SHORT COMMUNICATION

Widespread occurrence of the jellyfish *Pelagia noctiluca* in Irish coastal and shelf waters

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An oceanic cruise (October 2007) revealed the widespread occurrence of Pelagia noctiluca *in the NE Atlantic just prior to a major fish kill induced by* P. noctiluca *in Irish coastal waters.*

Constrained by a benthic polyp stage, most scyphozoan jellyfish have a predominantly coastal distribution. However, the scyphozoan *Pelagia noctiluca* lacks a benthic polyp stage and this species consequently has a very broad distribution across ocean basins (Arai, 1997; Purcell, 2005). *Pelagia noctiluca* is well known for its major outbreaks in the Mediterranean where it impacts negatively on both fisheries and tourism (CIESM, 2001). The impact of these blooms on fish populations may be considerable as *P. noctiluca* is a top planktonic predator (Larson, 1987), feeding on almost all zooplankton (Giorgi *et al.*, 1991; Zavodnik, 1991; Malej *et al.*, 1993), including eggs and larvae of nekton. *Pelagia noctiluca* may also cause fish mortalities in aquaculture cages possibly by irritating the fish gills (Merceron *et al.*, 1995). Considering this notoriety, there are comparatively few published records of *P. noctiluca* blooms outside the Mediterranean. Here we document the widespread occurrence of *P. noctiluca* in the NE Atlantic, just prior to a major fish kill induced by *P. noctiluca*, and discuss the historical occurrence and likely impacts of climate change for this species.

Net tows and visual observations for *P. noctiluca* were carried out during a cruise from 30 September to 22 October 2007 on board the *RV Pelagia* (Royal Netherlands Institute for Sea Research; NIOZ). Net tows, visual observations and dip netting were conducted in seven main areas of the slope and shelf waters west of Ireland (Fig. 1). Visual observations for *P. noctiluca* were also conducted when in transit between these areas when weather permitted. Vertical net tows were carried out from 200 m to the surface, using a 1 m diameter ring net with a 700 μm mesh towed at 0.5–1 m s^{-1}. Given the large mesh size and the fact that no large catches were made that could possibly clog the net, we assumed 100% filtration efficiency. All *P. noctiluca* were counted and bell diameter measured to the nearest mm immediately after collection. All net tows were deployed independent of surface observations, and all locations were randomly selected depending on

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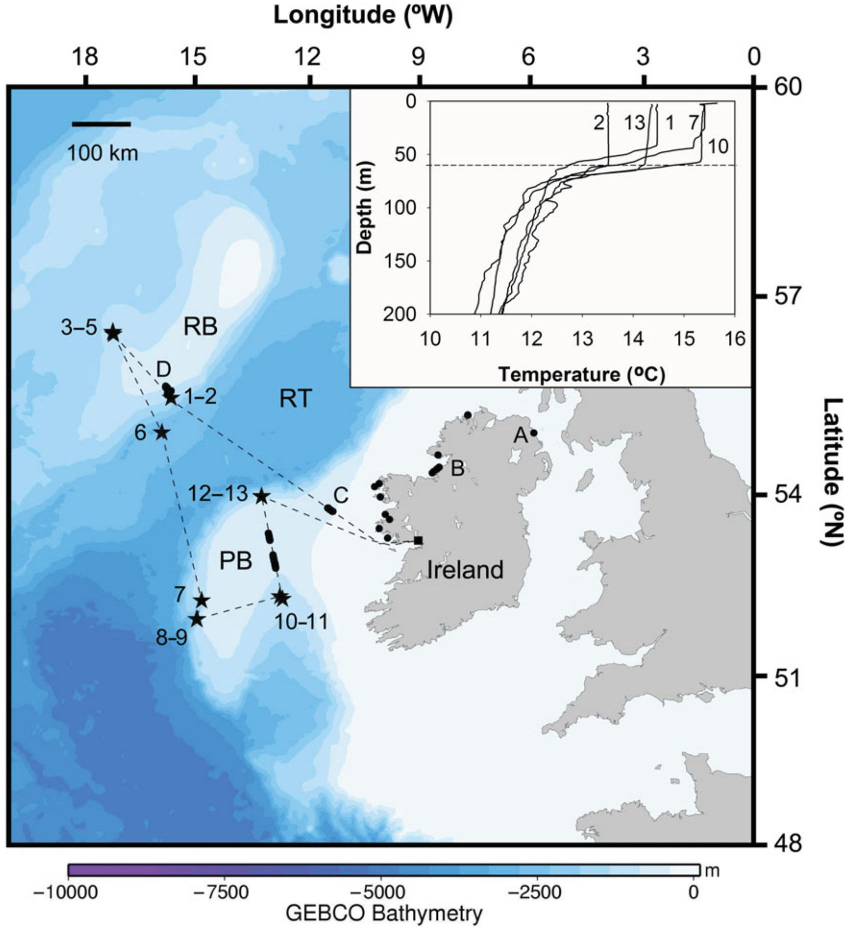

Fig. 1. Cruise track in October 2007 (hashed line). Location of net hauls indicated by the filled stars, and location of *P. noctiluca* beach strandings and other coastal observations by filled circles. Filled circles at sea indicate where *P. noctiluca* were observed in densities of at least 0.03 individuals 1000 m^{-2}. Indicated is the location of the salmon farm suffering mass mortality during mid-November 2007 (**A**). The greatest number of *P. noctiluca* estimated on a single stranding event was ~500 000 (estimated per m^2 at several sites along a 2.5 km beach and then scaled up for the whole beach) (**B**). Filled square denotes Galway city where cruise began and ended. RB, Rockall Bank; RT, Rockall Trough; PB, Porcupine Bank. A large daytime surface aggregation was observed on 30 October 2007 (**C**). The aggregation occurred over a linear distance of 9 km and *P. noctiluca* densities were often greater than 100 individuals m^{-2}. During this transect, we encountered small patches (10–20 m across) of water (slicks) that appeared to be *P. noctiluca*-free. Sea conditions were very calm (wind speed 6.4 knots, SST = 14.7°C). Also, during, a 10 min observation at night (8 October 2007), 34 Langmuir cells of *P. noctiluca* were observed in a 1.4 km stretch of water (**D**). Each cell was 2–4 m wide and with a mean distance of ~40 m separating each Langmuir cell. It was estimated that there were at least 100 *P. noctiluca* m^{-2} at times. Sea conditions: wind speed 20 knots, SST = 13.8°C. Insert: CTD profiles illustrating thermocline and sea surface temperatures during cruise. Numbers accompanying CTD profiles refer to location of Net haul of same number.

weather and ship operations. At some locations, both day and night tows were carried out. At each net sampling location, a Sea-Bird CTD was used to measure temperature/depth profiles (Fig. 1).

Daytime visual observations of *P. noctiluca* were made from an elevated position from the beam of the *RV Pelagia* (fore deck, 7.5 m above sea level), following the methodology described previously (Doyle *et al*., 2007). The abundance of *P. noctiluca* was estimated per 5 min interval using the following number categories: 0, 1–10, 11–50, 51–100, 101–500, 501–1000 and >1000. Nighttime observations were sometimes made from the work area (~mid ship, 4.5 m above sea level) when lights used to illuminate the work area also illuminated a small area of the sea surface (~5 m^2), but only the presence of large aggregations was noted. During one 5 min sampling period, a 0.5 m diameter net (dip net) with a 4 mm mesh size was used to scoop any observed *P. noctiluca* from the surface.

Several beaches in Ireland were patrolled to make observations of stranded jellyfish (Fig. 1) during October and November 2007. This targeted "beach strandings data" was further supported by other validated reports of beach strandings and visual observations of jellyfish in coastal waters made by known naturalists, fishermen and researchers working in the area. Furthermore, a review of the literature (from 1890 onwards) was also conducted to piece together the historical occurrence of *P. noctiluca* in Irish/UK waters. Only published reports that mentioned "blooms, swarms, or aggregations", or had several reports from different locations/authors were considered "*P. noctiluca* years". Data on the annual North Atlantic Oscillation (NAO) Index were obtained from the Climate Analysis Section, NCAR, Boulder, USA.

Pelagia noctiluca occurred in all net tows ($n = 13$, Table I) and was repeatedly seen at the surface, being found throughout the 1815 km of cruise track, which spanned 4° of latitude from 52 to 56°N (Fig. 1). Mean density in nets hauls was 0.7 individuals m^{-3} (117 individuals), with a maximum density of 2.8 individuals m^{-3} (447 individuals) (Table I). When this biggest catch was made (at night) a large surface aggregation of *P. noctiluca* was visible (net haul 4) and they coloured the sea brown/red, with densities of >100 individuals m^{-2} estimated by eye. This observation suggests that, in this haul, most *P. noctiluca* were probably located in the top 20 m, and indeed, observations of *P. noctiluca* in the Adriatic Sea found that they formed subsurface aggregations from a few to 20 m deep (Malej, 1989). However, during other hauls they may have been dispersed throughout the entire 200 m as other studies have shown *P. noctiluca* to be found much deeper (Franqueville, 1970; Larson *et al.*, 1991), although it is unsure whether these are typical depth distributions for the species or just dispersed individuals. Individuals taken in nets were generally small (mean diameter = 14.0 mm ± 7.1 SD, median = 13.0 mm, $n = 1867$, range: 1–80 mm). The species matures at a size of around 60 mm (Malej and Malej, 2004) suggesting that most individuals we collected were immature. For many plankton taxa, vertical distribution is influenced by developmental stage (e.g. Hays, 1995). Whether ontogenetic changes in depth occur in *P. noctiluca* is not known.

A total of 585 min of daytime visual observations were made over 6 days (114 five-min sampling events, ~100 min per day). Largest surface densities of *P. noctiluca* were 22.4 individuals 1000 m^{-2} (when >1000 jellyfish per 5-min observed), but lower densities of 0.08 individuals 1000 m^{-2} were typical (i.e. 1–10 *P. noctiluca* per 5 min sampling period). The mean density of *P. noctiluca* per 5 min sampling period was 0.94 individuals 1000 m^{-2} ($n = 114$). Local density maxima occurred at finer scales than was possible to record, even at 5 min intervals (i.e. >100 individuals m^{-2} were often seen but difficult to estimate accurately). Of note: *P. noctiluca* was observed during 69 out of 114 5-min sampling periods (or 61% of the time), either in low numbers, aggregations or both. Observations of single individuals of *P. noctiluca* (i.e. observations outside of aggregations) were probably in the 40+ mm size range, as smaller individuals were difficult to observe, unless tightly aggregated. This is supported by a 60 min surface sampling event during which all individual *P. noctiluca* observed were scooped out of the water using a dip-net, and measured ($n = 8$, mean = 40.4 mm ± 4.2 SD, range: 34–47 mm). Observations of some noteworthy surface aggregations were made (see legend to Fig. 1).

Beach strandings and coastal observations (at sea and within aquaculture cages) showed *P. noctiluca* in large numbers at seven different locations on the west and northwest coast of Ireland during October 2007 (furthest distance between locations was 250 km), when the cruise was still in progress (Table II), and at nine locations in November, notably at Antrim where there was a major fish kill reported (~250 000 salmon killed; John Russell, Director, The Northern Salmon Co. Ltd,

Table I: Details of net hauls

Net haul no.	Date	Longitude (°W)	Latitude (°N)	Time of net haul (GMT)	SST (°C)	No. of *P. noctiluca* (*n*)	Density of *P. noctiluca* (n m^3)
1	02 October 2007	15.68	55.51	08:15	14.3	18	0.1
2	05 October 2007	15.68	55.51	10:39	14.3	76	0.5
3	06 October 2007	17.23	56.47	08:34	13.9	1	0.0
4	06 October 2007	17.23	56.51	19:42	13.9	447	2.8
5	07 October 2007	17.25	56.50	08:10	13.8	26	0.2
6	09 October 2007	15.93	54.98	21:00	14.7	139	0.9
7	11 October 2007	14.86	52.29	09:24	15.5	148	0.9
8	11 October 2007	14.99	51.98	20:34	15.8	263	1.7
9	13 October 2007	14.99	51.98	15:36	15.7	148	0.9
10	14 October 2007	12.75	52.36	19:59	15.6	6	0.0
11	16 October 2007	12.68	52.31	09:32	15.5	23	0.1
12	16 October 2007	13.25	53.98	22:10	15.0	53	0.3
13	17 October 2007	13.25	53.98	11:32	14.8	173	1.1

Table II: Details of beach strandings and coastal observations of P. noctiluca (Abundance is minimum numbers observed)

Date	Location	Longitude (W)	Latitude (N)	Observation type	Abundance of *P. noctiluca*	Notes
12 October 2007	Achill Island, Mayo	10.06	53.97	At sea	>5000	100 m^2, alive and washing in
14 October 2007	Fintra Strand, Donegal	8.51	54.63	Beach	501–1000	
17 October 2007	Cloonagh Beach, Sligo	8.62	54.37	Beach	101–500	
18 October 2007	Yellow Strand, Sligo	8.48	54.44	Beach	10–50	
20 October 2007	Achill Island, Mayo	10.06	53.97	Beach	1–10	
29 October 2007	The Mullet, Mayo	10.09	54.18	Beach	>5000	1000's alight on incoming waves
29 October 2007	Iniskea North, Mayo	10.21	54.13	At sea	>5000	1000's adrift between channels
30 October 2007	Manin Bay, Galway	10.09	53.46	Fish farm	>5000	Millions of them, in cages too
04 November 2007	Ballyhiernan Bay, Donegal	7.71	55.25	Beach	1–10	
04 November 2007	Feenish Island, Galway	9.86	53.31	At sea	>5000	Shoals of small brown jellyfish
09 November 2007	Killary Harbour, Galway	9.81	53.61	Fish farm	1001–5000	All in top 2 m
10 November 2007	Streedagh Strand, Sligo	8.54	54.41	Beach	10–50	Many small brown jellyfish
11 November 2007	Ballyhiernan Bay, Donegal	7.71	55.25	Beach	1001–5000	
13 November 2007	Ballyhiernan Bay, Donegal	7.71	55.25	Beach	1001–5000	
14 November 2007	Louisbourgh, Mayo	9.92	53.69	Beach	1–10	
15 November 2007	Ballyhiernan Bay, Donegal	7.71	55.25	Beach	1001–5000	
16 November 2007	Streedagh Strand, Sligo	8.54	54.41	Beach	>5000	c500,000 estimated
16 November 2007	Yellow Strand, Sligo	8.66	54.35	Beach	>5000	c150,000 estimated
17 November 2007	Trawalua Strand, Sligo	8.48	54.44	Beach	1001–5000	1000s
17 November 2007	Achill Island, Mayo	10.06	53.97	Beach	>5000	
21 November 2007	Glenarm Bay, Antrim	5.93	54.97	Fish farm	>5000	
25 November 2007	Ballyhiernan Bay, Donegal	7.71	55.25	Beach	1–10	
25 November 2007	Streedagh Strand, Sligo	8.54	54.41	Beach	>5000	c100,000 estimated
26 November 2007	Streedagh Strand, Sligo	8.54	54.41	Beach	>5000	c500,000 estimated
06 December 2007	The Mullet, Mayo	10.09	54.18	Beach	1–10	
10 December 2007	Streedagh Strand, Sligo	8.54	54.41	Beach	101–500	

personal communication). However, *P. noctiluca* was also reported in a number of other salmon farms cages with very few mortalities.

These results suggest that the *P. noctiluca* bloom that caused a fish kill in the North Channel of the Irish Sea was not a localized occurrence, but was a symptom of an ocean-scale occurrence. Whether this was an exceptional event or typical of the North East Atlantic is uncertain, but the analysis of historical reports suggests that *P. noctiluca* might in fact be a regular component, at least in Irish and UK coastal waters (Boero *et al.*, 2008). Indeed, during the period 1890–1985, *P. noctiluca* was reported in Irish/UK waters in 21 out of a possible 95 years (1890, 1896–97, 1899, 1902–04, 1906–07, 1909, 1914, 1946, 1949, 1953, 1966, 1969, 1971–72, 1975–76 and 1982) (Delap and Delap, 1905; Delap, 1924; Cole, 1952; Russell, 1970; West and Jeal, 1971; Mauchline and Harvey, 1983; Hay *et al.*, 1990). So although *P. noctiluca* has not been reported every year, it clearly is not an infrequent visitor to the NE Atlantic. During the same time period, *P. noctiluca* was reported in 50 years in the western Mediterranean (Goy *et al.*, 1989; Malej and Malej, 2004). Unlike other plankton taxa that have been sampled historically and links between their abundance and climatic/oceanographic indices been established (e.g. Hays *et al.*, 1993; Lynam *et al.*, 2004; Hays *et al.*, 2005), there appeared to be no clear link between the NAO and the occurrence of *P. noctiluca* in Irish and UK waters (i.e. the mean NAO values between those years in which *P. noctiluca* was and was not recorded, being not significantly different (Student's $t_{52} = 0.52$, $P = 0.61$). However, it needs to be remembered that *P. noctiluca* has not been sampled quantitatively with historical records being subject to reporting biases. Hence improved sampling will be required to identify any trends between *P. noctiluca* abundance and climatic or oceanographic indices. However, it was interesting to note that of the 21 years *P. noctiluca* did occur, half were years when *P. noctiluca* was not recorded in the Mediterranean (Goy *et al.*, 1989).

From these historical coastal records, it is difficult to infer the wider oceanic distribution as reported in this study. Yet historical reports suggest that coastal records are indeed reflective of a widespread occurrence along the continental shelf (Fraser, 1952, 1955). For example, observations of young stages of *P. noctiluca* were made in deep waters southwest of Ireland (~48°N, and between 12 and 16°W) in April 1953, then on both sides of the Rockall Bank in June, and "by early November was abundant enough to interfere with fishing operations west of Scotland" (Fraser, 1955). Similarly, *P. noctiluca* was reported in the Rockall area during 1982 (Mauchline and Harvey, 1983) when also reported in the Scottish north and east coasts (Hay *et al.*, 1990). As such, the presence of *P. noctiluca* in coastal waters is probably (and logically) synonymous of an oceanic occurrence.

Considering the recent fish kill in Northern Ireland and the projected expansion of finfish aquaculture in Ireland, some way of routinely providing synoptic maps of *P. noctiluca* distribution would clearly be useful. Furthermore, given the inferred role of currents in driving *P. noctiluca* distribution, oceanographic particle tracking models, which have been applied to various species in the North Atlantic (e.g. Hays and Marsh, 1997; Kettle and Haines, 2006) may have some utility for predicting the fate of oceanic *P. noctiluca* blooms and so provide an early warming-system for predicting deleterious coastal blooms. Indeed, a particle tracking model to track jellyfish around the waters of Shetland under an EU-funded research project called EUROGEL has already been developed (Elzeir and Hay, 2005). Finally, how the intensity of *P. noctiluca* blooms will respond to climate change is not known. Given recent warming of the NE Atlantic and range extensions reported for a number of taxa including fish, turtles and plankton (Hays *et al.*, 2005; Perry *et al.*, 2005; McMahon and Hays, 2006), we might expect that a predominantly warm-water species such as *P. noctiluca* will be expanding its range.

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