the quality, quantity, and frequency of invaders.

2. Impacts of NIS

Adverse effects of NIS (especially invasive species) on ecosystems have been shown as biodiversity loss, alteration of food webs, physical habitat disruption, and import of parasites and diseases. Moreover, a progressive homogenization of biota across regions and continents, as a consequence of increased translocation of species, is raising concern among ecology students [3].

While information on the total number of non-indigenous species, their traits, invasiveness potential, and vectors of spread has accumulated in many parts of the world, scientific evidence is still generally scanty to draw general conclusions on the real magnitude of their ecological impact . Communities of organisms can change over historical (ecological) time in three ways: species can be deleted (extinctions), added (invasions), or can change in relative abundance. Ecological functions can change dramatically over time, or else changes can become evident only after long periods of innocuous presence of the alien species. Such cryptic processes may lead to an underestimation of the long-term impacts and constrain the effectiveness of management actions.

Biological introductions have implications for environmental quality. As with chemical pollutants, consequences can be detected at the individual level (as in the case of attacks by parasites or pathogens), or at the population (by genetic change, i.e., hybridization), or at the community level (by structural shifts). Habitat (by modification of physical–chemical conditions) and ecosystem changes (by alteration of energy flow and organic material cycling) are also possible. Some biopollution assessment methods have been proposed in order to classify the impact on natural ecosystems, while measures of the more complex assessment of economic impact are rare. Functional consequences of invasive NIS have not been explored extensively, yet published studies show that species addictions affect ecosystem functioning (e.g., productivity, biogeochemical cycles, and decomposition) and biotic relations (e.g., prey–predator interactions, and introductions of parasites and diseases). These effects will contribute to ecosystem functioning in complex ways and range from almost negligible to dramatic proportions.

In order to describe the relevance of the impacts caused by alien species the IUCN's Environment Impact Classification for Alien Taxa (EICAT) is being proposed as a standard for categorizing alien species' impact. It is used to classify individual alien taxa according to the magnitude of their impacts on native taxa, based on the organizational level in the affected community (https://www.iucn.org/theme/species/our-work/invasive-species/eicat). Impact categories range from Minimal Concern to Massive. If only individual performance is affected, it is considered a Minor impact; if a native taxon is removed from the community (locally extinct or extirpated), it is considered Major or Massive, based on the reversibility of the change. The IUCN EICAT Standard is the product of a long process of developing and adapting frameworks to quantify impacts. One evolution is SEICAT, a standardized method for classifying alien taxa in terms of the magnitude of their impacts on human wellbeing, based on the capability approach from welfare economics. The core characteristic of this approach is that it uses changes in people's activities as a common metric for evaluating impacts on wellbeing.

The INvasive Species Effects Assessment Tool (INSEAT) also contributes to the current scenario of invasive species assessment. INSEAT considers both positive and negative impacts of IAS on ecosystem services (ES) and uses the ES framework, commonly classified into provisioning, regulating, and cultural services. This differs from SEICAT, which uses the constituents of human wellbeing, and from EICAT, which defines its own categories of environmental impacts .

Adverse effects of invasive NIS, or biological pollution, is an increasing problem and is getting the attention of managers and decision makers. The need for assessing the size of the problem and the decision to put in place effective mechanisms to prevent introductions—as well as to contain, control or eradicate the introduced species that may cause damages—are more-and-more felt as an imperative. However, it is very difficult to predict which of NIS introductions may result in detrimental effects on environmental quality by way of changes to the biological, chemical, and/or physical properties of an invaded ecosystem.

Risk assessment and management strategies have been in many instances derived from the practice of chemical pollutants. Moreover, environmental quality criteria have encompassed both biological, physical, and chemical conditions of the environment in many legislations based on scientific knowledge, including the presence and the effects of NIS.

3. Prospects of Biopollution in a Global Warming Scenario

Impacts by biopollution cannot be adequately described without considering climate change. Climate change will interact with many other human impacts to produce effects greater than with climate change alone. Together they will impact ecosystem goods and services [6].

Climate change is accompanied by unprecedented rates of between-continent dispersal events, associated with ever-increasing levels of international trade and human travelling. The combined effects of climate and rapid transport are likely to bring worldwide changes to the earth's biota, which could easily exceed the impact of either climate change or invasion acting on its own. Indeed, many of the species that will become major components of the new globalized biological communities are already present, either as rare naturalized species or in artificial manmade habitats. In protected areas, the risk of invasion also needs to be quantified under current and projected climate conditions. Prioritization of key vectors and vulnerable areas enable development of effective management strategies.

Modelling approaches to predict NIS population developments in a changing climate are being developed, demonstrating that global warming promotes the expansion of NIS towards higher latitudes and increases the risks of introductions originating from warmer climate regions.

The sustainability of social and economic development must be based on the functioning of natural ecosystems. The coupled effects of climatic change and biopollution must be incorporated into environmental planning. The economic development in the coastal zone should be based on ecological integrity, because natural resources of the coastal zone represent a valuable capital that supports the economic health of society. The goods and services provided by natural capital represent the interest generated by human investment in protecting ecosystems. The perspective of sustainable development should be linked to ecological integrity of ecosystems with healthy and resilient conditions .

The changes, which are taking place across many different taxa and through different regions of the globe, have significant implications for biodiversity, ecosystems, and society, and are considered to be particularly apparent in the Mediterranean, a semi-enclosed sea, which is warming faster than any other marine region in the world.

4. Policy and Management Issues

In response to the threats from invasive species, many countries have adopted the twin goals of preventing the introduction of new invaders and of controlling the spread and population size of those already established. These policy goals have been formalized through local, state, and national legislation, and through the ratification of international treaties, such as the international Convention on Biological Diversity (CBD). Cost-effective solutions have been proposed involving also industrial counterparts. The management of alien species introductions, already contemplated in international treaties, should be further enforced in national legislations, notwithstanding the difficulties arising from the global nature of the phenomena.

In many aspects introduced biological organisms can be regarded as being no different from chemical pollutants. In comparing the approach used by traditional and innovative strategies put in place to protect the environment, established paradigms used for chemical pollutants and attempts made to tackle the threat posed by the biological pollution of NIS have many points in common.

A promising approach to summarize large datasets of complex data in integrative indices and to simplify the interpretation for stakeholders and decision makers is, for instance, the quantitative Weight of Evidence (WOE) model (Sediqualsoft) [7]. The model supports a comprehensive process of “site-oriented” management decisions. A further integration with biological pollution aspects could lead to a generalized framework for strengthening the current environmental legislation that aims to preserve and protect marine ecosystems more effectively, and promoting their sustainable use.

Integrated approach schemes are needed to improve our understanding of the concomitant, and often interrelated, factors of ecosystem damage. A crucial knowledge gap is also the elaboration of internationally agreed assessment criteria for both environmental pollutants and biological responses. Knowledge about the environmental behaviour and ecotoxicity of pollutants, as well as about the ecological determinants of NIS introduction and their impact on native communities, is particularly relevant for integrative monitoring purposes, together with the development of new approaches and technologies in marine pollution monitoring.

To identify future challenges and opportunities facing invasion science, a systematic approach known as Horizon Scanning can be applied. It is used for exploring emerging trends, issues, opportunities, threats, and events that can facilitate proactive responses by scientists, managers, and policy makers. Through consensus, Ricciardi et al. [8] sought to identify emerging scientific, technological, and socio-political issues that are likely to affect how invasion processes and dynamics have to be studied and managed within the next 20 years. They presented issues that are relevant to a broad range of taxa, environments, and geographical regions. These diverse issues suggest an expanding interdisciplinary role for invasion science in biosecurity and ecosystem management, burgeoning applications of biotechnology in alien species detection and control, and new frontiers, with particular attention to the microbial ecology of invasions. Scrutiny and debate that spurs the development of new research foci and policy objectives will be reinforced by such an approach.

Increasingly, the consequences of human-induced problems need to be considered fundamental on final ecosystem services and societal benefits, again focusing on both the ecological and economic repercussions of biopollution. In short, biological invasions are an economic problem [9]. Risks of invasions may be very low, but the potential damages are high.

The precautionary principle holds that where the effects of some activity are uncertain, but are potentially both costly and irreversible, society should take action to limit those effects before the uncertainty is resolved. The rationale for the principle is generally that the conjectured costs of not taking action are much greater than the known costs of preventative or anticipatory action . This approach entails careful and well-organised communication to the public and the notion that only individual and social behaviour changes can succeed in obtaining the desired results in mitigating the threat by bioinvasions.

In conclusion, biological pollution should be treated in the same way as other types of pollution and contingency plans for NIS introductions should be developed, including an efficient rapid response upon finding a newly introduced species, where possible.

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