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Fisheries bycatch data provide insights into the distribution of the mauve stinger (*Pelagia noctiluca*) around Ireland

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There is concern that jellyfish populations are proliferating in the Northeast Atlantic and that their socio-economic impacts will increase. Using information from the Irish Groundfish Survey, data are presented on the distribution of the mauve stinger, *Pelagia noctiluca*, over an area >160 000 km^2 around Ireland and the UK in 2009. The species accounted for 93% of the overall catch of gelatinous organisms, with an average catch biomass of 0.26 $\pm$ 2.3 kg ha^{-1}. The study area was divided into four subregions (North, West, Southwest, and South), and the distribution and abundance of *P. noctiluca* displayed both inter- and intraregional variations. Individual bell diameters ranged from 1 to 13.5 cm (median 4.5 cm, s.d. 1.2 cm), and the size distribution also varied spatially. It is the first time that such detailed information has been made available for *P. noctiluca* in a part of the Northeast Atlantic where its impact on the salmon aquaculture industry can be considerable. Finally, the possibility of using annual datasets from this type of fisheries survey to develop time-series that, in the future, will allow investigation of relationships between long-term variations of *P. noctiluca* populations and climatic factors in the area is addressed.

Keywords: biogeography, fish kill, gelatinous zooplankton, jellyfish, Northeast Atlantic, patchiness, salmon aquaculture, Scyphozoa.

Introduction

Concern about the role and place of jellyfish within marine ecosystems has increased during recent decades as an increasing number of cases of negative interactions with human activities have been reported (see review by Purcell *et al.*, 2007). It has been suggested that, in different places, jellyfish abundance may have increased in response to eutrophication, overfishing, and/or climate change (Arai, 2001; Mills, 2001; Purcell, 2005; Richardson *et al.*, 2009). However, a global increase in jellyfish populations has not yet been formally proven (Purcell *et al.*, 2007; Boero *et al.*, 2008; Haddock, 2008). It is also important to realize that some of the recent reports of the detrimental impacts of jellyfish may simply result from interactions between relatively new, quickly expanding coastal activities (e.g. aquaculture) and possible natural cycles in the outbreaks of some gelatinous organisms (Boero *et al.*, 2008).

In Irish and UK waters, the mauve stinger *Pelagia noctiluca* (Scyphozoa, Semaeostomeae, Pelagiidae) became a serious concern when it caused a major fish kill (~250 000 fish) in November 2007 in Northern Ireland's only salmon farm, resulting in an economic loss of more than €1 million (Boero *et al.*, 2008; Doyle *et al.*, 2008). The species also caused fish loss off Scotland in the same year (Hay and Murray, 2008), and its involvement in other fish kills in the past has been established (Merceron *et al.*, 1995). Such catastrophic fish kills are relatively rare, but it is likely that *P. noctiluca* has also been responsible for some of the chronic zooplankton-related mortalities experienced by finfish farms annually (Hay and Murray, 2008).

Pelagia noctiluca is a holoplanktonic oceanic species, found from the warm waters of the Gulf of Mexico and the Mediterranean Sea to the temperate waters of the North Sea (Russell, 1970; Graham *et al.*, 2003; Licandro *et al.*, 2010). A study of plankton samples collected around Scotland indicated that the abundance of oceanic species, including *P. noctiluca*, peaks in autumn off the north coast of Ireland (Fraser, 1968). However, apart from that work, our knowledge of *P. noctiluca* around Ireland and the UK remains mostly limited to reports of anecdotal sightings and stranding events (Russell, 1970; Doyle *et al.*, 2008). These historical records show that the species has been frequently (but irregularly) observed around Irish and UK coasts at least since the 19th century, but are too scarce to investigate reliably the broad-scale distribution of the species or the potential factors driving interannual variability in the records, as has been done for other areas (Goy *et al.*, 1989; Kogovsek *et al.*, 2010).

In contrast, the species has been studied extensively in the Mediterranean Sea, where critical outbreaks and related economic detrimental impacts stimulated international research programmes during the 1980s (UNEP, 1984, 1991). There, the

species appears to follow cycles of "years with *Pelagia*" followed by "several years without *Pelagia*", the length and frequency of which differ in the various basins, and can be related to hydroclimatological and other environmental factors (Goy *et al.*, 1989; Axiak and Civili, 1991; Kogovsek *et al.*, 2010). However, even in the Mediterranean where the impacts of *P. noctiluca* on public health and tourism are critical (CIESM, 2008; Mariottini *et al.*, 2008), detailed information on its ecology, and in particular on its broad-scale distribution, is generally lacking.

The paucity of broad-scale data is a common issue in jellyfish studies (Purcell, 2009), mainly because of limited opportunities to access expensive ship time. For *P. noctiluca*, the irregular nature of the species' outbreaks mentioned above is an additional obstacle to organizing access to such resources. As a result, most studies on the species have been restricted to nearshore areas (see examples in UNEP, 1991), and only a few basin-wide studies have been conducted (in the Adriatic and Ligurian Seas; see Goy *et al.*, 1991; Piccinetti and Piccinetti-Manfrin, 1991). Yet, considering the potential effect of the species on marine ecosystems, e.g. competition with planktivorous fish and predation on fish eggs and larvae (see Malej, 1989; Giorgi *et al.*, 1991; Sabatès *et al.*, 2010) and aquaculture, it is critical to access information on its widespread distribution.

Here, we show how bycatch data from non-dedicated surveys such as the Irish Groundfish Survey (IGFS) can provide original insights into the distribution of *P. noctiluca* over extended spatial scales around Ireland and the UK. To our knowledge, it is the first time that such detailed information is available for the species in an area of the Northeast Atlantic on a scale equal to or larger than any known study from the Mediterranean Sea. We also discuss the possibility of using the annual dataset from the IGFS to develop a time-series that will, in future, allow investigation of relationships between long-term variations of *P. noctiluca* populations and climatic and other environmental factors, as has been done successfully for other species, in other parts of the world (Hay *et al.*, 1990; Brodeur *et al.*, 1999, 2008; Graham, 2001; Lynam *et al.*, 2005).

Methods

The IGFS is an annual demersal trawl survey conducted in autumn/winter by the Fisheries Science Services of the Irish Marine Institute, on the Irish continental shelf (Figure 1), using the RV "Celtic Explorer". Its primary aim is to collect data on juvenile recruitment patterns for commercially exploited stocks of demersal fish. However, the IGFS encounters a certain level of bycatch of non-targeted species that provides the opportunity to collect additional information. The survey uses a semi-random, depth-stratified survey sampling design that yields ~170 fishing hauls. Each haul is carried out during daylight over a 6-week period and is part of an internationally coordinated survey effort under the International Bottom Trawl Working Group (IBTSWG) of ICES (see IBTSWG reports at www.ices.dk).

Sampling is by a high headline, four-panel demersal trawl (mesh size 200 mm at wings, 20 mm at codend) towed over the seabed for 30 min at a speed of ~4 knots (for more detail, see Anon., 1999). SCANMAR sensors monitor doors, wings, and

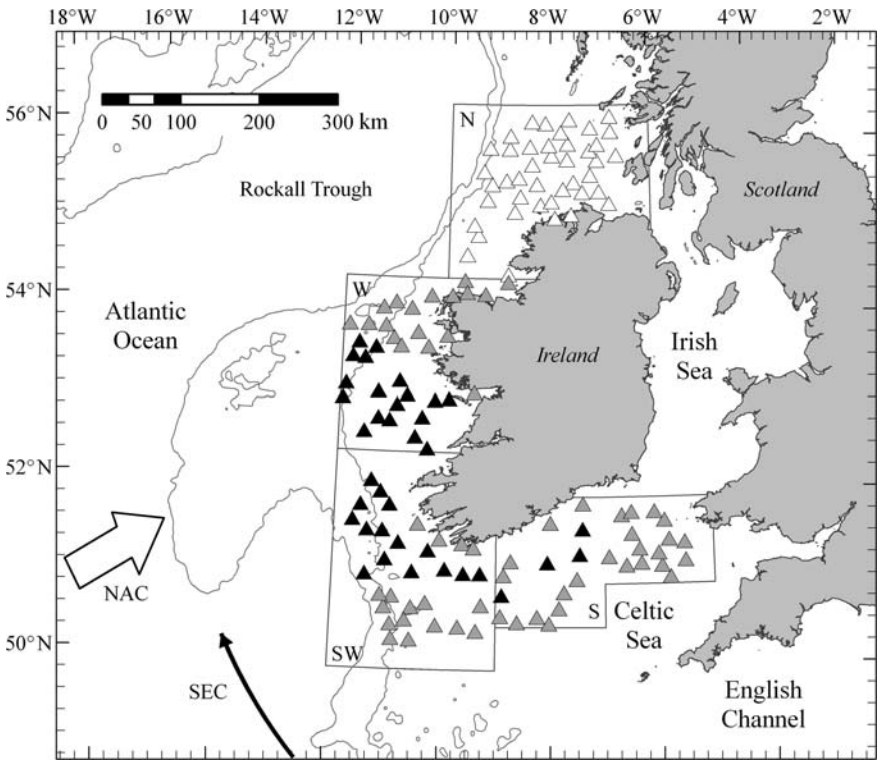

Figure 1. The study area, with sampling stations represented by triangles, different shading depicting the temporal organization of the survey: first leg 26 September 2009 to 5 October 2009 (white), second leg 29 October 2009 to 13 November 2009 (grey), third leg 14–30 November 2009 (black). The study area has been subdivided into four subregions referred to herein as N, W, SW, and S based on ICES Divisions VIa VIIb, VIIj2, and VIIg (Table 1). The grey lines represent the 200- and 1000-m isobaths, and the general directions of the Shelf Edge Current (SEC) and North Atlantic Current (NAC) are shown as labelled arrows. The system of projection used is the Irish National Grid.

headline opening throughout the operation and the average value for each station, as well as the GPS positions of the start and the end of the transect, are recorded. Information on bottom depth is provided by vessel echosounder.

In 2009, for the first time, scyphozoan jellyfish bycatch was systematically identified to the level of species for each sampling station. The IGFS 2009 was organized in three legs, the first from 26 September to 5 October, the second from 29 October to 13 November, and the third from 14 to 30 November. Four subregions were defined within the study area: North (N), West (W), Southwest (SW) and South (S), each based, respectively, on ICES Divisions VIa, VIIb, VIIj2, and VIIg (cf. http://www.ices.dk/aboutus/icesareas.asp), but restricted to the extent of the sampling stations (Table 1, Figure 1).

Scyphozoan jellyfish were sorted by species, and the corresponding wet weight was measured using motion-compensated scales (POLs marine scales ± 2 g). Individual bell diameters were measured to the nearest 0.5 cm using a measuring board and the jellyfish placed with the external surface of the bell facing up. Large catches were subsampled by measuring only the first 150 individuals after successive equal divisions. This was done by placing two empty boxes under the box containing the jellyfish and tipping out the jellyfish sample into the two boxes, essentially splitting the sample into two with reasonable randomization. Measurements were completed within 2 h of the catch being brought on board.

Following the method described by Brodeur *et al.* (1999), a standardized catch (kg ha^{-1}) of each jellyfish species was calculated for each station by dividing the recorded wet weight of medusae by the width of the net multiplied by the distance towed (average per tow calculated from net-sensor records). When wing-spread information was missing as a result of sensor failure ($n = 27$), the average value of 20.97 m calculated from all other available data was used (s.d. = 1.59, $n = 113$). Distance covered was established using GPS coordinates of the start point, i.e. the point at which the trawl is on the seabed and stable, and the coordinates of the endpoint, i.e. 30 min thereafter.

The bottom trawl used on the IGFS is not ideal for sampling jellyfish effectively, because they are likely to be distributed throughout the water column, or located in dense surface aggregations, although dead jellyfish can potentially be aggregated on the seabed (Billett *et al.*, 2006; Yamamoto *et al.*, 2008). However, because deployment and recovery is standardized as part of an international survey programme, i.e. it did not vary throughout the survey, the quantity of jellyfish sampled can be used as an index to reveal spatial and temporal patterns (Brodeur *et al.*, 1999). The significance of the differences in catch-biomass between the subregions was tested using the Wilcoxon rank-sum tests.

Table 1. Characteristics of each subregion of the study area presented in Figure 1, where *n* is the number of valid sampling stations within each subregion during the IGFS 2009. The surface area of each subregion was calculated after projection in the Irish National Grid coordinates system.

Subregion	ICES Division	Surface area (km^2)	*n*
North (N)	VIa	42 829	42
West (W)	VIIb	35 634	36
Southwest (SW)	VIIj2	50 444	32
South (S)	VIIg	35 713	30

During the survey, an external temperature sensor and thermosalinograph (SEABIRD SBE38 and SBE21) continuously recorded temperature and salinity from 3 m below the surface. These data were used to describe the environmental context of each catch. Unfortunately, the sensors were only working well during the first leg of the cruise.

Results

In all, 140 valid hauls were conducted. The mean ($\pm$ s.d.) distance travelled was 3.67 $\pm$ 0.25 km. The mean ($\pm$ s.d.) spread of the net wings was 20.97 $\pm$ 1.59 m, and the mean ($\pm$ s.d.) height of the headline was 4.09 $\pm$ 0.29 m. Sampling depths ranged from 21 to 436 m (Figure 1). In all, 283.5 kg of gelatinous organisms was caught (mean per haul 2.0 $\pm$ 16.5 kg). Overall, *P. noctiluca* was the most abundant species recorded; it was present in 62.9% of the hauls, representing 92.9% of the overall wet weight of gelatinous species recorded during the survey. Other scyphozoan species were *Aurelia aurita* (present at 27.1% of the stations; 3.2% of overall wet weight), *Rhizostoma octopus* (four individuals present at four stations in the S subregion), and *Periphylla periphylla* (a single individual weighing 0.11 kg, in the SW subregion 51°36′N 11°06′W). All *A. aurita* were in poor condition and were likely dead or decaying animals, whereas *R. octopus* individuals were in excellent condition, with bright blue colouration around the bell (bell diameter 17–31 cm, wet weight 1.15–2.04 kg). Unidentified salps (Phylum Urochordata) were present in 22.1% of the hauls, contributing another 1.8% to overall gelatinous wet weight. Unidentified pieces of gelatinous material (most likely pieces of torn medusa bells) accounted for <1% of the overall wet weight recorded. The spatial and quantitative distributions of the catch of the overall gelatinous material, *P. noctiluca*, *A. aurita*, and salps are presented in Figure 2 and Table 2.

The distribution of *P. noctiluca* was heterogeneous, with an apparent North–South gradient in density (Spearman's rank correlation on density and latitude $r_s = 0.62$, $p < 0.001$). The N subregion yielded the highest biomass overall (mean catch rate 0.82 kg ha^{-1}, s.d. = 4.2), with *P. noctiluca* present at 90.4% of the stations. The same species was present at 88.9% of the stations of the W subregion and at 53.1% of the stations in the SW. Just five individuals were caught in the S. Table 2 summarizes *P. noctiluca* catches for each subregion. The catches in the N were significantly higher than those in the SW (Wilcoxon's rank-sum $W = 934$, $p < 0.01$), but the difference between the N and the W subregions was not significant ($W = 813$, $p = 0.57$). The difference between the W and the SW subregions was significant ($W = 805$, $p < 0.01$). It is of note too that space and time were highly correlated, so any North–South gradient could also be the results of delays in sampling (Spearman's rank correlation run on latitude and day of year, $r_s = 0.62$, $p < 0.001$).

Variation in abundance between stations was great within the N subregion, with catches of *P. noctiluca* ranging from zero to an exceptional 195 kg (27.1 kg ha^{-1}) between two stations located 17 km apart (Figure 3). Based on the wet weight of a random sample of 150 individuals (wet weight 1.27 kg), we estimated that this catch from ~30 km off the north coast of Ireland (55°37'N 07°32'W) contained >23 000 animals. Within the W and the SW subregions, differences between stations were less pronounced and biomass was less (Table 2). The species was present over the full ranges of temperature (11.4–14.7°C) and salinity (34.13–35.58 psu) experienced during the survey (Figure 4). An overall positive correlation was found between *P. noctiluca*

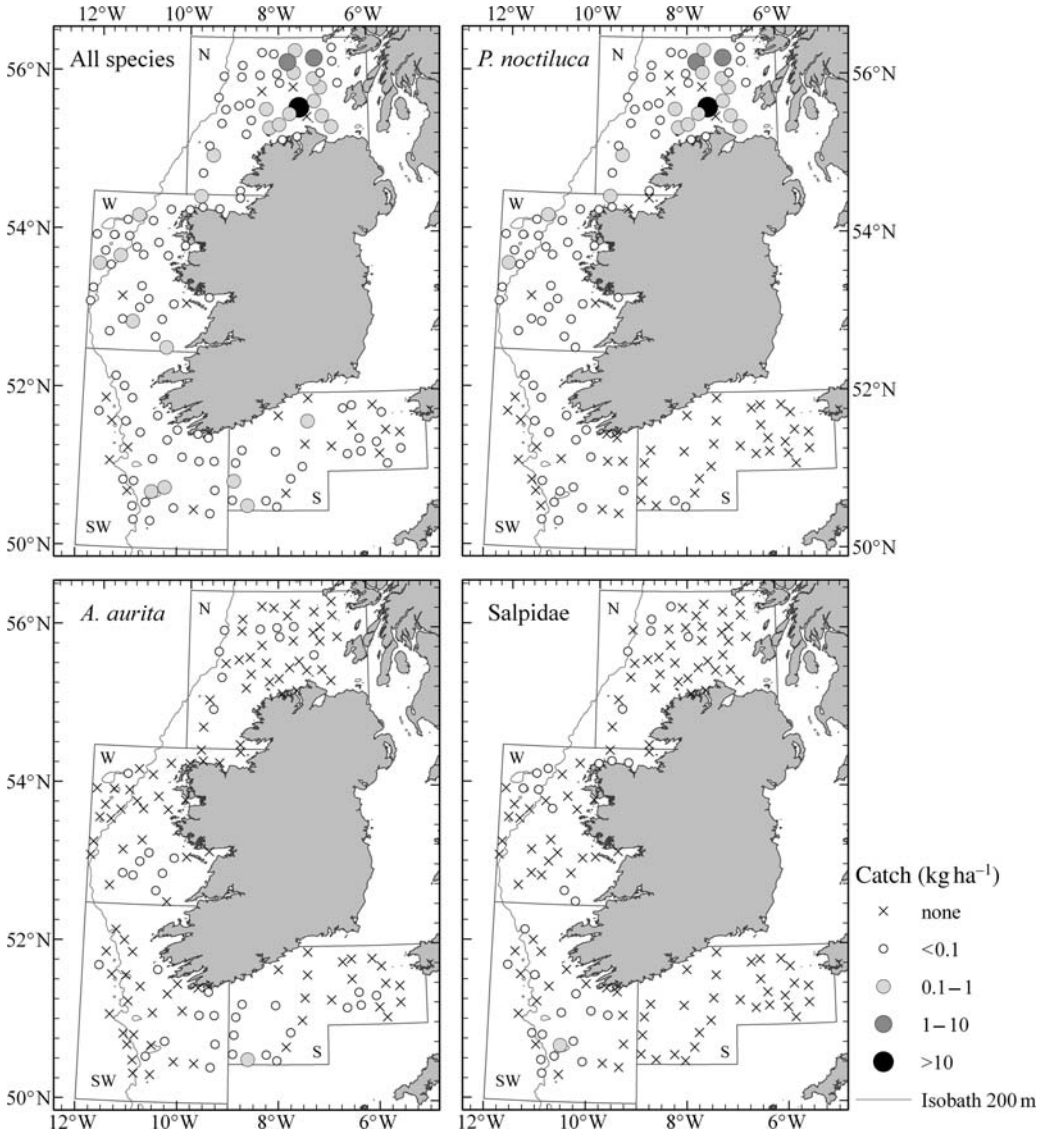

Figure 2. Catches of overall gelatinous material, *P. noctiluca*, *A. aurita*, and salps on the IGFS 2009. A close-up of the *P. noctiluca* bycatch data in the N is given in Figure 3. The solid grey line represents the 200-m isobath.

catches and subsurface temperature ($r_s = 0.34$, $p = 0.002$) and salinity ($r_s = 0.22$, $p = 0.01$). However, there were no consistent patterns across individual subregions, but low sample size caused by sensor failure during the second and the third legs rendered reliable analysis impossible. The *Pelagia noctiluca* catch rate (kg ha^{-1}) was not correlated with depth ($r_s = -0.02$, $p = 0.80$; alternative values if the catch of 27 kg ha^{-1} is excluded, $r_s = -0.005$, $p = 0.96$).

The bell diameter of individual *P. noctiluca* varied from 1 to 13.5 cm, with a median of 4.5 cm (s.d. = 1.2, $n = 4116$; Figure 5). Small individuals (<4.5 cm) had a very thin/fragile/flexible yellowish or transparent bell, sometimes with triangular yellow/brown coloured markings. Large individuals (>5 cm) were usually characterized by having a thicker transparent bell with clear warts on top, and dark mauve gonads. Samples in the N had significantly larger median bell diameters than those from the other subregions (Wilcoxon's rank-sum test: N–W: $W = 840$, $p < 0.01$; N–SW: $W = 524$, $p < 0.001$; W–SW: $W = 397$, $p < 0.01$), with an overall median bell diameter of 5.0 cm for the N ($n = 2644$), 4.0 cm for the W ($n = 1278$), and 3.5 for the SW ($n = 211$). Median bell diameter was not correlated with sample size in any subregion (Spearman's rank correlation: N: $r_s = 6421.1$, $p = 0.1545$; W: $r_s = 5605.5$, $p = 0.8817$; SW: $r_s = 776.9$, $p = 0.855$). However, because of the significant correlation between time and space mentioned above, it was not possible to determine whether the interregional variation in size was attributable to an evolution of population with time or to different sizes being associated with different areas.

Based on the total wet weight of *P. noctiluca* at each station, divided by the number of individuals at each station, we calculated a mean ($\pm$ s.d.) individual wet weight of 7.9 $\pm$ 5.9 g for the overall survey.

Discussion

Our results show that the broad-scale distribution of *P. noctiluca* in the NE Atlantic is marked by a high level of heterogeneity at

Table 2. Summary of gelatinous catch data (kg ha^{-1}) for the different subregions of the study area, where *n* is the number of stations per subregion, frequency refers to the frequency of occurrence of each species, and % catch the contribution of each species to the overall catch of gelatinous organisms in each subregion.

Taxon and parameter	Overall ($n = 140$)	North (a) ($n = 42$)	North (b) ($n = 41$)	West ($n = 36$)	Southwest ($n = 32$)	South ($n = 30$)
Pelagia noctiluca						
Frequency	0.64	0.90	0.90	0.89	0.53	0.07
% catch	93	>99	98	72	19	0.5
Mean	0.26	0.82	0.18	0.039	6.4×10^{-4}	1.7×10^{-4}
Median	0.0067	0.027	0.026	0.022	4.5×10^{-4}	0
s.d.	2.3	4.2	0.37	0.054	0.014	8.3×10^{-4}
Maximum	27.1	27.1	1.7	0.3	0.065	0.0045
Aurelia aurita						
Frequency	0.27	0.21	0.22	0.22	0.28	0.4
% catch	3	0.5	2	10	22	60
Mean	0.0084	0.0035	0.0036	0.0054	0.0072	0.020
Median	0	0	0	0	0	0
s.d.	0.024	0.0087	0.0088	0.014	0.019	0.044
Maximum	0.23	0.043	0.043	0.058	0.096	0.23
Salpa spp.						
Frequency	0.22	0.14	0.15	0.28	0.47	0
% catch	1.8	<0.1	0.1	6.9	51	0
Mean	0.0049	1.8×10^{-4}	1.9×10^{-4}	0.0037	0.017	0
Median	0	0	0	0	0	0
s.d.	0.027	5.2×10^{-4}	5.3×10^{-4}	0.013	0.053	0
Maximum	0.30	0.0025	0.0025	0.073	0.30	0
Total catch						
Mean	0.28	0.83	0.18	0.054	0.033	0.034
Median	0.024	0.033	0.032	0.038	0.016	0.0095
s.d.	2.3	4.2	0.36	0.052	0.057	0.058
Maximum	27.1	27.1	1.7	0.31	0.30	0.23

Mean, median, and s.d. are calculated over all stations, including zero stations. Statistics for the N subregion are presented (a) with and (b) without the single large catch of 196 kg (27.1 kg ha^{-1}) of *P. noctiluca* taken into account. Details for unidentified and rarely caught species (*R. octopus*) are not presented.

both small (between consecutive stations) and large (between subregions) scales (Figures 2 and 3).

At the large scale, there was a clear north–south gradient, with largest catches in the N subregion, intermediate and small catches in the W and SW subregions, and an almost total absence in the S subregion (Figure 2). Drivers of this observed interregional variation are uncertain (especially given the delay between sampling in the N and the other subregions), but the highest densities in the N (Figures 2 and 3) are most likely explained by the advection of a large pulse of oceanic water from the Rockall Trough (Figure 1) onto the continental shelf. The actual origin of *P. noctiluca* in the Rockall Trough area is uncertain, but with *P. noctiluca* generally considered to be a warm-water species (Russell, 1970), it is likely that either the Shelf Edge Current (a midwater current running north along the slope of the European continental shelf from the Iberian Peninsula up to Norwegian waters; White and Bowyer, 1997) or the North Atlantic Current (the branch of the Gulf Stream flowing towards Europe; Schmitz and McCartney, 1993) is the ultimate driver of the northern limit of the species (Figure 1). Fraser (1968) showed that, in the north, the overflow of oceanic waters peaks in September/October, but in the other areas sampled here, the seasonality of oceanic inflows is more uncertain. However, it is of note that historical records report the presence of *P. noctiluca* off the southwest coast of Ireland in November and even December in some years (reviewed in Russell, 1970). Offshore, over the Rockall Trough (Figure 1), the presence of the species has been documented in September, October, and November 2007 (Doyle *et al.*, 2008; Baxter *et al.*, 2010). The absence of the species in the south (except at two stations in the southwest of the survey area) likely reflects the relative isolation of the Celtic Sea from oceanic inputs at that time of year, as also indicated by the absence of salps in the catches there (Figure 2).

At a smaller scale, the high level of heterogeneity between stations reflects how jellyfish can form large highly localized aggregations. This horizontal patchiness was most striking in the N, with one catch of >23 000 *P. noctiluca* (27.1 kg ha^{-1}) contrasting with its absence at the previous station, just 17 km away (Figure 3). Similar local heterogeneity in the catch of *P. noctiluca* has been documented in the Adriatic Sea using data from an ichthyoplankton survey (Piccinetti and Piccinetti-Manfrin, 1991), suggesting that this result is likely not a sampling artefact. The formation of such horizontal patchiness is usually a result of local hydrographic conditions (Graham *et al.*, 2001), such as a current frontal system (Vanhöffen, 1896, cited in Russell, 1970), a convergence zone (Piccinetti and Piccinetti-Manfrin, 1991; Sabatès *et al.*, 2010), or the presence of Langmuir cells (Larson, 1992; Doyle *et al.*, 2008). Unfortunately, there are no data available on the configuration of local currents at the time of the survey at a scale that could allow investigation of such patterns.

Within the N subregion, where catches of *P. noctiluca* were largest, analysis of environmental conditions at the different stations revealed that the species was found within a small temperature range (13.2–14.7°C), but within a relatively broad salinity range (34.13–35.58 psu; Figure 4). Therefore, although there was a large variation in individual catches (and similar variation in bell

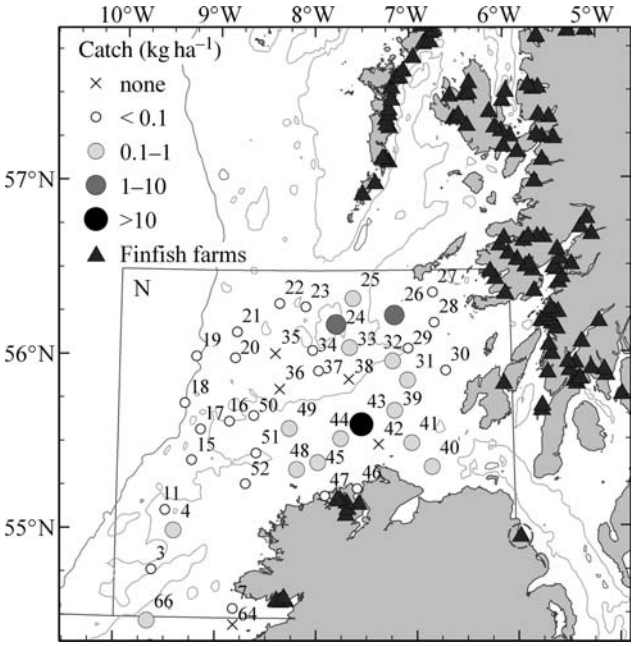

Figure 3. Distribution of *P. noctiluca* bycatch in the N subregion. Jellyfish bycatch (kg ha^{-1}) during IGFS 2009 is represented by plain circles (see legend), and sampling stations with no jellyfish bycatch are denoted by crosses. Dark triangles represent the position of finfish farms, and a dashed grey circle identifies the Northern Irish farm where a massive fish kill happened in November 2007. Sampling station number is indicated to facilitate comparison with Figure 4. Solid grey lines are the 100 m (light grey) and 200 m (dark grey) isobaths.

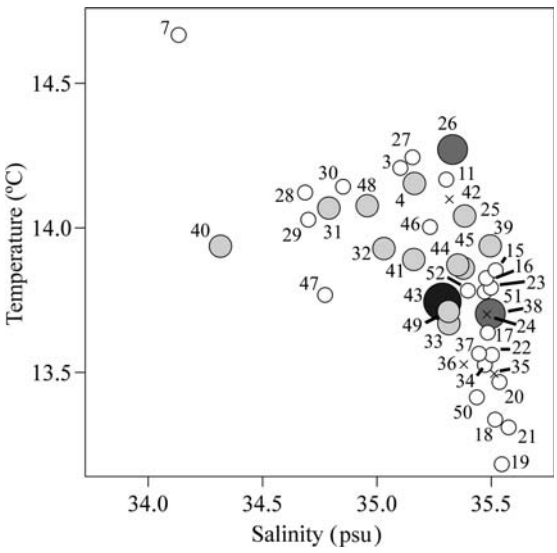

Figure 4. Environmental context of the *P. noctiluca* bycatch in the N subregion. Temperature and salinity (3 m subsurface) were measured at each station by an on-board temperature sensor and thermosalinograph. Sampling station number is indicated to facilitate comparison with Figure 3.

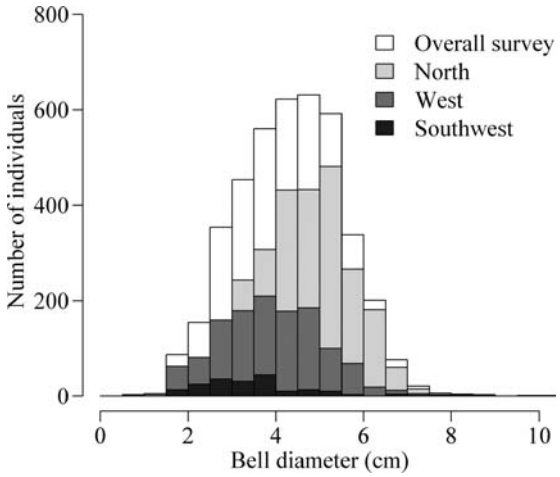

Figure 5. Size distribution of *P. noctiluca* bell diameter in the N (light grey, $n = 2640$), W (grey, $n = 1276$) and SW (dark grey, $n = 195$) subregions. The distribution for the overall survey is also represented (in white, $n = 4116$). The five individuals caught in the S subregion are not shown.

diameters between catches; Figure 5) in the N subregion, this variation could not be attributed to any particular environmental variable. Individual catches of *P. noctiluca* in the W and SW subregions were associated with lower temperatures but similar salinity values as in the N, but because the timing of these hauls was from <4 to >9 weeks after the initial hauls, no broad-scale comparison between all stations sampled was possible. In the Mediterranean Sea, the species experiences much higher salinity (>37 psu) and temperatures (>23°C; Piccinetti and Piccinetti-Manfrin, 1991; Yahia *et al.*, 2003).

The insights into the distribution of *P. noctiluca* provided by our data are of interest to the aquaculture industry. Indeed, as mentioned in the "Introduction" section, *P. noctiluca* has already caused serious damage to the industry (Merceron *et al.*, 1995; Doyle *et al.*, 2008; Hay and Murray, 2008). Considering that the aquaculture industry generates thousands of jobs and several million euros each year within the EU and is expected to expand to meet the decline in wild fisheries catch (FAO, 2000), the potential threats posed by *P. noctiluca* blooms assume great importance.

Worryingly, our data highlighted the presence of large aggregations of *P. noctiluca* in an area where many aquaculture facilities are concentrated (Figure 3). This provides an interesting snapshot at a given time that could serve as a basis to develop early warning systems. Indeed, the recent application of a particle-tracking model to jellyfish spatial dynamics (Moon *et al.*, 2010) indicates the potential for developing forecasting systems to plot the trajectory of these large aggregations and to estimate the probability that they may impact on aquaculture facilities. Data such as ours could be useful in defining realistic initial conditions for those simulations. In the meantime, mitigation measures such as the development of cost–effective barrier systems to deflect jellyfish incursions, e.g. bubble nets, need to be considered.

An additional use of jellyfish bycatch datasets collected over several years can be in supporting tools to investigate how climate and jellyfish occurrence/abundance are related (reviewed by Purcell, 2009). One of the best examples of such use comes from the eastern Bering Sea, where more than 20 years of bycatch data from quantitative bottom-trawl surveys have described how jellyfish abundance in that area is responding to successive regional climate shifts (Brodeur *et al.*, 2008).

Those results demonstrate that, although bottom-trawl surveys are not designed to sample planktonic species, they can still provide useful indices of jellyfish biomass. We believe that the data from the IGFS have the potential to provide such time-series for *P. noctiluca*, if species-specific records are maintained. Indeed, although other scyphozoan species tend to peak in summer (Doyle *et al.*, 2007; Houghton *et al.*, 2007), some are found during autumn (Figure 2), and our results show that a catch of 0.18 kg ha^{-1} in the N subregion (56°20′N 7°37′W) consisted of >200 *P. noctiluca* and that a similar catch (by weight) in the S subregion (51°38′N 7°24′W) was of a single *R. octopus* of 1.6 kg. The same happened, to a lesser extent, with catches of salps or *A. aurita* (Figure 2).

To conclude, it appears that jellyfish bycatch data not only provide information on the distribution of *P. noctiluca* at a scale and a resolution that has not been possible before in the Northeast Atlantic, but also offer one of the best available options to record year-on-year variations in the abundance of the species there. More generally, we believe that such data can provide the necessary baseline to investigate how jellyfish populations are responding to changes in marine ecosystems (Richardson *et al.*, 2009). For that reason, therefore, we urge that efforts to record jellyfish bycatch at a species level be maintained in future, and perhaps also extended to other national and international fisheries surveys.

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References

Anon. 1999. Manual for the international bottom trawl surveys. Revision VI. Addendum III. ICES Document CM 1999/D: 02.

Arai, M. N. 2001. Pelagic coelenterates and eutrophication: a review. Hydrobiologia, 451: 69–87.

Axiak, V., and Civili, F. S. 1991. Jellyfish blooms in the Mediterranean: causes, mechanisms, impact on man and the environment. A programme review. *In* Proceedings of the Second Workshop on Jellyfish in the Mediterranean Sea, Trieste, 2–5 September 1987, pp. 1–21. MAP Technical Reports Series, 47. UNEP, Athens.

Baxter, E. J., Walne, A. W., Purcell, J. E., McAllen, R., and Doyle, T. K. 2010. Identification of jellyfish from Continuous Plankton Recorder samples. Hydrobiologia, 645: 193–201.

Billett, D. S. M., Bett, B. J., Jacobs, C. L., Rouse, I. P., and Wigham, B. D. 2006. Mass deposition of jellyfish in the deep Arabian Sea. Limnology and Oceanography, 51: 2077–2083.

Boero, F., Bouillon, J., Gravili, C., Miglietta, M. P., Parsons, T., and Piraino, S. 2008. Gelatinous plankton: irregularities rule the world (sometimes). Marine Ecology Progress Series, 356: 299–310.

Brodeur, R. D., Decker, M. B., Ciannelli, L., Purcell, J. E., Bond, N. A., Stabeno, P. J., Acuna, E., *et al.* 2008. Rise and fall of jellyfish in the eastern Bering Sea in relation to climate regime shifts. Progress in Oceanography, 77: 103–111.

Brodeur, R. D., Mills, C. E., Overland, J. E., Walters, G. E., and Schumacher, J. D. 1999. Evidence for a substantial increase in gelatinous zooplankton in the Bering Sea, with possible links to climate change. Fisheries Oceanography, 8: 296–306.

CIESM. 2008. Economic valuation of natural coastal and marine ecosystems. *In* CIESM Workshop Monographs, 37, pp. 16–17. Ed. by F. Bridans. CIESM, Monaco. 112 pp.

Doyle, T. K., De Haas, H., Cotton, D., Dorschel, B., Cummins, V., Houghton, J. D. R., Davenport, J., *et al.* 2008. Widespread occurrence of the jellyfish *Pelagia noctiluca* in Irish coastal and shelf waters. Journal of Plankton Research, 30: 963–968.

Doyle, T. K., Houghton, J. D. R., Buckley, S. M., Hays, G. C., and Davenport, J. 2007. The broad-scale distribution of five jellyfish species across a temperate coastal environment. Hydrobiologia, 579: 29–39.

FAO. 2000. The State of World Fisheries and Aquaculture. FAO, Rome.

Fraser, J. H. 1968. The overflow of oceanic plankton to the shelf waters of the North-East Atlantic. Sarsia, 34: 313–330.

Giorgi, R., Avian, M., De Olazabal, S., and Rottini Sandrini, L. 1991. Feeding of *Pelagia noctiluca* in open sea. *In* Proceedings of the Second Workshop on Jellyfish in the Mediterranean Sea, Trieste, 2–5 September 1987, pp. 102–111. MAP Technical Reports Series, 47. UNEP, Athens.

Goy, J., Morand, P., and Dallot, S. 1991. Dynamique d'une population de *Pelagia noctiluca* (Cnidaria, Scyphozoa) en Mer Ligure. *In* Proceedings of the Second Workshop on Jellyfish in the Mediterranean Sea, Trieste, 2–5 September 1987, pp. 112–118. MAP Technical Reports Series, 47. UNEP, Athens.

Goy, J., Morand, P., and Etienne, M. 1989. Long-term fluctuations of *Pelagia noctiluca* (Cnidaria, Scyphomedusa) in the western Mediterranean Sea. Prediction by climatic variables. Deep Sea Research, Part A: Oceanographic Research Papers, 36: 269–279.

Graham, W. M. 2001. Numerical increases and distributional shifts of *Chrysaora quinquecirrha* (Desor) and *Aurelia aurita* (Linne) (Cnidaria : Scyphozoa) in the northern Gulf of Mexico. Hydrobiologia, 451: 97–111.

Graham, W. M., Martin, D. L., and Martin, J. C. 2003. *In situ* quantification and analysis of large jellyfish using a novel video profiler. Marine Ecology Progress Series, 254: 129–140.

Graham, W. M., Pagès, F., and Hamner, W. M. 2001. A physical context for gelatinous zooplankton aggregations: a review. Hydrobiologia, 451: 199–212.

Haddock, S. H. D. 2008. Reconsidering evidence for potential climate-related increases in jellyfish. Limnology and Oceanography, 53: 2759–2762.

Hay, S., and Murray, A. 2008. Jellyfish problems faced by the aquaculture industry. Fish Farmer, September–October 2008: 40–41.

Hay, S. J., Hislop, J. R. G., and Shanks, A. M. 1990. North-Sea scyphomedusae; summer distribution, estimated biomass and significance particularly for 0-group gadoid fish. Netherlands Journal of Sea Research, 25: 113–130.

Houghton, J. D. R., Doyle, T. K., Davenport, J., Lilley, M. K. S., Wilson, R. P., and Hays, G. C. 2007. Stranding events provide indirect insights into the seasonality and persistence of jellyfish medusae (Cnidaria : Scyphozoa). Hydrobiologia, 589: 1–13.

Kogovsek, T., Bogunovic, B., and Malej, A. 2010. Recurrence of bloom-forming scyphomedusae: wavelet analysis of a 200-year time series. Hydrobiologia, 645: 81–96.

Larson, R. J. 1992. Riding Langmuir circulations and swimming in circles—a novel form of clustering behavior by the scyphomedusa *Linuche unguiculata*. Marine Biology, 112: 229–235.

Licandro, P., Conway, D. V. P., Daly Yahia, M. N., Fernandez de Puelles, M. L., Gasparini, S., Hecq, J. H., Tranter, P., *et al.* 2010. A blooming jellyfish in the northeast Atlantic and Mediterranean. Biology Letters, 6: 688–691.

Lynam, C. P., Hay, S. J., and Brierley, A. S. 2005. Jellyfish abundance and climatic variation: contrasting responses in oceanographically distinct regions of the North Sea, and possible implications for fisheries. Journal of the Marine Biological Association of the UK, 85: 435–450.

Malej, A. 1989. Behavior and trophic ecology of the jellyfish *Pelagia noctiluca* (Forsskål, 1775). Journal of Experimental Marine Biology and Ecology, 126: 259–270.

Mariottini, G. L., Giacco, E., and Pane, L. 2008. The mauve stinger *Pelagia noctiluca* (Forsskål, 1775). Distribution, ecology, toxicity and epidemiology of stings. A review. Marine Drugs, 6: 496–513.

Merceron, M., Le Fèvre-Lehoërff, G., Bizouarn, Y., and Kempf, M. 1995. Des poissons médusés. Equinoxe (Ifremer), 56: 6–8.

Mills, C. E. 2001. Jellyfish blooms: are populations increasing globally in response to changing ocean conditions? Hydrobiologia, 451: 55–68.

Moon, J. H., Pang, I. C., Yang, J. Y., and Yoon, W. D. 2010. Behavior of the giant jellyfish *Nemopilema nomurai* in the East China Sea and East/Japan Sea during the summer of 2005: a numerical model approach using a particle-tracking experiment. Journal of Marine Systems, 80: 101–114.

Piccinetti, C., and Piccinetti-Manfrin, G. 1991. Considérations sur la distribution de *Pelagia noctiluca* (Forskal) dans l'Adriatique de 1976 à 1987. *In* Proceedings of the Second Workshop on Jellyfish in the Mediterranean Sea, Trieste, 2–5 September 1987, pp. 133–140. MAP Technical Reports Series, 47. UNEP, Athens.

Purcell, J. E. 2005. Climate effects on formation of jellyfish and ctenophore blooms: a review. Journal of the Marine Biological Association of the UK, 85: 461–476.

Purcell, J. E. 2009. Extension of methods for jellyfish and ctenophore trophic ecology to large-scale research. Hydrobiologia, 616: 23–50.

Purcell, J. E., Uye, S., and Lo, W. T. 2007. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. Marine Ecology Progress Series, 350: 153–174.

Richardson, A. J., Bakun, A., Hays, G. C., and Gibbons, M. J. 2009. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. Trends in Ecology and Evolution, 24: 312–322.

Russell, F. S. 1970. The Medusae of the British Isles. 2. Pelagic Scyphozoa. Cambridge University Press, Cambridge, UK.

Sabatès, A., Pagès, F., Atienza, D., Fuentes, V., Purcell, J. E., and Gili, J-M. 2010. Planktonic cnidarian distribution and feeding of *Pelagia nociluca* in the NW Mediterranean Sea. Hydrobiologia, 645: 153–165.

Schmitz, W. J., and McCartney, M. S. 1993. On the North-Atlantic circulation. Reviews of Geophysics, 31: 29–49.

UNEP. 1984. Workshop on jellyfish blooms in the Mediterranean, Athens, 31 October–4 November 1983. UNEP, Athens

UNEP. 1991. Jellyfish blooms in the Mediterranean. Proceedings of the Second Workshop on Jellyfish in the Mediterranean Sea, Trieste, 2–5 September 1987. UNEP, Athens. 320 pp.

White, M., and Bowyer, P. 1997. The shelf-edge current north-west of Ireland. Annales Geophysicae: Atmospheres Hydrospheres and Space Sciences, 15: 1076–1083.

Yahia, M. N. D., Goy, J., and Yahia-Kefi, O. D. 2003. Distribution and ecology of medusae and scyphomedusae (Cnidaria) in Tunis Gulf (SW Mediterranean). Oceanologica Acta, 26: 645–655.

Yamamoto, J., Hirose, M., Ohtani, T., Sugimoto, K., Hirase, K., Shimamoto, N., Shimura, T., *et al.* 2008. Transportation of organic matter to the sea floor by carrion falls of the giant jellyfish *Nemopilema nomurai* in the Sea of Japan. Marine Biology, 153: 311–317.