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A multispecific accumulation of gelatinous organisms in the central Aegean Sea as a case of biological evidence for unnoticed offshore events

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Abstract: An exceptionally high density of gelatinous organisms was observed in May 2015, off the coasts of Doğanbey, central Aegean Sea. Eight gelatinous species were found in the accumulation, with salps being the main component. The hydromedusae *Solmaris corona* and *Aequorea forskalea*, the siphonophore *Nanomia bijuga* and the ctenophore *Leucothea* sp. are recorded for the first time from the Aegean Sea. The hydromedusa *S. corona*, the siphonophores *Hippopodius hippopus* and *N. bijuga*, the salp *Salpa maxima* and the ctenophore *Leucothea sp.* are first records for the Turkish coasts. We suggest that the various life histories and different ecological traits of the gelatinous components in the accumulation are indicators of an apparent bloom, i.e., the organisms bloomed/increased their abundances in response to different processes and were aggregated only subsequently at the coast, due to strong southwesterly winds and north-eastward currents originating a few days prior to our observations. The offshore area facing Doğanbey is characterized by a large gyre coupled with one of the most vigorous upwelling zones in the Mediterranean Sea, therefore creating favourable conditions for the aggregation of salps and the presence of siphonophores.

Résumé : *Une accumulation plurispécifique d'organismes gélatineux en Mer Egée centrale, signal biologique d'évènements non signalés survenus au large.* Une densité exceptionnellement élevée d'organismes gélatineux a été observée en mai 2015, sur les côtes de Doğanbey, en Mer Egée centrale. Huit espèces gélatineuses ont été trouvées dans l'accumulation, les salpes constituant la composante principale. Les hydroméduses *Solmaris corona* et *Aequorea forskalea*, le siphonophore *Nanomia bijuga* et le cténophore *Leucothea sp.* sont des premiers signalements pour la Mer Egée. L'hydroméduse *S. corona*, les siphonophores *Hippopodius hippopus* et *N. bijuga, le salpe Salpa maxima* et le cténophore *Leucothea sp.* sont des premiers signalements pour les côtes turques. Nous suggérons que les divers cycles de vie et les différents traits écologiques des composants gélatineux dans l'accumulation sont des indicateurs d'une prolifération apparente : les organismes ont proliféré/augmenté leurs abondances en réponse à des processus différents et n'ont été accumulés aux côtes que par la suite, par des vents forts provenant du sud-ouest et des courants en direction du nord-est, prédominants quelques jours avant nos observations. La zone au large de Doğanbey est caractérisée par un large tourbillon couplé à une des zones de remontée d'eaux profondes les plus importantes, créant ainsi les conditions favorables pour l'accumulation des salpes et la présence des siphonophores.

Keywords: Hydromedusae ● Siphonophores ● Salps ● Ctenophores ● Surface circulation

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Introduction

The term "gelatinous zooplankton" applies to several kinds of organisms belonging to different taxa, including (but not restricted to) medusae, ctenophores, siphonophores, salps, and appendicularians. These organisms share morphological and biophysical traits (i.e. gelatinous body, a degree of transparency, slow movement), but nonetheless differ in their evolutionary and ecological features, the latter including, in many cases, the sudden presence of high densities of individuals at a specific time and place (Mills, 2001; Purcell, 2005; Lucas & Dawson, 2014). The accumulation of gelatinous zooplankton in blooms and aggregations is thus a natural consequence of the life-history strategies of many species, but despite their acknowledged role in shaping marine ecosystems, there are still gaps in our understanding of the factors that trigger and maintain these events, as well as their consequences and general characteristics (Boero et al., 2008; Duarte et al., 2014; Benedetti-Cecchi et al., 2015). Massive aggregations of gelatinous zooplankton might last for months or be of very short duration, not following a regular basis or periodicity and therefore might pass unnoticed or unrecorded by the scientific community (Mills, 2001; CIESM, 2001). Moreover, not all of these accumulations are "true blooms/outbreaks" resulting from rapid population growth of jellyfish or thaliaceans, as the concentration of gelatinous zooplankters may be the result of the redistribution by winds and currents of a stable population (i.e. "apparent bloom") (CIESM, 2001; Graham et al., 2001).

Some gelatinous zooplankton accumulations might cause severe ecological and economic consequences, thus gathering great public and scientific attention (Purcell et al., 2007; Uye, 2008). Negative effects associated with blooms and aggregations of jellyfish and thaliaceans include interference with commercial fisheries activities, disruption of the operation of power plants, and major alterations in marine ecosystems, as has been documented for the blooms of the invasive ctenophore *Mnemiopsis leidyi* A. Agassiz, 1865 in the Black Sea in the 1990's (Kıdeyş, 2002) or that of the scyphozoan *Pelagia noctiluca* (Forsskål, 1775) in the 1980's in the western Mediterranean Sea (UNEP, 1984 & 1991). The economic and ecological costs of these accumulations may be high (Lucas et al., 2014; Palmieri et al., 2014), and therefore documenting the geographical and temporal patterns in the abundance of gelatinous zooplankton is an important research initiative that will help the scientific community and public managers to develop better strategies to manage jellyfish blooms and aggregations. Recording unusual bloom events, in particular, might help us understand the irregularities of the population dynamics of some blooming species, as pointed out by Boero (2013). In this study we report on an exceptionally high density of gelatinous organisms off the coasts of Doğanbey, central Aegean Sea. The aim of the study was to determine the species composing the accumulation and to understand the driving factors behind this unusual event.

Material and Methods

The coasts between Doğanbey and Seferihisar (Izmir, Turkey), are located on the eastern side of the Sığacık Bay, Central Aegean Sea, and often are impacted by the northward flowing currents from the high seas area between Chios and Samos Islands (Fig. 1). The salinity is

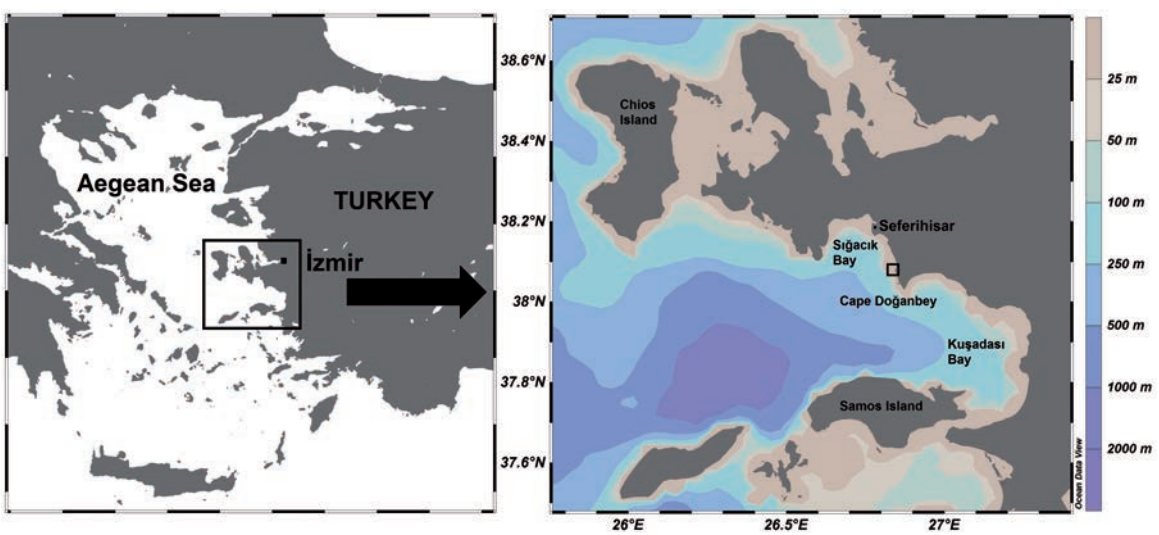

Figure 1. Location of Doğanbey, on the Aegean Sea, where the accumulation of gelatinous zooplankton was observed.

around 39 and the water temperature varies between 18 and 20°C during the month of May (Poulos et al., 1997). The coasts of Doğanbey are mainly rocky and the bottom consists of boulders, covered by photophilic brown algae, spread among sandy bottoms and *Posidonia oceanica* meadows.

The sampling area (38°04'37.04"N-26°50'41.29"E) was being monitored for another study when this unusual accumulation occurred. Therefore, we were able to sample and perform observations from the beginning to the end of the event (16-19 May 2015). Specimens were sampled while snorkelling and preserved in formaldehyde for identification in the laboratory with the aid of specialized literature (e.g. Godeaux, 1998; Bouillon et al., 2004). Gelatinous organisms were counted by snorkelling during 10 minutes at a fixed speed in order to obtain an idea of their density along 6 transects of 100 meters. For each transect, the % of occurrence was determined by dividing the number of observations of a species by the total number of gelatinous organisms/transect and multiplying the result by 100. The mean frequency of occurrence of each species was then calculated by taking the average of the percentages in the 6 transects for that species. Six categories were assigned on a semi-quantitative basis using the ACFOR scale: Abundant (> 75%), Common (75-51%), Frequent (50-26%), Occasional (25-6%) and Rare (5-1%). Forecasts of the surface winds and local circulation were obtained from http://poseidon.hcmr.gr/ and used to identify environmental signals potentially responsible for the observed accumulation.

Results

Eight taxa were present in the accumulation (Table 1). *Aequorea forskalea* was the only species present on 16 May 2015, but the next day the accumulation was composed of hydromedusae, siphonophores, ctenophores and salps (Fig. 2A & B). The latter were the main components of the accumulation in terms of biomass and number (Table 1). Dead and dying gelatinous zooplankton started to accumulate near the shore in the afternoon, forming large

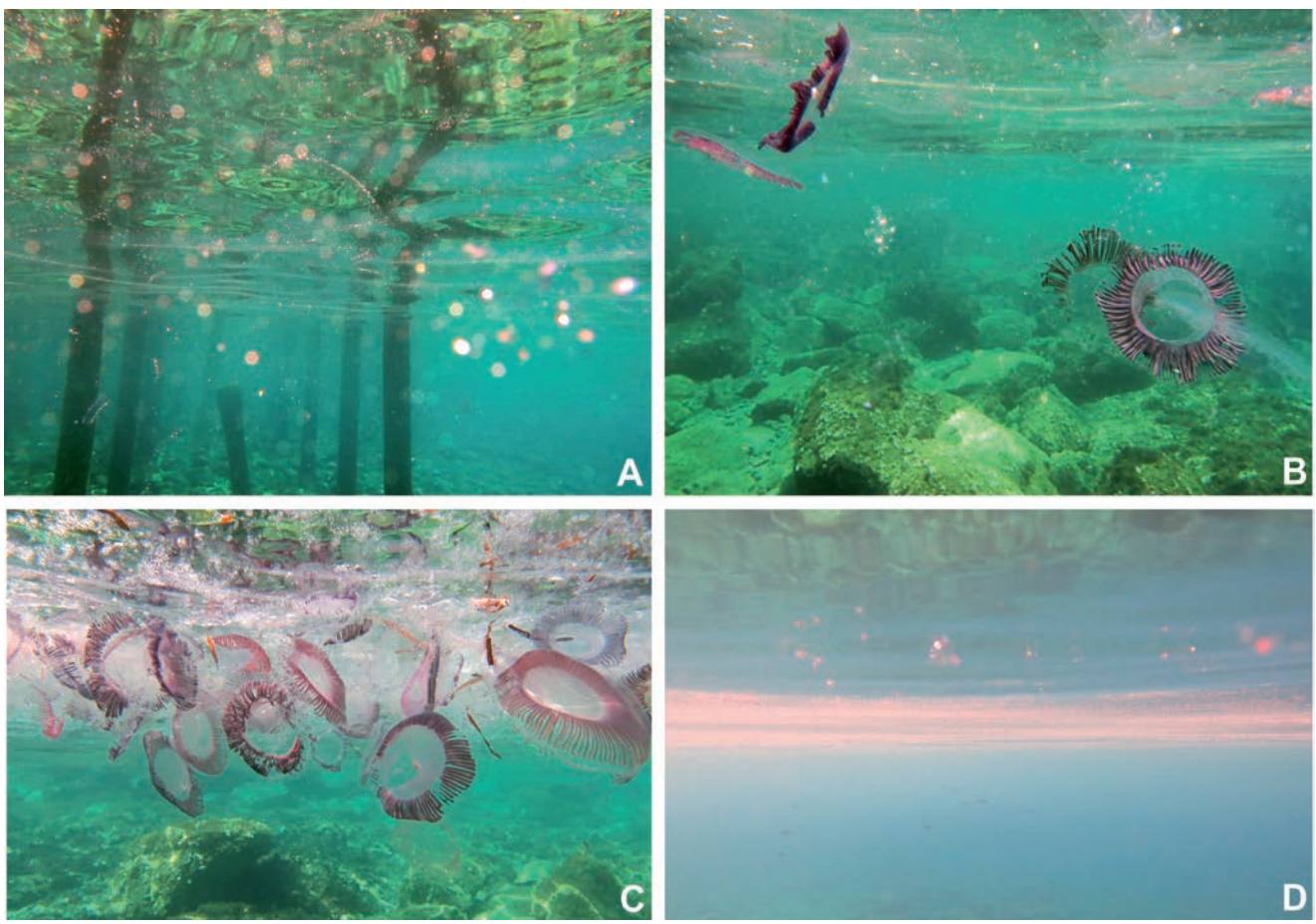

Figure 2. Gelatinous organisms, accumulated off the shallow coast of Doğanbey, consisted mainly of salps **(A)** and *Aequorea* medusae **(B)**; large decomposing aggregates occurred during the following days **(C & D)**.

Table 1. The frequency of occurrence of each species expressed in ACFOR scale: Abundant (> 75%), Common (75%-51%), Frequent (50%-26%), Occasional (25%-6%), Rare (5%-1%) and None. Species observed only once are marked as present (P).

	May 16th	May 17th
Phylum Cnidaria		
Class Hydrozoa		
Order Narcomedusae		
Family Solmarisidae		
***Solmaris corona* (Keferstein & Ehlers, 1861)**	N	R
Order Leptothecata		
Family Aequoreidae		
***Aequorea forskalea* Péron & Lesueur, 1810**	F	F
Order Siphonophorae		
Family Hippopodiidae		
***Hippopodius hippopus* (Forsskål, 1776)**	N	O
Family Agalmatidae		
***Nanomia bijuga* (Delle Chiaje, 1844)**	N	R
Phylum Ctenophora		
Class Tentaculata		
Order Cestida		
Family Cestidae		
***Cestum veneris* Lesueur, 1813**	N	P
Order Lobata		
Family Leucotheidae		
Leucothea sp.	N	P
Phylum Chordata		
Class Thaliacea		
Order Salpida		
Family Salpidae		
***Salpa maxima* Forskål, 1775**	N	C
***Thalia democratica* (Forskål, 1775)**	N	A

decomposing aggregates (Fig. 2C & D). This situation continued during the third day while no sign of the bloom was left on the fourth day.

The various components of the accumulation belonged to non-related, phylogenetically distant taxa with diverse life histories, distinct morphology and very different ecological traits (Fig. 3). Both salp species were present only in blastozooid form. *Thalia democratica* chains were generally 10-30 cm long, while the zooids were 6-8 mm long. Large-sized blastozooids of *Salpa maxima* (up to 15 cm excluding projections) were generally detached and chains were only composed of a small number of zooids. Medusae of *Aequorea forskalea* were the largest single component of the aggregation, with a diameter of the umbrella of up to 20 cm in most cases, although slightly larger individuals were also observed. Long masses of gonadic tissue were present along almost all the length of the radial canals in the majority of the organisms. In contrast, all observed individuals of *Solmaris corona* were non-reproductive, flat, small (10-14 mm in diameter) medusae with 17-30 long tentacles. Polygastric stages of siphonophores recorded in the accumulation included mostly medium to small colonies, ranging from those of the calycophoran *Hippopodius hippopus* (up to 15 cm long, nectophores 10 mm in the longest axis) to those of the physonectid *Nanomia bijuga* (up to 29 cm long when not contracted, nectophores 2-4 mm in the longest axis). The two specimens of ctenophores observed were also large: *Leucothea sp.* measured around 15 cm in length, while *Cestum veneris* was smaller, measuring about 10 cm in length.

Discussion

Solmaris corona, Aequorea forskalea, Nanomia bijuga and the genus *Leucothea* are recorded for the first time from the Aegean Sea. *A. forskalea* has previously been recorded from the Levantine Coasts of Turkey (Gürlek et al., 2013) but had not yet been observed off the Aegean coasts. *S. corona, Hippopodius hippopus, N. bijuga, Salpa maxima* and the genus *Leucothea* are first records for the Turkish coast.

The most prominent feature of the gelatinous accumulation off Doğanbey is the gathering of several organisms characterized by very different life histories and ecological traits. The life cycle of *A. forskalea* includes a benthic polyp stage, while the other gelatinous taxa are truly holoplanktonic. Besides, some species such as *S. corona* and the siphonophores, but also to a certain extent the ctenophores and thaliaceans, can be considered more "offshore species" (e.g. Russell, 1953; Totton, 1965; Robison et al., 1998), and by no means are they common in such shallow waters as we surveyed in this study. Therefore, the factors that triggered an increase in the abundances of species with such different ecological traits and the reasons for their aggregation in shallow coastal waters need to be clarified.

Aequorea forskalea is a bloom forming species elsewhere in the Mediterranean Sea (Malej, 2001), but was not previously reported to form blooms in the Aegean Sea. *Aequorea* medusae are gelatinous predators, the diet of which consists of a large variety of organisms including copepods, fish eggs, larvae, and other gelatinous organisms (Purcell, 1989), and in the studied accumulation some specimens were observed with the stomach filled with salps (Fig. 3B), suggesting that the blooming of this species might be related to both, the high abundances of salps and the concentration of individuals by local currents. Salp

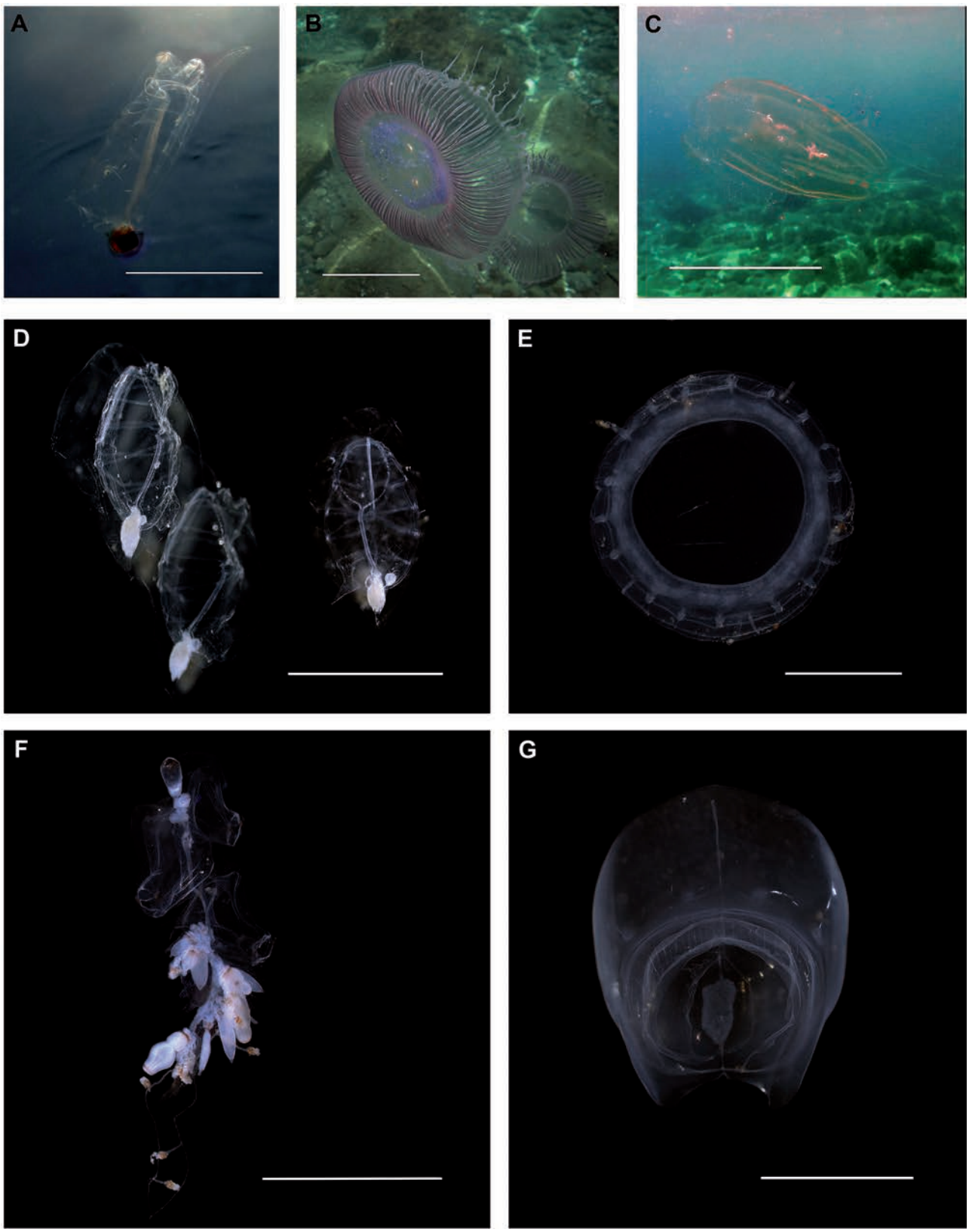

Figure 3. Major components of the accumulation of gelatinous organisms off Doğanbey. **A.** Blastozooid of *Salpa maxima*. **B.** Medusae of *Aequorea forskalea*. **C.** *Leucothea sp.* **D.** Blastozooids of *Thalia democratica*. **E.** *Solmaris corona* medusa. **F.** Polygastric colony of *Nanomia bijuga*. **G.** Nectophore of *Hippopodius hippopus*. Scale bar is 10 cm in A-C and 5 mm in D-G.

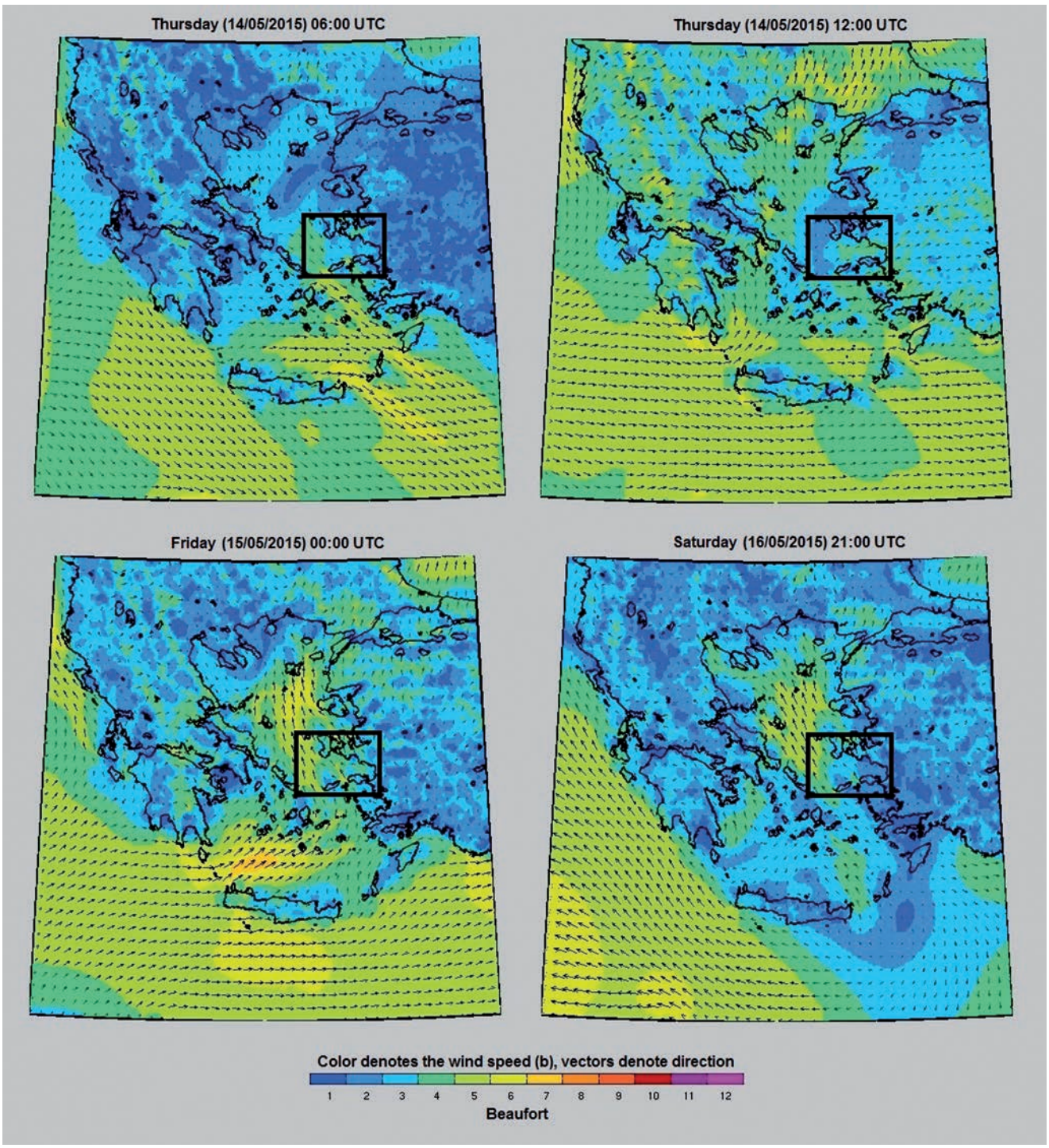

Figure 4. Surface wind (10 m) from 14-16 May 2015, before and during the accumulation of gelatinous zooplankton near the shore. Source: http://poseidon.hcmr.gr/

blooms on the other hand, seem to be related to high rates of phytoplankton production in response to upwelling, and require boundary currents with eddies and meanders (Deibel & Paffenhöfer, 2009). Similarly, the abundance of the siphonophores *N. bijuga* is related to the upwelling season and peaks of primary production (Gasca & Suárez, 1991; Robison et al., 1998). The other siphonophore species, *H. hippopus*, appears to be more concentrated in

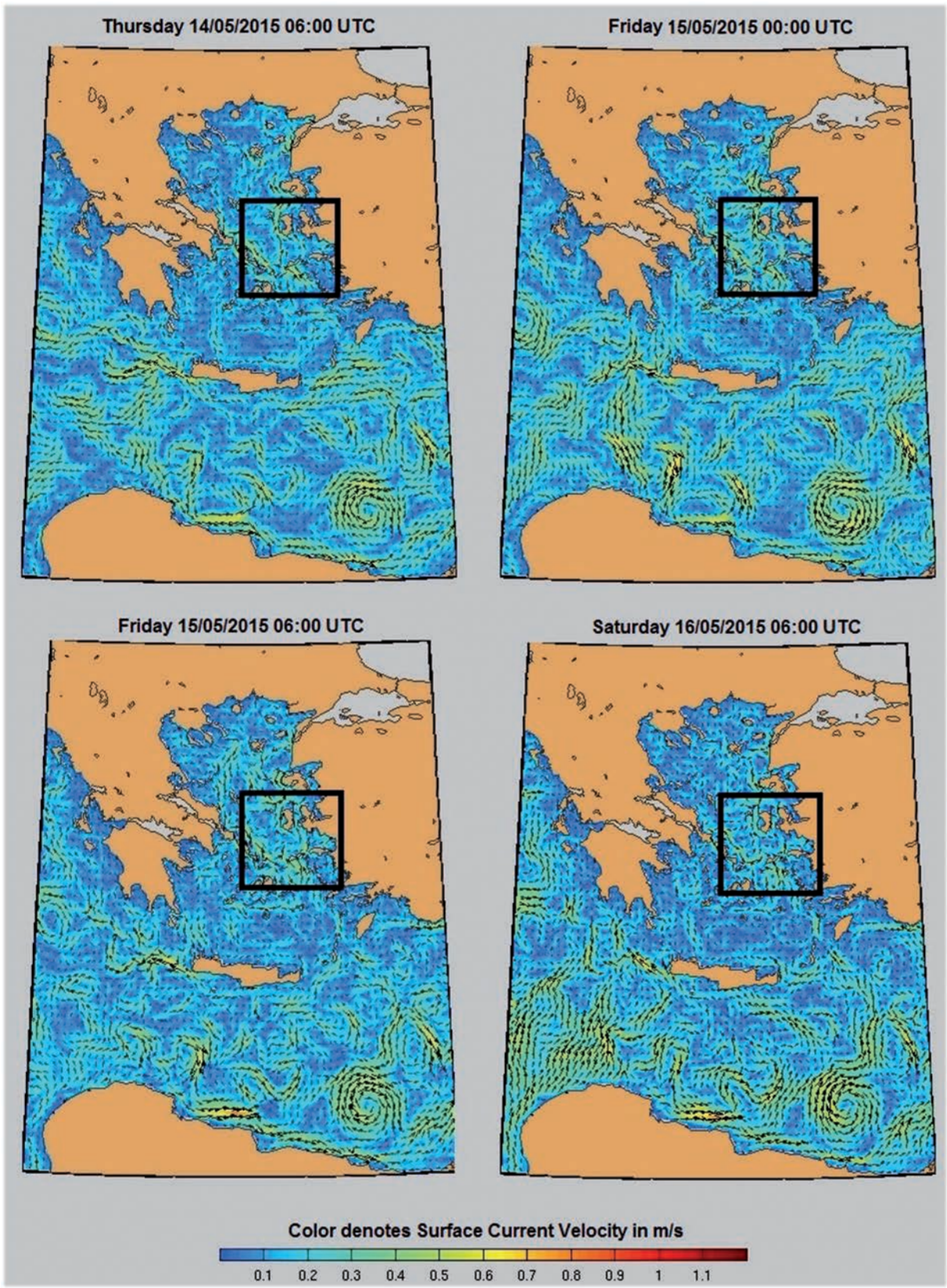

Figure 5. Sea surface circulation (5 m) from 14-16 May 2015, before and during the accumulation of gelatinous zooplankton near the shore. Source: http://poseidon.hcmr.gr/

open waters, where it undergoes extensive vertical migrations (Bouillon et al., 2004 and references therein). *Solmaris corona* has also been considered a mainly oceanic species that can be found sporadically in coastal waters, but the presence of which in large numbers is a sure indication of water movement from offshore (Russell, 1953; Furnestin, 1959; Beaudouin, 1971; Nogueira Jr. et al., 2014). In addition, it is known to prey particularly on other gelatinous zooplankton, especially pelagic tunicates (Larson et al., 1989).

All of the above mentioned characteristics suggest that an offshore upwelling event may have triggered a significant increase in primary production that resulted in a salp bloom. Indeed, one of the most vigorous upwelling zones in the Mediterranean Sea lies in the vicinity of the studied locality (Bakun & Agostini, 2001), and the offshore area is characterized by a large gyre (Olson et al., 2007). Therefore a bloom of salps, following an upwelling and an increase in primary production, might have occurred in the area between Chios, Ikaria and Samos Islands in the period between April and the beginning of May, if we consider the generation times for salps (Deibel & Lowen, 2011).

The presence of offshore salps and siphonophores in constricted shallow coastal areas is most likely related to regional patterns of wind and current circulation. Surface winds in the study area before 14 May were northeasterly (Fig. 4); then, strong southwesterly winds started on 14 May, while the circulation pattern shifted north-eastward (Fig. 5). This surface wind/circulation pattern could have carried the bloom components (salps) together with other gelatinous organisms to the shores between Doğanbey and Seferihisar, resulting in the aggregation that was observed in this study. Strong wind patterns ended on 16 May, allowing the aggregates to stay and decompose along the shallow coast over the following days.

The state of the salp chains and *Aequorea* medusae also suggest transportation by winds and currents, since most of the former were fragmented, with some individuals completely detached. Transportation by currents would also explain the presence of ctenophores which feed mainly on copepods and were probably not involved in the salp bloom. The siphonophore *H. hippopus* is a selective feeder on ostracods (Purcell, 1981) and even though its presence seems linked to upwellings (Totton, 1965), its co-occurence with an outbreak of salps and *A. forskalea,* can be better explained by transportation from offshore areas to the coast.

In conclusion, the aggregation of gelatinous organisms observed off Doğanbey was an apparent bloom, i.e., composed of organisms that bloomed/increased their abundances in response to different processes, but were concentrated at one coastal location due to strong winds/currents, transporting them to the coast. The offshore area between the islands of Chios, Ikaria and Samos seems a favourable place for outbreaks of salps, which were the main components of this apparent bloom. Historical records of abundant salps in the Aegean Sea are rare (Ramfos et al., 2006; Siokou et al., 2013) and their outbreaks might pass unnoticed due to their rare occurrence in coastal waters. Salps are conspicuous gelatinous organisms but despite their large size, there are few records of outbreaks in the Mediterranean Sea (e.g. Boero et al., 2013) probably due to offshore thriving (CIESM, 2001). Salps are very efficient nonselective filter-feeders of micro-particles up to 1 mm size, may increase in numbers very rapidly due to the alternation of asexual/sexual reproduction, and contribute significantly to the transportation of organic matter to the bottom via faeces sinking (Andersen, 1998). As suggested by Boero et al. (2013), salp outbreaks might redirect the functioning of marine ecosystems in a sudden and dramatic way, leaving little evidence of the cause of changes. Therefore records and studies of gelatinous outbreaks are very important in order to better evaluate the mechanisms underlying plankton fluctuations and even local marine ecosystems.

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