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No more reason for ignoring gelatinous zooplankton in ecosystem assessment and marine management: Concrete cost-effective methodology during routine fishery trawl surveys

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ABSTRACT

Gelatinous zooplankton, including cnidarians, ctenophores, and tunicates (appendicularians, pyrosomes, salps and doliolids), are often overlooked by scientific studies, ecosystem assessments and at a management level. Despite the important economic consequences that they can have on human activities and on the marine food-web, arguments often related to the costs of monitoring or their coordination, or simply negligence, have resulted in the absence of relevant monitoring programs. A cost-effective protocol has been applied on trawling from existing fishery surveys conducted by national laboratories in England and France. The testing phase has successfully demonstrated the adequacy of such a tool to sample macro- and mega-zooplankton gelatinous organisms in a cost-effective way. This success has led to the acceptance of this protocol into the French implementation of the EU's Marine Strategy Framework Directive (MSFD). Here, a protocol which can be applied to any trawl-based fishery survey and in any new large-scale monitoring program is provided. As an ecosystem approach to marine management is currently adopted, exemplified by the MSFD in Europe, gelatinous zooplankton should be monitored correctly to prevent a knowledge gap and bias to ecosystem assessments in future.

1. Introduction

Gelatinous zooplankton (GZ) is comprised by species, with a planktonic stage (living in the water column) and characterized by a gelatinous body, of the phyla Cnidaria (classes Scyphozoa, Cubozoa, Hydrozoa and Staurozoa; with the term jellyfish comprising the first three classes), Ctenophora (classes Nuda and Tentaculata) and Chordata (class Appendicularia and Thaliacea). GZ are widely known for their amazing shape and colors, and due to their formation of dense aggregations ("blooms") along coasts during spring and summer seasons and subsequent human health and economic consequences [1–3]. GZ are also of great importance as food for other animals including humans, and have potential medical applications. Nevertheless, their detrimental effects on tourism can be particularly important. For example, along the Salento coastline in Italy, first-aid services due to jellyfish stings reached a direct cost of 400,000 euros over a 5-year period [4]. Jellyfish aggregations became so common in the area that one wonders whether the coming year will be a "jellyfish year". Oscillations in frequency of GZ blooms of 10–15 years [5] have been reported in the northwest Atlantic, but the current knowledge does not allow to effectively predict their seasonal onset and geographical dynamics. Behind this lack of information is a clear absence of long-term data sets [6–8].

Current GZ data collection activities are usually designed for specific short-term projects [9], or through citizen science initiatives (e.g. Marine Conservation Society of the UK jellyfish survey, JellyWatch, JellyRisk…) and only in rare instances are they included in national monitoring programs. As a result, the data available are generally scarce in terms of spatial and temporal coverage and often of limited use. Moreover, data collected near shore do not necessarily reflect the processes occurring offshore [10], and this constrains the potential ability to understand population dynamics. Beyond the jellyfish group, whose stinging cells have harmful effects on economic activities (fisheries, tourism), other GZ such as ctenophore or salp differ greatly in

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terms of morphology, phylogeny, biology, and physiology [11]. The lack of data on those organisms is detrimental to our understanding of ecosystem functioning and their role has been neglected, including in trophic models where they are often wrongly depicted as trophic dead-ends [12].

GZ have the potential to impact marine food webs at multiple levels. Predatory jellyfish and ctenophores often feed on both the same prey items as planktivorous forage fish and the juvenile stages of piscivorous ones [1,13] having, thus, the potential to adversely impact fish recruitment through competition and predation [14–16]. In the most extreme case scenario, where high fishing pressure results in the collapse of fish stocks, newly available ecological niches could become occupied by jellyfish. Jellyfish then, exerting top-down control on zooplankton to primary producers further reduces the availability of prey items for the depleted fish stocks (also known as the jellyfish 'joyride') [18,19] implying important economic repercussions on weakened fisheries. As clear examples, the northern Benguela off Namibia and the Black Sea used to support abundant commercial fish stocks, which following overexploitation became fish-poor and dominated by GZ [20,21]. In addition, numerous short-term and direct economic impacts of extensive aggregations of GZ have been reported worldwide, such as: clogging of fishery nets, aquaculture fish mortality, or obstruction of cooling systems of coastal desalination, nuclear and coal-fired power plants [22]. It has been also shown that jellyfish polyps can fix on artificial structures at sea, thus coastline development will provide more surface for settling of polyps [23].

A better understanding of the population dynamics of GZ and socio-economic effects would allow management measures to be implemented to prevent or mitigate their impacts (adaptation rather than transformational governance strategies, cf. [22]). Improved spatial planning of coastal development or the implementation of a tool to predict the risk of high jellyfish abundance on tourist beaches are examples of such management measures. Within ecosystem based management and assessment, indicators of ecosystem instability could be developed based on GZ data since their populations have been shown to rise rapidly following disturbance [17,22]. GZ do not however only represent negative impacts for ecosystems services. Jellyfish as a commercial food already supports an important market in Asia, which is likely to develop in other parts of the world [22]. Medical advances have also been made using some GZ components (i.e. collagen, qniumucin) and new applications have been discovered, such as the potential use of GZ mucus for nanoparticles depollution [24]. Improved ability to predict GZ population dynamics and distribution would also allow for the successful management of new economic resources. GZ also play a key ecological role in the marine ecosystem: they have been shown to represent an important food supply for key fish species such as blue fin tuna, in the western Mediterranean [25], as well as for spiny dogfish and benthic scavengers [26]; they can transfer nutriments to the benthos through the production of large fecal pellets [27], or through decomposition of jellyfish, particularly following a blooming event [28]; they can also provide shelters for small fish from predation by larger species [20] and can act as drifting carriers for several crustaceans and anemones. Whether having a detrimental or a positive impact on marine ecosystems and the services they provide, GZ should be included in research and monitoring.

Following the adoption of suitable monitoring of GZ, indicators should be developed that reflect the food web role of GZ and inform ecosystem assessments such as those required by the Marine Strategy Framework Directive (MSFD) in Europe [29] or the Ecosystem Status Report in North America [30]. Previously, there has been concern by policy makers and managers that even if GZ are monitored, their populations are unmanageable, so scarce monetary resources would be better spent on other monitoring. Monitoring for GZ must be thus of minimal cost and ideally be coordinated with current fisheries surveys. So far, very few cost-effective monitoring methods that can cover broad spatial coverage and replicate the effort over time have been developed for GZ, either for scientific or management purposes [8]. There is therefore a necessity to implement a methodological approach to enable such monitoring [8,31,32]. Monitoring should rely on internationally standardized approaches which would allow for quality assurance and for comparisons across surveys. It will give the opportunity to the scientific community to estimate and model the spatio-temporal distribution of GZ across large marine ecosystems in a way that has not been possible previously [33,34]. Ideally, GZ data should be obtained from surveys with dedicated plankton sampling in place, which is the case for the Irish Sea Young Fish Survey and the quarter 1 International Bottom Trawl Survey of the North Sea in which GZ are caught using a midwater ring net (MIK net), a standard gear for sampling fish larvae [17,35]. However, the deployment of these nets requires specific logistics, and dedicated staff on board. Trawl surveys targeting adult fish using pelagic trawls [14], demersal trawls [36,37] and even beam trawls [38] have been found to catch large GZ in abundance, allowing for the most notable work on jellyfish dynamics [8]. Consequently, it has been recommended that GZ should be routinely monitored on fisheries surveys [8]. This is particularly promising because data could be acquired with high spatio-temporal coverage and following standardized practices [35].

There is currently no clear protocol for GZ in the scientific literature, which is mandatory if one wants to expand monitoring to fishery surveys in an orderly manner. The heavy reliance by EU Member States on previously developed monitoring programs meant that GZ were not monitored in many areas. Fortunately, projects (such as DEVOTES, DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status) and government funding have supported some scientists to test the ability of fishing nets to sample GZ on current scientific surveys. Based on trawling carried out by Cefas (UK) and by Ifremer (France), a robust protocol for GZ monitoring on routine fisheries surveys has been tested since 2012 and 2014 respectively and is proposed here. This protocol has been officially implemented in the MSFD monitoring program in France since 2017. The resulting methodology for monitoring mega- and macro-gelatinous organisms is detailed here. The goal of the present paper is: 1) To raise stakeholder awareness, at the political, scientific and management level, for the need of GZ monitoring, 2) to provide a clear protocol, based on a successful trial phase, that can be directly used during similar fishery surveys using fish trawling and 3) to open the discussion for adopting a harmonized GZ data production in the frame of large scale efficient monitoring.

2. Main comments on the protocol and its testing phase

The full step-protocol provided here (Supplementary Material 1) should be laminated for use at sea. This protocol has been tested and improved through the testing phase during several fishery surveys within the English and the French EEZ (Exclusive Economic Zone) by Cefas and Ifremer respectively (cf. Table 1).

Trawling positions where GZ were recorded are presented in Fig. 1. The testing phase within the French marine waters was implemented from 2014 to 2016 as part of the French implementation of the Marine Strategy Framework Directive, and from 2012 to 2015 within the English contribution to the quarter 3 International Bottom Trawl Survey. Both testing phases in English and French waters relied on existing fishery cruises and had to be adapted to fit within the ongoing fishery tasks without increasing significantly workload both in terms of time and human resources.

To limit additional work for the implementation of the GZ protocol on existing fishery surveys, the proposed methodology is very similar to that used routinely for fish. For instance, at first volume of GZ was used as a proxy for biomass, but sea conditions, amount of GZ being at time very large and, adjustment to the fish tasks, required to switch to weight measurements. The list of basic equipment required is given in Table 2. Gloves should always be worn, and arms should be covered