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From microscope to management: The critical value of plankton taxonomy to marine policy and biodiversity conservation

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ABSTRACT

Taxonomic information provides a crucial understanding of the most basic component of biodiversity – which organisms are present in a region or ecosystem. Taxonomy, however, is a discipline in decline, at times perceived as 'obsolete' due to technical advances in science, and with fewer trained taxonomists and analysts emerging each year to replace the previous generation as it retires. Simultaneously, increasing focus is turned towards sustainable management of the marine environment using an ecosystem approach, and towards conserving biodiversity, key species, and habitats. Sensitive indicators derived from taxonomic data are instrumental to the successful delivery of these efforts. At the base of the marine food web and closely linked to their immediate environment, plankton are increasingly needed as indicators to support marine policy, inform conservation efforts for higher trophic organisms, and protect human health. Detailed taxonomic data, containing information on the presence/absence and abundance of individual plankton species, are required to underpin the development of sensitive species- and community-level indicators which are necessary to understand subtle changes in marine ecosystems and inform management and conservation efforts. Here the critical importance of plankton taxonomic data is illustrated, and therefore plankton taxonomic expertise, in informing marine policy and conservation and outline challenges, and potential solutions, facing this discipline.

1. Introduction

A fundamental understanding of marine biodiversity is still lacking. Of the estimated 2–8 million species on Earth, 0.7–2.2 million are thought to be marine although many (between 33% and 90%) are yet to be described (see [1,2]). Since publication of the Convention of Biological Diversity in 1992, 'biodiversity' has become a buzzword, frequently mentioned in the media, but also explicitly named in other pieces of legislation, including those with marine components [3,4]. This overt inclusion into policy provides the legislative impetus for improving our understanding of marine biodiversity and its conservation; however, in order to conserve marine biodiversity and effectively manage the marine environment, it is important to understand which species are present, the relationships between them, and their roles in marine ecosystem functioning. Taxonomy and taxonomic analysis, the field of science with the ability to provide this essential and basic species-level data, therefore has a clear and crucial role in articulating, understanding, and conserving marine biodiversity.

Taxonomy, and its associated identification and analysis skills, is a discipline in crisis [5]. In terms of investment, taxonomy is highly specialised, involving a long-term training process. There is a lack of positions in which taxonomists can develop their skills because retiring taxonomists are not being replaced, resulting in weak recruitment of young scientists into taxonomy and fewer taxonomists to train the next

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generation. Furthermore, funding for taxonomy, as with much other assessment science, has been reduced by science funding bodies and monitoring costs are now supplemented by industries for whom ecology is of minor importance [6]. Taxonomy is often considered 'unsexy' or basic 'stamp collecting', rather than innovative science. Thus, the impact factor of taxonomic journals is low, discouraging the publication of descriptive papers, and diminishing respect for the field of taxonomy [7,8]. This decline in taxonomic expertise is particularly concerning because the requirement for taxonomic information is increasing due to rising impetus placed on biodiversity conservation and ecosystem-based management [6,9]. Costello et al. [10] optimistically state that there has been an increase in taxonomists, in Asian and South American countries in particular, but their definition includes only scientists listed on publications describing species new to science. Taxonomy is actually a significantly broader area, not only restrained to the discovery and description of new species, but also including the identification, analysis, classification and reclassification, and naming of organisms, all of which rely on specialist knowledge. Authors using this wider definition have observed a decrease in working scientists with taxonomic expertise, highlighting the decline of this discipline [5,11–13]. In the context of this paper, a wider definition of taxonomy is used, which includes the discipline of taxonomic identification and analysis as well as descriptive taxonomy.

In contrast to its reputation as outdated, taxonomy is in fact an evolving and relevant field. This is particularly evident in the marine environment; for example, between 2000 and 2010, the Census of Marine Life taxonomists described 1200 species new to science, emphasising the number of taxonomic challenges that still exist in the marine environment [14]. A formidable challenge to marine taxonomy is the fact that a significant portion of marine biodiversity is microscopic and therefore either undiscovered, undescribed, or misclassified due to high occurrence of synonyms and cryptic species [1]. Additionally, fewer taxonomists focus on less charismatic and small-sized marine invertebrates, such as plankton, than on megafauna such as fish and mammals [1]. Some of the best-studied plankton groups, including Bacillariophyceae (diatoms) and Copepoda (copepods), are among the least well-known taxonomic groups, and are thought to contain more than 50,000 and 30,000–50,000 undiscovered species, respectively [1]. Due to their small size and apparent lack of distinct morphotaxonomical characteristics, identifying plankton taxa to species level requires a high level of taxonomic skill. For example, taxonomic analysts at the Continuous Plankton Recorder Survey did not reliably distinguish the trophically-important copepod species *Calanus helgolandicus* and *C. finmarchicus* until 1958, as these cogeners are so morphologically similar [15]. It was only when this taxonomic distinction was made that the relative proportion and importance of the two species as a climate indicator in the Northeast Atlantic was revealed [16]. Up to date and correct taxonomic information, dependent on skilled taxonomic analysts, is thus needed to progress ecological research and further our understanding of marine environmental change.

The new generation of policy mechanisms seeks to manage the marine environment holistically through the ecosystem approach [17–20]. Central to this management method is the incorporation of scientific evidence into the decision making process, which often occurs through the development and informing of environmental indicators [21–24]. Plankton are highly diverse [25] and play a key role in ecosystem functioning [26] that is closely linked to environmental change [27,28]. Accordingly, plankton can be used as sensitive indicators of ecosystem change and plankton time-series are increasingly used to inform marine policy and management [29]. These time-series both supply essential taxonomic plankton community data needed to inform decision making, but also harbour significant taxonomic expertise. Ensuring the accuracy and credibility of the data, and therefore its usefulness in supporting marine policy and conservation, is closely tied to the skills of the taxonomic analysts analysing the plankton samples.

Taxonomic expertise is required to both generate and interpret the data underpinning and advancing our understanding of the marine environment, and to inform aspects of marine conservation and management. Although other work (e.g. [17,29] among others) convincingly makes the case for applying plankton indicators in marine policy and conservation, the issue of the crucial and threatened role of plankton taxonomy, and its associated identification and analysis skills, as a discipline in supporting policy and conservation indicator development and use remains largely unaddressed. Here, taxonomically-resolved data is referred to as 'plankton taxonomic data', which are produced as a direct result of plankton taxonomic identification expertise. This paper aims to illustrate the critical importance of plankton taxonomic data in informing marine policy and conservation, and therefore implicitly the crucial role of plankton taxonomic classification, identification, and analysis expertise. Finally, future challenges, and potential solutions facing this discipline are outlined.

2. Plankton taxonomy and the policy landscape

The Convention on Biological Diversity (CBD) was introduced in 1992, giving a political impetus to marine taxonomy on a global scale. The CBD defines 'biodiversity' as: "the variability among living organisms, from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" [30]. This definition specifically recognises the species-level component of marine biodiversity. In support of the critical role of taxonomy in conserving biodiversity, the CBD also established the Global Taxonomy Initiative, to specifically address the "taxonomic impediments" of knowledge gaps in our taxonomic system, the shortage of trained taxonomists and curators, and the impact these deficiencies have on our ability to conserve, use and share the benefits of our biological diversity (https://www.cbd.int/gti/). No cohesive global biodiversity monitoring programme exists, but the Group on Earth Observations Biodiversity Observation Network (GEO-BON) recommends taxonomic diversity as part of a suite of Essential Biodiversity Variables, meant to capture major dimensions of biodiversity change needed to inform science and policy at a global scale [31].

As understanding of the ecological role of plankton in marine systems has developed, so has the aim of statutory plankton monitoring, which has evolved from informing legislation focused on water quality to supporting increasingly complex ecosystem aspects such as food webs and biodiversity under the ecosystem approach. This evolution is clearly illustrated by changes in the role of plankton in European Union (EU) policy during the past 30 years. Since 1991, the Shellfish Hygiene Directive has mandated the monitoring of potential toxin-producing phytoplankton species in shellfish production areas as part of a statutory monitoring programme to protect human health from algal toxins [32]. Passed in 2000, the Water Framework Directive requires the monitoring of composition and abundance of coastal phytoplankton taxa to assess eutrophication, taxonomically broadening the contribution of plankton to informing European policy [33]. Most recently and most holistically, the EU's Marine Strategy Framework Directive (MSFD) requires the monitoring of community-level phytoplankton and zooplankton indicators in support of environmental targets for eutrophication, biodiversity and food webs [3]. These legislative examples use increasingly complex aspects of plankton community dynamics, all of which require taxonomically-resolved plankton data.

In addition to supporting legally-binding policy instruments, taxonomic plankton data feature prominently in recent global-scale assessments of the state of the seas. The fifth report of the Intergovernmental Panel on Climate Change (IPCC) and the United Nation's (UN) World Ocean Assessment both featured comprehensive overviews of inter- and intra-annual changes in regional plankton communities with links to climate and direct anthropogenic pressures [34,35]. The strong pre-