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Research Article

Flowering Events of *Posidonia oceanica* Meadows along the Western Mediterranean Coasts of Italy

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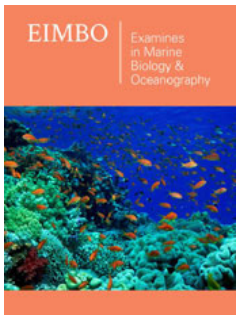

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Abstract

Posidonia oceanica (L.) Delile, endemic species of the Mediterranean sea, forms extensive meadows in the infralittoral coastal seawaters of the basin. Actually, Posidonia beds are suffering a fast regression caused by marine pollution and by an increasing human pressure. However, in these last decades the warming trend of Mediterranean coastal waters have caused an increase of Posidonia flowering events, as a consequence of a sexual reproduction of the species, especially along the Western Mediterranean coasts of Italy. This study shows all the flowering events occurred along Italian coasts in last decades, reporting a lot of records in the Western Mediterranean basin. The research highlights a clear link between the increasing trend of flowering events and the gradual rise of Sea Surface Temperature occurring in the Western Mediterranean seawaters. A case study reporting a massive flowering event in the Calabria Tyrrhenian coast, occurred in the year 2025, confirms this increasing trend and the shift of reproductive modes of the species towards sexual reproduction. So, *Posidonia oceanica* could represent an early signal of a climate change scenario.

Keywords: Posidonia flowerings; Sea olives; Seedlings; Sea surface temperatures; Italian coasts

Introduction

The marine phanerogam *Posidonia oceanica (L.)* Delile is one of the most important endemic species living in the infralittoral bottoms of the basin [1] where it can forms, in good and pristine conditions, the typical “climax” ecosystem [2] on rocks and sandy bottoms from the surface to over 40 meters depth, according to light conditions [3,4]. In time, Posidonia beds, covering a global surface area of 2.5 million hectares [5], have become priority habitat within the Habitat Directive (92/43/EC) and inserted as “Best Concern Ecosystem” as stated by the Red List of International Union for Conservation of Nature (IUCN) [6]. However, in recent decades Posidonia meadows are undergoing rapid regression mainly due to marine pollution caused by an increasing human pressure. To date, scientific data, updated to 2015, have confirmed this negative trend reporting a total extension of the Mediterranean meadows such as 1.2 million hectares [7] with a reduction rate of about 50% in a time lag of only fifteen years. These conditions have been strengthened by the poor genetic variability of the species whose primary mechanism of reproduction is vegetative through a kind of clonal growth from perennial rhizomes while flowering and fruiting, by sexual reproduction, have been always considered rare and uncommon [8,9]. Nevertheless, the gradual warming of Mediterranean seawaters, together with the increasing number of field studies have given a sharp increase of Posidonia flowerings in the Mediterranean Sea, especially along Italian coasts [10-50]. *Posidonia oceanica* shows in these last decades a gradual shift towards modes of sexual reproduction giving to the species a greater genetic diversity and a better response against environmental changes [51].

Materials and Methods

The study has been realized through a detailed research of peer-reviewed scientific literature searched by the most important electronic databases such as Web of Science, Science Direct, Scopus and Research Gate. In this way, it was possible to select the most important papers regarding the following keywords: Posidonia flowerings, Posidonia seedlings, sea olives, Sea Surface Temperatures, Western Mediterranean Sea, Italian coasts. The bibliographic research has been conducted until 31 december 2024, regarding all the most relevant and available scientific literature. From the comprehensive data set, it has been removed articles unrelated to the searched keywords, grey literature and duplicate articles. From this choice, a total of 120 articles has been selected. Afterwards, 61 records were excluded for publication titles and subject areas. Finally, according to a deep analysis of their contents, 59 articles have been selected, cited in the main text and reported in the list of references.

Results and Discussions

This study gives some information about the occurrence of flowering events of Posidonia meadows in the period 1973-2023 along Italian coastal waters in the Western Mediterranean basin, as shown in the following table (Table 1). The yearly data reported by scientific literature in Table 1 show 173 records along the Italian coasts of the western Mediterranean basin. The flowering events are characterized by a weak but steady increasing trend (R^2=0.0003) from 1973 to 2023 years, as highlighted by the dotted line of figure 1, where the continuous line suggests a sort of cyclicity of flowering records with peaks occurring regularly every 10-12 years (Figure 1).

Table 1: Flowering reports recorded in the Western Mediterranean basin of Italian seawaters drawn by scientific literature (legend: N=Number of records).

Years	N.	Italian Regions	Citations
1973	1	Liguria	[20]
1979	1	Campania, Ischia Island	[18]
1983	2	Liguria	[20]
1985	4	Liguria; Campania, Ischia Island	[20,18]
1986	2	Sicilia, Egadi Island	[16]
1989	3	Toscana	[30]
1990	5	Toscana	[30]
1991	6	Toscana; Liguria	[30,21]
1992	4	Liguria	[21,30]
1993	6	Sicilia, Egadi Island	[28,41]
1994	26	Sicilia, Favignana Island; Liguria; Toscana	[28,20,21,30,41,22,23,24,25]
1995	5	Sicilia, Favignana Island; Toscana	[41,30]
1996	4	Toscana; Sardegna	[30,27]
1997	6	Toscana; Sicilia, Ustica Island	[30,41,26]
1998	8	Campania, Ischia Island; Toscana	[26,30]
1999	6	Campania, Ischia Island; Toscana	[26,30]
2003	16	Toscana	[33,35,30]
2004	20	Sicilia, Favignana Island; Toscana	[33,31,34,32,36,37,40]
2005	3	Toscana	[33,32]
2009	3	Sicilia, Ustica Island	[41]
2011	3	Sicilia	[46]
2012	4	Liguria	[38]
2013	7	Sicilia	[38,36]
2015	4	Sicilia	[39,36]
2016	10	Sicilia	[41,48]
2019	5	Sicilia; Campania, Ischia Island	[44,47]
2020	5	Sardegna; Sicilia	[45,42,43]
2021	1	Sicilia	[49]
2022	2	Sicilia; Sardegna	[49,50]
2023	1	Sardegna	[50]

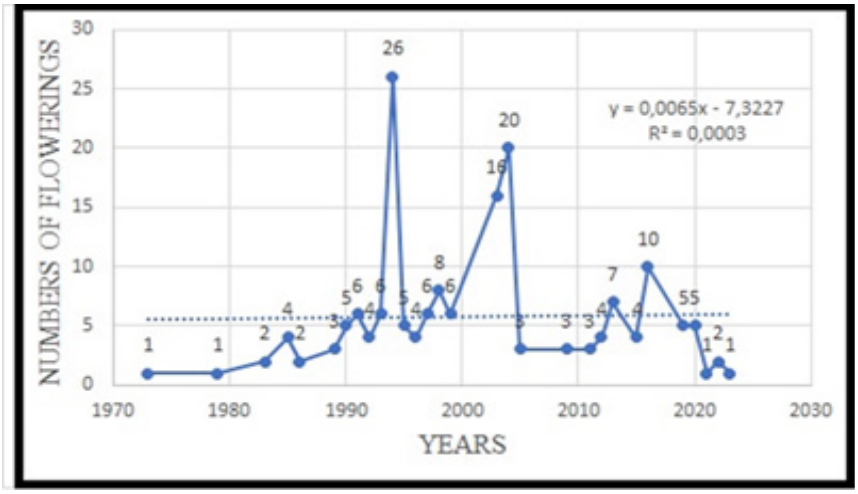

Figure 1: The increasing trend of flowering events, reported from 1973 to 2023 years, in the coastal seawaters of Italian coasts.

Amongst the main factors affecting the reproductive trait of *Posidonia oceanica* it could be hypothesized the light and gradual increase of Sea Surface Temperature (hereafter, SST) in the western Mediterranean seawaters. The trend of the course, characterized by some regular and spaced peaks, could be induced by conditions of thermal stress because such massive flowering events are closely related to corresponding peaks in seawater temperatures [10,12, 31,52]. Therefore, it could be suggested a close relationship between the flowerings of Posidonia meadows and the warming trend of Mediterranean seawaters. As a matter of fact, the species is characterized by an effective acclimatization capacity through its high thermotolerance against the increasing overheating of Mediterranean waters [53,54]. This warming trend was reported for the last decades as 0.04 °Cyr-1 [31] while the thermal increase of SST medium values in the Western Mediterranean seawaters, for the period 1959-2022, was released by NOAA data (USA National Oceanic and Atmospheric Administration) as +1.2 °C [55] (Figure 2). The continuous line in bold characters (Figure 2) shows the increasing trend, in the long run, valued through polynomial regression (from: www.snpambiente.it, accessed on 15 July 2025).

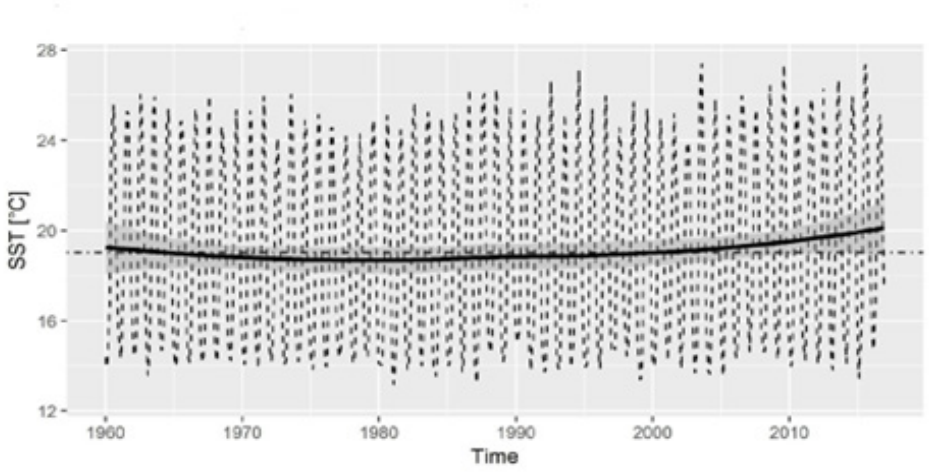

Figure 2: Increasing trend of SST in the Western Mediterranean seawaters from 1960 to 2022 years.

In this way, the Atmospheric Ocean Regional Climate (AORCM) predicted a global increase of Mediterranean SST of 2.6 °C in the period 2070-2099 [56]. Finally, the regional distribution of flowerings, for a whole national number of 173 reports, showed a great variability between the different Italian coastal regions of the Western Mediterranean sea with Sicilia, as the first country (73 records=42%), Toscana as second (62 records=35%), Liguria as third (20 records=12%), Campania as fourth (12 records=7%) and Sardegna as fifth (6 records=4%) (Figure 3). The high number of flowering records, recorded around Sicilia, was reported by scientific literature because the recruitment sites of seedlings was very often located in the shallow seawaters of Marine Protected Areas (MPAs) along the insulated coasts of Mediterranean Sea as Sicily, Egadi, Favignana and Ustica islands,

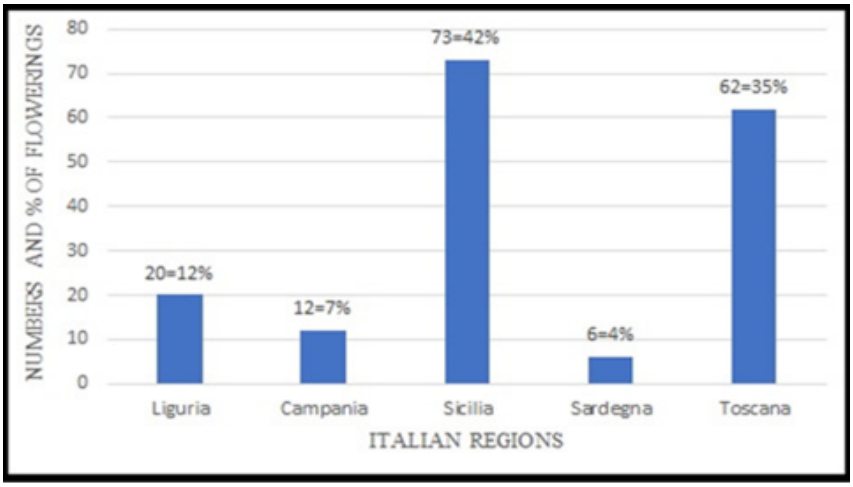

Figure 3: The regional distribution of flowerings in Italian coastal regions from 1973 to 2023 years.

A case study: flowering events in Calabria Tyrrhenian coasts recorded on 2025 year

During a survey conducted to update the presence of the invasive algal species Caulerpa cylindracea Sonder, 1845 in the Western Mediterranean basin of Calabria coasts (Figure 4) it was observed on 15 May 2025 a massive event of flowering by *Posidonia oceanica* meadow whose fruits, named "sea olives", was washed up on a sandy beach of *S. Litterata* Point (Cosenza, Calabria, Southern Italy). The Posidonia fruits found stranded in the study area mostly derive from an extensive meadow growing nearby in the shallow seawaters of *S. Litterata*. It was measured a high density of the beach-cast fruits from 10 to 30 units in quadrats 40cmx40 cm, while the main fruit density values varied from 15 to 40 fruits per m^2, resulting from a big production of fruits ended up and stranded in great quantities on a sandy beach (Figure 5). Then, the fruits were collected and transported in the laboratory of the Center of Marine Environmental Education (C.E.A.M.) of Belmonte Calabro (Cs., Italy), managed by the World Wildlife Fund (W.W.F.) of Italy, to better understand the main patterns of this important beach-coast event. The fruits were embedded in spongy and ovoid pericarps and one of the fruits opened longitudinally releasing its single seed (Figure 6). The findings of this last occurence happened on 2025 year seem to confirm the assumption that sexual reproduction is becoming more widespread along italian coastal regions and this present trend is actually ongoing, coupled with the warming trend of the Western Mediterranean sea.

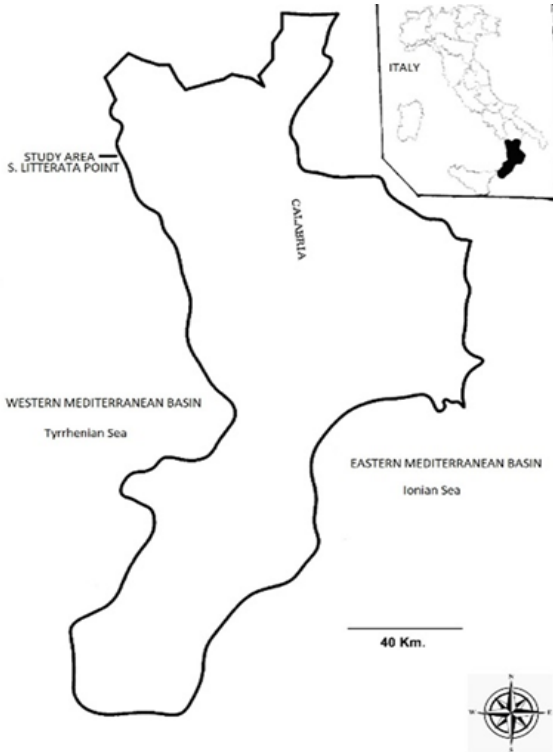

Figure 4: Geographic map of the study area along Calabria Tyrrhenian coast.

Figure 5: Beach-cast fruits of *Posidonia oceanica* stranded on the sandy beach of *S. Litterata*.

Figure 6: The fruits of *Posidonia oceanica* collected from the sandy beach of *S. Litterata* and a single seed released by its pericarp.

Conclusion

From the resulting data it is shown that the growing trend of SST in Mediterranean seawaters is supporting the sexual reproduction of *Posidonia oceanica* plants [57], as highlighted, also, by the increasing flowering events occurred from 1973 to 2023 years. In this way, the gradual shift of reproductive modes could favour a greater genetic diversity in the gene pool of the species, leading to a better thermotolerance to the warming trend of Mediterranean seawaters, particularly marked in the western basin. Besides, some experiments of restoration from beach-cast fruits, conducted on dead matte and on rocky substrata covered by seaweeds, seem to be a feasible tool for the recovery of *Posidonia oceanica* meadows in calm coastal environments with moderate depths [58,59]. Anyway, there are a lot of gaps in flowering dynamics and it is suggested to better understand the great variability of Posidonia flowerings

in the western Mediterranean basin. In conclusions, *Posidonia oceanica* meadows could represent an early environmental signal in the climate change scenario induced by the warming trend of Mediterranean seawaters.

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