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CURRENT AND POTENTIAL DISTRIBUTION OF PELAGIA NOCTILUCA (CNIDARIA, SCYPHOZOA) IN THE TURKISH SEAS

ABSTRACT

The present study is an investigation the current distribution and abundance of the jellyfish species *Pelagia noctiluca* along the Turkish coastline. To date, a total of 17 records from 11 locations have been reported for this species. The extant data demonstrate that citizen science plays a significant role in monitoring the species' distribution. The modelling scenarios developed in order to predict the species' future distribution and potential bloom events estimate that the threshold transition enabling entry into the Black Sea ecosystem will occur around mid-2036. As sea surface temperatures continue to rise, there is a possibility that the species will alter the bloom dynamics of blooms, trophic interactions and the functioning of coastal ecosystems.

Keywords: Jellyfish, Mauve Stinger, Future Distribution, Blooms, Mediterranean Sea

1. INTRODUCTION

Jellyfish are a common feature of Mediterranean marine ecosystems. It is estimated that approximately 12 species of Scyphomedusae can form mass blooms in Mediterranean waters [1, 2, 3 and 4]. A total of sixteen species of Scyphozoa species have been identified along the Turkish coastline [5, 6, 7 and 8]. Of these, four species are known to form dense blooms.

The Scyphozoan *Pelagia noctiluca* (Forsskål, 1775) is found in both the Mediterranean Sea and the Atlantic Ocean. Its primary habit is open oceans and coastal waters [9]. This species exhibits direct development without a benthic stage, lacking a polyp phase and maintaining its life cycle solely in the medusa form. The species exhibits a holoplanktonic life cycle in the open ocean, vertical migration and distinctive feeding behaviour. As is well documented, blooms along the Mediterranean coast have been observed since the 19th century. However, distribution of such blooms in open waters remains uncertain [10]. *P. noctiluca*, also known as the ocean jellyfish, is a species adapted to living in open waters. The mean lifespan has been recorded as ranging from two to six months, with the presence of *P.*

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noctiluca, water temperature and salinity having been shown to correlate positively with this duration. The survival rate of *P. noctiluca* has been shown to increase with rising nutrient concentrations and eutrophication [10, 11, 12 and 13]. However, the presence of this scyphozoan has been demonstrated to exert a deleterious effect on dissolved oxygen levels [14].

The potential correlations between the bloom periods of *P. noctiluca* and environmental factors are being examined as part of the Mediterranean Long-Term Pollution Monitoring and Research Programme (MED POL – Phase II)[15]. However, to date, only a limited number of clear relationships have been established to date and the environmental variables determining the distribution of this species are still under investigation [10, 16 and 17].

The aim of this study is to ascertain the distribution of *P. noctiluca* in Turkish seas, its bloom periods, and the relationship between these periods and environmental factors, particularly temperature.

2. RESEARCH SIGNIFICANCE

This study examined the current distribution of *P. noctiluca* in Turkish seas and investigated the link between its explosive growth and temperature.

Highlights:

- The current distribution of *P. noctiluca* in Turkish seas was determined.
- The relationship between the potential distribution of *P. noctiluca* and temperature was demonstrated.
- The impact of *P. noctiluca*'s explosion potential on public health was demonstrated.

3. MATERIALS AND METHODS

This study determined the zoogeographical distribution of *P. noctiluca* in the Turkish coastal ecosystem, its population density status, and its relationship with temperature using data on *P. noctiluca* from the authors' unpublished data and existing literature (Web of Science, Google Scholar, ResearchGate, etc.).

- **Data Pre-processing:** The seawater temperature datasets utilised in this study were provided by the Turkish State Meteorological Service in CSV format. In order to guarantee both consistency and reproducibility, it was imperative that all data processing steps were carried out in the Google Colab environment [18] using the Python programming language [19]. The process of importing and merging all CSV files into a single, unified data frame was successfully executed. The standardisation of columns across files was achieved by utilising a common key, thereby ensuring reliable merging of daily records from diverse measurement types.

  All calculations were performed using the Pandas [20] and NumPy libraries [21], which enable the efficient processing of large datasets that exceed the practical limits of spreadsheet software such as Excel. Statistical summaries (e.g. daily, monthly and annual mean sea surface temperatures and minimum and maximum values) were calculated directly from the unified data frame. The visualisation and exploratory analysis of temperature data was performed using Matplotlib [22] (and Seaborn where applicable [23]). The former provides high resolution plotting of station specific temporal patterns, while the latter provides high resolution plotting of regional temporal patterns.

- **Geospatial modelling:** Subsequent to the implementation of preprocessing, the combined dataset was imported into ArcGIS Pro [24] for the purpose of spatial analysis and visualisation. The Turkish State Meteorological Service provided station coordinates, which were used to create georeferenced point layers, which were then employed to model spatial patterns in sea surface temperature and related environmental variables. Attribute tables were combined with station-level metrics to enable the mapping and comparison of temporal summaries (e.g. annual mean sea surface temperatures) across regions.
  Special symbology conventions were applied in order to represent changes in temperature, bloom density and observation counts, thus enabling hotspot locations to be clearly identified. The geospatial models generated in ArcGIS Pro underpin the spatial maps and figures presented in this article, which illustrate the distribution of stations and the spatial variability of the measured parameters in Turkish coastal waters.

4. RESULTS AND DISCUSSION

Despite the comprehensive analysis of all records of the species from Turkish coasts from 1966-1967 to the present have been analysed, it should be noted that information on the species' true distribution remains incomplete. A total of seventeen records [25-33] have been reported from eleven locations along the Turkish coast. Twelve of these records reported one individual, and five reported densities between 80 and 750 individuals. As illustrated in Figure 1, three of the documented records reported blooms with a number of individuals exceeding 100 (Figure 1).

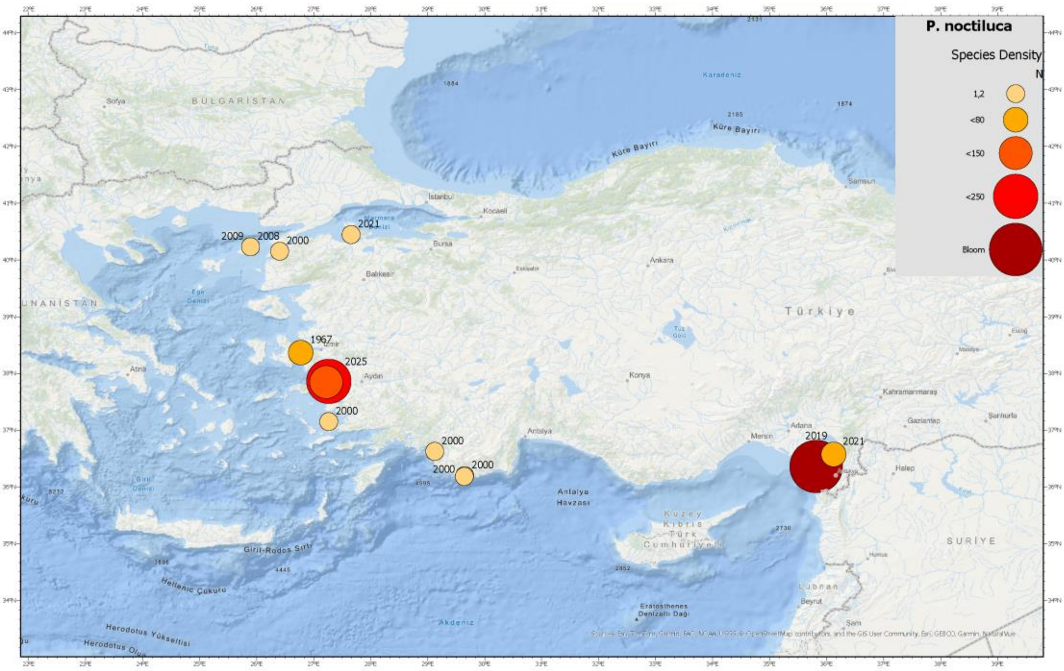

Figure 1. Current distribution and density map of the *Pelagia noctiluca* along the Turkish coastline

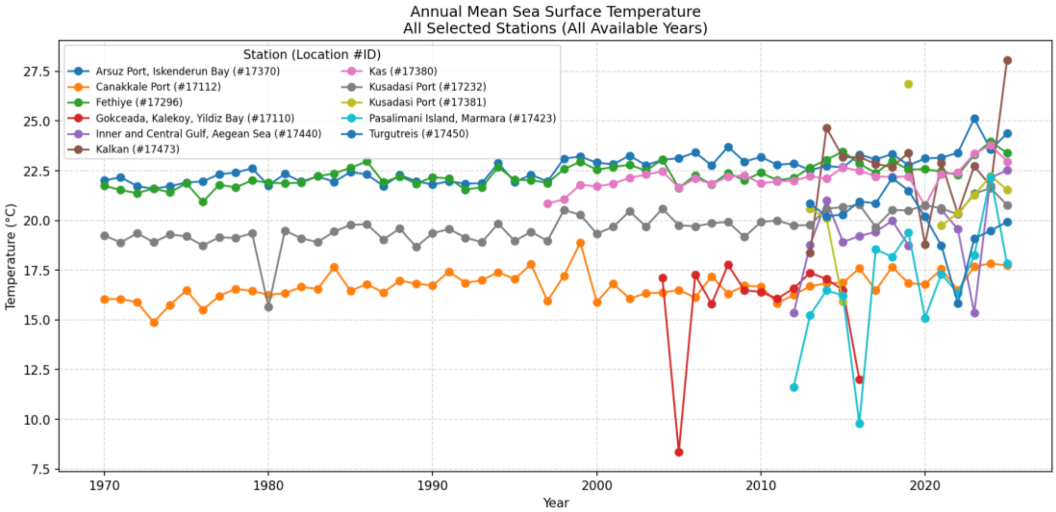

Figure 2. The annual mean sea surface temperatures at stations where the species is distributed from 1970 to 2025

An analysis of temperature data from stations where the species is present between 1970 and 2025 reveals fluctuations ranging from 8 to 25°C. Despite the presence of amoebas at certain stations, a general increase in temperature is evident (Figure 2).

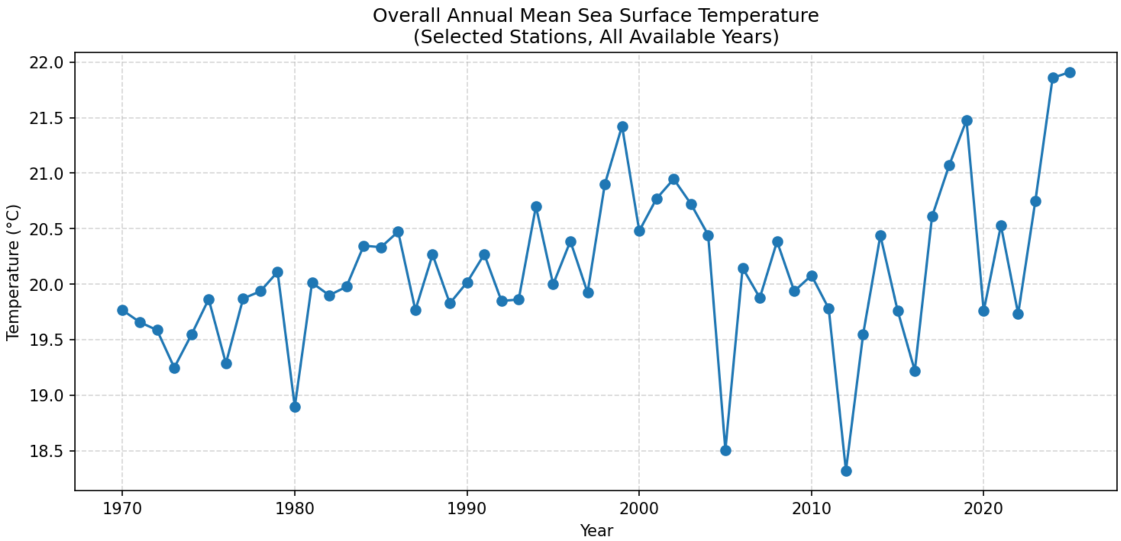

Figure 3. Annual average sea surface temperatures along the Turkish coast between 1970 and 2025

The annual average sea surface temperatures recorded at 150 selected stations between 1970 and 2025 clearly reveal a significant and accelerating increase in sea surface temperature in Turkey's seas over the last 50 years (Figure 3). A marked upward trend is particularly evident. Temperatures recorded in the 1970s ranged from 19.0-19.5°C, with a subsequent increase to 21.5 to 22.0°C since 2020. This sustained warming of approximately +2°C serves as a definitive indicator of climate change in regional seas. As demonsrated in the figure, there have been frequent temperature fluctuations and anomalies. Since the 2000s, there has been observational evidence of warming of the seawater, providing strong evidence of marine warming due to climate change.

The modelling study suggests that water temperature is the most significant barrier to the species' future entry into the Black Sea and its potential distribution.

For the Black Sea Coastal Thermal Structure and the Role of İnebolu as a Western Thermal Barrier.

The present study sought to characterise the contemporary thermal regime of the region. To this end, a comprehensive analysis was conducted on six coastal stations situated along the southern Black Sea margin namely İnebolu, Sinop, Samsun, Ordu, Giresun and Hopa. The annual mean sea surface temperatures (SSTs) averaged over the period 2011-2025 indicate a clear eastward warming gradient ranging from 14.96°C in İnebolu to 16.92°C in Hopa. The six locations were georeferenced and visualised in ArcGIS Pro to illustrate the spatial distribution of nearshore SST conditions (Figure 4). The resulting spatial model demonstrates that İnebolu is the coldest and most westerly of these stations, thereby acting as the primary thermal barrier that restricts the eastward movement of Pelagia noctiluca into the Black Sea. As demonstrated by earlier ecological observations, the species is unable to successfully establish itself in areas with an annual mean SST below ~17°C. Therefore, it is imperative to identify the warming trajectory of İnebolu in order to assess the likelihood of future incursions.

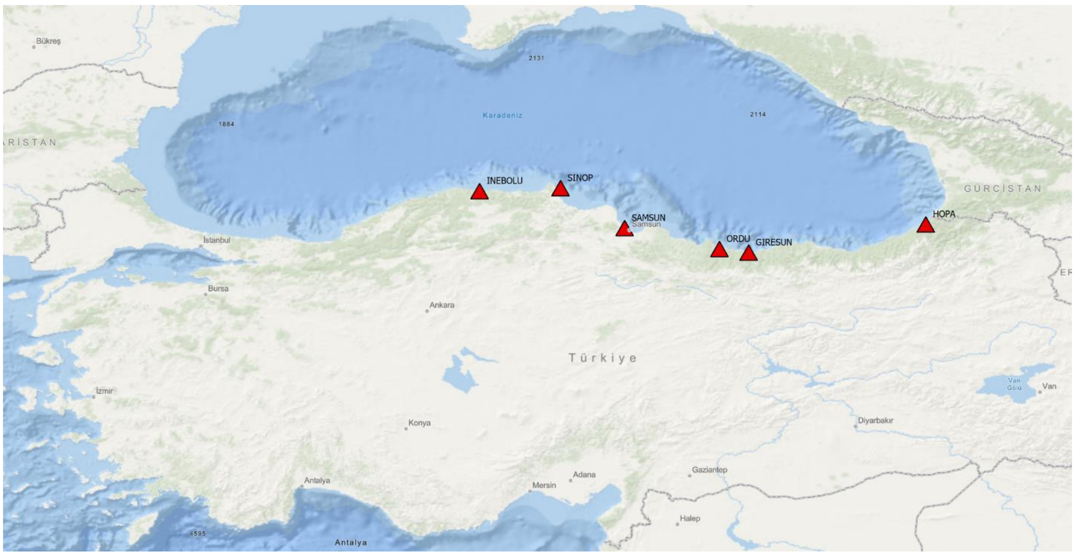

Figure 4. Spatial distribution of six Black Sea coastal stations and their 2011-2025 mean sea surface temperatures

In order to determine the historically associated temperature regime with the presence of *P. noctiluca* in the vicinity of the Black Sea entrance region, three confirmed observations from ecologically analogous sites were analysed: Paşalimanı Island (Station 17423, 2021: 17.31°C) and Gökçeada-Yıldız Bay (Station 17110, 2008: 17.77°C; 2009: 16.49°C). These values are representative of the annual mean sea surface temperatures (SSTs) in the precise years in which the species was documented. The arithmetic mean of these observations, 17.20°C, was therefore adopted as an ecologically grounded threshold representing the thermal conditions under which *P. noctiluca* reliably occurs in regions comparable to the southwestern boundary of the Black Sea.

The projection of future sea surface temperatures (SST) at İnebolu provides important insight into the potential evolution of the thermal environment of the western Black Sea may evolve in the coming decades. The post 2010 warming trend, derived from one of the most internally consistent segments of the observational record, reveals a steady increase in annual mean SST. When this linear trend is extended forward in time, the results suggest that İnebolu will reach the *P. noctiluca* ecological threshold of approximately 17.20°C will be reached by İnebolu around the middle of 2036 (Figure 5). This finding carries several ecological and oceanographic implications that warrant careful consideration.

Firstly, it is important to note that İnebolu is currently one of the coldest locations examined in the Black Sea region. It acts as a thermal barrier that prevents *P. noctiluca* from expanding eastwards into the Black Sea. Should this barrier weaken as a result of ongoing warming, the thermal landscape that has historically restricted the species' distribution may undergo significant change. Projections indicate that Inebolu may soon experience temperature regimes comparable to those observed in the Mediterranean and Marmara regions, where P. noctiluca has been documented on multiple occasions This implies an increasing likelihood of incursions in the future, particularly during periods of enhanced stratification or anomalous seasonal warmth.

Secondly, while the linear model offers a transparent and interpretable estimate of future warming, it is important to recognise its limitations. The projection is predicated on the assumption that the recent rate of change will continue uninterrupted a supposition that may not fully capture potential non-linearities, such as regime shifts, altered regional circulation or multi-decadal oscillations, which have an influence on the Black Sea. Nevertheless, linear extrapolation remains a reasonable first-order approximation, particularly when long-term drivers such as large-scale atmospheric warming exert a dominant influence.

The projected timing of the threshold crossing in mid-2036 is of ecological significance. It is suggested that within approximately ten years, the waters of İnebolu may undergo a transition to a temperature range that has historically been associated with the viability of P. noctiluca. This has the potential to modify bloom dynamics, trophic interactions, and the functioning of coastal ecosystems. The projection displayed in Figure 5. As demonstrated in this study, the western Black Sea is warming, which is of concern as it brings to light an emerging risk. The research provides a quantitative basis for anticipating ecological responses.

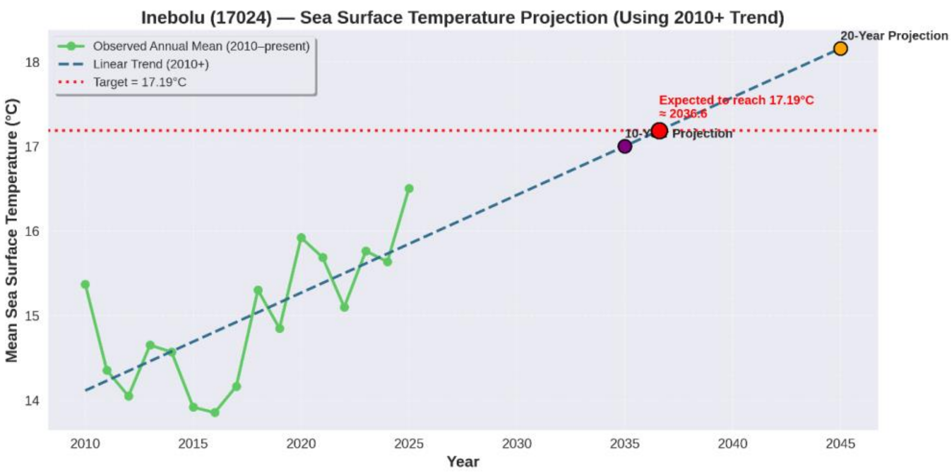

Figure 5. Sea surface temperature projection for İnebolu using the post-2010 data

The phenomenon of jellyfish blooms has been demonstrated to occasion considerable socio-economic repercussions, most notably with regard to public health, tourism, aquaculture, and the fishing industry [34].

P. noctiluca is the most prevalent and toxic jellyfish species in the western Mediterranean [35], but its distribution remains largely uncharted [10]. Evidence suggests that *P. noctiluca* is abundant around the North Current, a persistent geostrophic current in the Ligurian Sea (western Mediterranean) that is known to be persistent. Alternatively, the proliferation of *P. noctiluca* may be influenced by various environmental and ecological factors, including large-scale ocean circulation, nutrient enrichment and the decline of fish species that typically feed on zooplankton (14 and 37). In the Mediterranean ecosystem, P. noctiluca has repeatedly formed large swarms, significantly impacting fishing and tourism [38]. For instance, in October 2007, density of *P. noctiluca* density along the Irish coastline reached 2.8 individuals per cubic meter, resulting in the loss of approximately 250,000 farmed salmon. During this period, the emergence of such high numbers of this warm-water species was thought to be linked to rising ocean temperatures in the north-east Atlantic [39]. Similarly, the event reported in the Strait of Messina (Italy) in 1999 had lasting effects on local fishing and tourism [40].

P. noctiluca is a species of jellyfish that is both toxic and prone to intense proliferation (blooms). It is imperative that the adverse effects of this species on Turkish coastlines are closely monitored, as they are of significant concern. Along the western Mediterranean coast (in countries such as Italy, Spain, Malta and Tunisia), a campaign conducted between 2009 and 2015 is regarded as one of the most effective and successful examples of citizen science. The programme encompassed a range of jellyfish observation and detection studies, yielding significant scientific data [34]. Comparable studies have also been conducted in the Iskenderun and Kuşadası Bay on the Turkish coast.

Jellyfish species play an important role in ecosystem functioning and interspecies competition. Notwithstanding the possibility that they may contain active compounds with the potential to treat cardiovascular, nervous, endocrine, immune, infectious and inflammatory disorders, the toxicity of these substances has the capacity to exert a deleterious effect on public health and the economy, with the possibility of impacting certain human activities [41].

If temperature increases continue at this rate, future simulations suggest that the ecological barrier preventing the species from transitioning to the Black Sea ecosystem may disappear by the mid-2030s.

This study examined the relationship between temperature data and the spatial distribution and bloom characteristics of the species. The development of prediction scenarios that can be used to monitor the distribution of toxic jellyfish species and forecast bloom periods is of critical importance. Such scenarios have the potential to mitigate the adverse effects of jellyfish on human activities, particularly in coastal regions, while concurrently providing substantial support for marine spatial planning, Blue economy (Blue growth) initiatives and conservation strategy implementation.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

FINANCIAL DISCLOSURE
The authors received no financial support for the research.

DECLARATION OF ETHICAL STANDARDS

The authors of the article declare that the materials and methods used in this study do not require ethics committee approval and/or legal special permission.

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