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Jellyfish blooms in the Northern Adriatic Sea: Fishermen's perceptions and economic impacts on fisheries

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ABSTRACT

Extensive blooms of gelatinous macrozooplankton species ("Jellyfish") have appeared in recent decades in Northern Adriatic (NA) waters. Anecdotal evidence suggests that these blooms have had a considerable impact on fishing operations, as this region is one of the most heavily exploited Mediterranean fishing grounds. In order to gain a better understanding of the possible economic losses for the Italian NA fishing industry due to jellyfish impacts, we conducted a survey of fishermen in the city of Chioggia, which is the main fishing port for the NA basin. The study focused on fishermen's perceptions about jellyfish blooms in the NA Sea and also investigated whether and how blooms compromised fishing operations. Survey results confirm that blooms have negatively affected fishing operations in the last few decades. We estimate that economic losses due to reduction in fish catches could amount to as much as € 8.2 million per year for the Italian NA trawling fleet. Other costs on this fleet include additional fuel costs due to displacement of fishing operations, which could represent an increase in costs of over € 460,000 per year. Moreover, during a jellyfish bloom episode it can happen that time has to be spent by fishermen to repair nets damaged by jellyfish caught in them, leading to an estimated cost for the trawling fleet and small scale fisheries of over 89,000 man-hours per year. This study not only confirms that jellyfish blooms have a considerable impact on fishing operations but also shows how costly blooms can be for the NA fisheries.

1. Introduction

The abundance of gelatinous macrozooplankton species ("Jellyfish") increases temporally and spatially as part of natural boom and bust periods (Boero et al., 2008; Condon et al., 2012). However, there is widespread concern about a possible jellification of the global seas (Jackson et al., 2001; Mills, 2001; Lynam et al., 2006; Attrill et al., 2007; Richardson et al., 2009).

A number of anthropogenic perturbations have been suggested as potential causes of abnormal jellyfish mass occurrence, including global warming, eutrophication, overfishing, and the increase of artificial hard substrates (reviewed in Purcell et al., 2007; Richardson et al., 2009; Purcell, 2012). These perturbations may enhance jellyfish populations and blooms in the future, increasing the likelihood of negative jellyfish impacts on human activities (Purcell et al., 2007).

Jellyfish blooms can impose a range of negative social and economic impacts (reviewed in Purcell et al., 2007). Some macrozooplankton species interfere with recreational activities and have impacts on human health (Fenner and Williamson, 1996; Burnett, 2001; Mariottini and Pane, 2010). Jellyfish blooms have been reported to interfere with coastal power plant operations (Galil, 2008; Dong et al., 2010) and with diamond mining (Lynam et al., 2006), increasing the operational costs of these activities. Effects on fisheries are the most frequently reported impacts (Purcell et al., 2007). These impacts arise because of the biological effects of jellyfish on food webs and because of interference with fishing operations. Biological changes are caused by resource competition with fish and predation on fish eggs and juveniles, which lead to reduced fish stocks (Purcell and Arai, 2001). A well-known example is the case of the alien ctenophore *Mnemiopsis leidyi*, which contributed to the collapse of the anchovy fisheries in the Black Sea (Shiganova et al., 2001, 2003). Other jellyfish impacts on fisheries relate to interference with fishing operations. The evidence base includes reports of the temporary complete prevention of fishing operations (Schiariti et al., 2008; Nagata et al., 2009); the need for

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extra hauls in areas more distant from landing ports (Nagata et al., 2009); clogging and bursting of nets (Graham et al., 2003; Uye and Ueta, 2004; Nagata et al., 2009); reduced fish catches (Graham et al., 2003; Kawahara et al., 2006b; Nagata et al., 2009; Dong et al., 2010; Quiñones et al., 2013); increased fish catch sorting time (Uye, 2008; Kawahara et al., 2006b); and painful stings to fishermen sorting fish catches (Kawahara et al., 2006a). Only a few estimates of the economic losses caused by jellyfish interfering with fishing operations are available. In 2000 blooms of the alien *Phyllorhiza punctata* may have caused losses of up to 10 million US$ to the shrimp fishery of the Gulf of Mexico because of fouled fishing gear and harvest (Graham et al., 2003). In 2003 blooms of *Nemopilema nomurai* caused a loss in fishing revenue of approximately 20 million US$ in just one of the 17 Japanese prefectures, where interferences of jellyfish with fishing operations were reported (Kawahara et al., 2006b). Quiñones et al. (2013) estimated that during the austral summer 2008–2009 by-catch of *Chrysoara plocamia* caused losses of more than 200,000 US$ to the Peruvian purse seiners of Ilo in only 35 days of fishing.

In this study we investigate the impacts of jellyfish blooms on the fishing operations of the Italian NA fisheries. Extensive blooms of both alien and indigenous jellyfish species have occurred in the last decades in Mediterranean waters, including the NA Sea (UNEP, 1991; CIESM, 2001; Galil, 2008; Fuentes et al., 2010; Kogovšek et al., 2010; Brotz and Pauly, 2012; Malej et al., 2012). Anecdotal evidence suggests considerable impacts of these blooms on fisheries (Galil, 2008; Nastasi, 2010; Boero, 2013). Boero (2001) states that the massive outbreaks of *Pelagia noctiluca* of the early 1980s caused enormous economic losses to the fisheries of the NA Sea due to net clogging. However, these losses have not been quantified and, to our knowledge, no attempt has been made to date to assess the magnitude of the economic losses that jellyfish blooms cause to fisheries in the Mediterranean region. The aim of this paper is therefore to begin to fill this evidence gap. We focus on a limited spatial area (the NA region and specifically the port of Chioggia) and conduct a structured interview-based survey of fishermen in order to collect empirical data on jellyfish impacts. Although the survey is limited to one location, the study area is one of the most exploited Mediterranean fishing grounds (Barausse et al., 2009) and the port is the primary fishing centre for the NA region. Since the basis of the economic valuation work is the economic agent's (fishermen) perception of jellyfish impacts, we do not believe that widening the survey to cover other ports in the region would result in substantially different perceptions and related economic effects. We therefore rely on simple aggregation (value transfer) to arrive at the overall economic loss estimates for the whole NA region.

2. Methods

2.1. Case study area

The NA Sea is a coastal sub-basin of about 32,000 km^2 in the central Mediterranean Sea, semi-enclosed by Italy, Slovenia and Croatia (Fig. 1). This ecosystem is one of the most exploited Mediterranean fishing grounds, due to its high primary productivity. It supports valuable fisheries containing both pelagic and demersal resources (Barausse et al., 2009). However, the ecosystem has clearly become less productive since the late 1990s (Mozetic et al., 2010). The NA underwent a regime shift starting from the end of the 1980s, with abrupt changes in planktonic, fish and invertebrate communities, probably driven by multiple synergistic factors. The environmental change process was complex and encompassed climate change effects, such as variations in water temperature and circulation; a reduction of nutrient loads from river catchments; anoxic phenomena; and the crash of the anchovy stock, which has

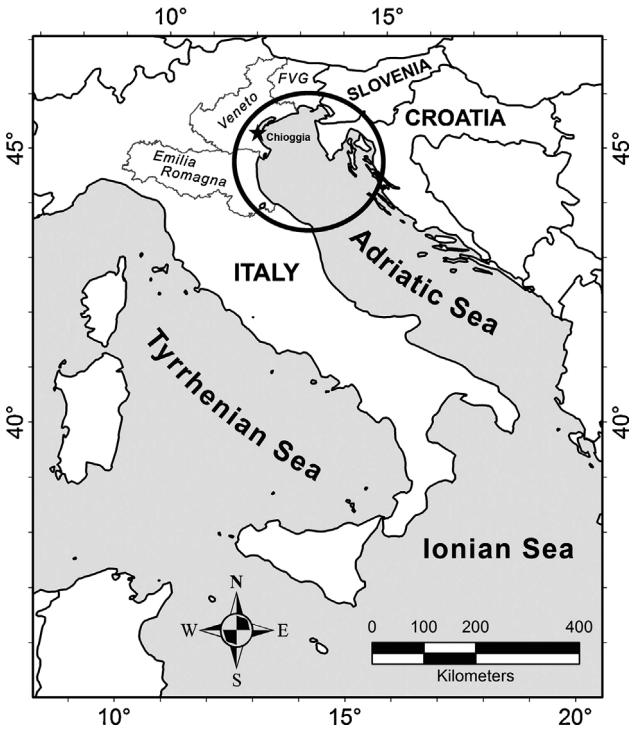

Fig. 1. The Northern Adriatic Sea. The study area is circled and the fishing port of Chioggia is indicated.

a key trophic role in the ecosystem (Barausse et al., 2011). The 10-year long bloom of the jellyfish *P. noctiluca* of the 1980s added to the problem because this species competed with small pelagics for zooplankton, predated upon fish eggs, larvae and even adults, and possibly stimulated the anchovy population collapse (Boero and Bonsdorff, 2007; Conversi et al., 2010; Kogovšek et al., 2010; Barausse et al., 2011).

A major human pressure impacting on the NA Sea is fishing, with feedbacks on Adriatic communities at least over the past two centuries (Fortibuoni et al., 2010). After World War II, fishing pressure steadily increased causing marked changes in the ecosystem, such as a reduction in large and long-lived fish species, which are vulnerable to exploitation. These species were replaced by more fecund, smaller-sized and faster growing organisms (the so-called r-strategists), which are now dominating the ecosystem (Barausse et al., 2011). Possible explanations for this replacement are that r-strategist species are fitter and more able to tolerate conditions induced by high human pressures and that the decrease in large species, mostly predatory fish, released smaller species from predation pressure (Barausse et al., 2009, 2011). Jellyfish are a good example of an r-strategist but they have few natural predators (e.g. loggerhead turtles) in the Adriatic Sea. Consequently, if fisheries benefited jellyfish in the system, they probably did so by reducing the abundance of the species competing with jellyfish for zooplankton food, such as small pelagic fish (sardine, anchovy), which are intensely exploited in the basin.

Despite the decrease in fleet size and landings over recent years (IREPA, 2012b), the NA fisheries are still of considerable importance at the national level in terms of number of vessels, gross tonnage, crew, and landings (Table 1). The fishing systems practised in the three Italian NA regions (Veneto, Emilia Romagna, and Friuli Venezia Giulia) are bottom- and mid-water trawling, hydraulic dredges, small scale fisheries, and purse seiners (the latter in the Friuli Venezia Giulia region only). The NA mid-water trawling fleet is of particular importance at the national level. In 2011 this fleet comprised 53% of the mid-water trawling vessels operating in Italy