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Advances in Environmental and Engineering Research

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Communication

Back to the Sea: The Long and Winding Road of the Seagrass Species *Posidonia oceanica*

Nicola Cantasano *

National Research Council of Italy, Institute for Agricultural and Forest Systems in the Mediterranean, I.S.A.Fo.M S.S. Rende (CS), Via Cavour 4/6, 87036 Rende (Cs), Italy; E-Mail: cantasano@tiscali.it

* **Correspondence:** Nicola Cantasano; E-Mail: cantasano@tiscali.it

Academic Editor: Gabriella Marfe

Special Issue: Waste Management and Human Health Impact

Adv Environ Eng Res
2023, volume 4, issue 1
doi:10.21926/aeer.2301003

Received: June 12, 2022
Accepted: December 20, 2022
Published: January 05, 2023

Abstract

Posidonia oceanica (Linnaeus) Delile is one of the most important endemic species of the Mediterranean Sea. The long phylogenetic pathway of this species deserves special attention because its evolutionary history allows us to think back over the debated issue of life evolution on Earth. Hence, this marine plant, by terrestrial origin, was born from an ancient ancestor named *Posidonia cretacea* Hosius & Von der Marck. This seagrass species, currently extinct, lived in the coastal waters of the Tethys Ocean about 100 million years ago, during the geological times of the late Cretaceous. In the following Cenozoic Era, during the Miocene period, in the time lag from sixty to forty million years ago,a long process of allopatric speciation by separate areas led to eight species of Posidonia genus developed in the northern and southern hemispheres. *Posidonia oceanica* is established in the boreal marine regions, so representing, within the long and winding road of life evolution on Earth, a typical example of paleo-Mediterranean relict. Nowadays, *Posidonia oceanica* meadows perform important ecological functions in the Mediterranean Sea, not only for biodiversity conservation but also to mitigate climate change. In this way, meadows play a leading role in carbon sequestration, reducing the concentration of carbon dioxide in coastal waters. Lastly, the meadows of

Posidonia oceanica promote an effective removal process of plastic debris from Mediterranean sea waters.

Keywords
Phylogenesis; *Posidonia oceanica* meadows; Mediterranean Sea; marine pollution

Marine angiosperms are an important element of coastal ecosystems [1-4]. There are 130 aquatic species of this plant division today, but only 30 marine ones [5, 6]. The rarity of seagrasses is due to their troubles in adapting to marine life, such as their tolerance in adapting to high levels of salinity and the innovative reproductive pattern as hydrofily and effective anchorage systems to different kinds of bottoms [7]. It is suggested that these marine angiosperms are a "biological group" that originated from freshwater species successively adjusted to coastal seawaters [8]. Instead, according to other authors [9, 10], these marine plants developed from aquatic ancestors living in the brackish waters of water pools and/or coastal lagoons. Amongst them, it deserves special attention that the species of the *Posidonia* genus completely adapted to marine life where they can form coastal biocenosis favoring high levels of biodiversity and productivity in coastal ecosystems [4]. Nowadays, in the marine biosphere, there are eight different species of *Posidonia* genus: *Posidonia oceanica* (Linnaeus) Delile in the northern terrestrial hemisphere, bound to the limited extent of the Mediterranean Sea, and seven species in the southern hemisphere of Australian coastal waters as are: *Posidonia australis* Hooker, *Posidonia sinuosa* Cambridge & J. Kuo, *Posidonia augustifolia* Cambridge & J. Kuo within the complex Australis and *Posidonia kirkmanii* J. Kuo & Cambridge, *Posidonia Osterfeld* Hartog, *Posidonia coriacea* Cambridge & J. Kuo and *Posidonia denhartogii* J. Kuo & Cambridge within the complex Ostenfeldii [11, 12]. In the Mediterranean Sea, *the Posidonia* genus is represented solely by the species *Posidonia oceanica* covering an assessed surface area between 2.5 and 3.5 million hectares [13]. The bipolar geographic pattern of the genus *Posidonia* and the exclusive presence of the species *Posidonia oceanica* in the Mediterranean coastal waters suggests thinking back over the phylogenetic pathway of the species. The long history of life on Earth could be compared with a traveling book of four billion years when Earth appeared in our Solar system. It is a time lag extremely long and very difficult to conceive for any human mind. Therefore, it could be easier to summarize this unconceivable period into an imaginary and hypothetical year from 1 January to the thirty-one of December, as suggested by a popular Italian essay [14]. In this way, the first step of life evolution on Earth was primitive unicellular living forms, as proteobacteria, widespread in marine depth, appeared on Earth 3.5 billion years ago on 14 February. Then, after a long geologic period of biological stalemate, the first pluricellular organisms appeared on Earth just 700 million years ago on 17 October. Finally, at the beginning of the Paleozoic era, in the warm seawaters of the Cambrian period in the time lag between 570 to 505 million years ago, from 8 to 15 November, there was an impressive vegetal explosion in marine waters leading to a great plant variety. Afterward, 430 million years ago, at the date of 22 November, the first plants began to land on continental Earth. In this decisive geologic period, in the middle of the Paleozoic era, a great diversification happened in the plant kingdom, leading to the appearance of terrestrial angiosperms, amongst which a prototype of *the Posidonia* genus, terrestrial ancestor of the present *Posidonia* marine species. Finally, during the late geologic period of the Cretaceous, towards the end of the Mesozoic era, at the date of 20 December, when all the creatures were engaged in the achievement of surface lands, some species of terrestrial angiosperms started a movement in the opposite direction from continental lands to sea-wards, leading to the appearance of first marine angiosperms [10, 15]. It is thought that these plants could be a “biological group” derived from freshwater and brackish waters that gradually adapted to marine life [8-10], probably living in coastal lagoons and/or water pools, actually still existing in some Italian seaboard areas (Figure 1).

Figure 1 The coastal lagoon of Le Cesine (Lecce, Italy, Photo by Francesco Montinari, Photo Archive by WWF Italy).

Such a slow process of adjustment was achieved in time through morphological and physiological adaptations as [16]:

- strap-shaped leaves;
- osmotic adaptations of the leaf blades;
- reduction of cuticula on leaf blades;

- modifications of roots in rhizomes;
- hydrophilous pollination in sexual reproduction;
- seed formations and dispersal mechanisms.

Indeed, marine seagrasses could represent the "whales" of the plant kingdom because these marine angiosperms returned to the sea as marine mammals deriving from terrestrial ones [16, 17]. Hence, *Posidonia cretacea* Hosius & Von der Mark, 1880, is currently extinct, established in the Tethys Sea (Figure 2), as confirmed by some fossil records discovered on Earth going back to a long geologic period extended from Cretaceous to Miocene [9, 18].

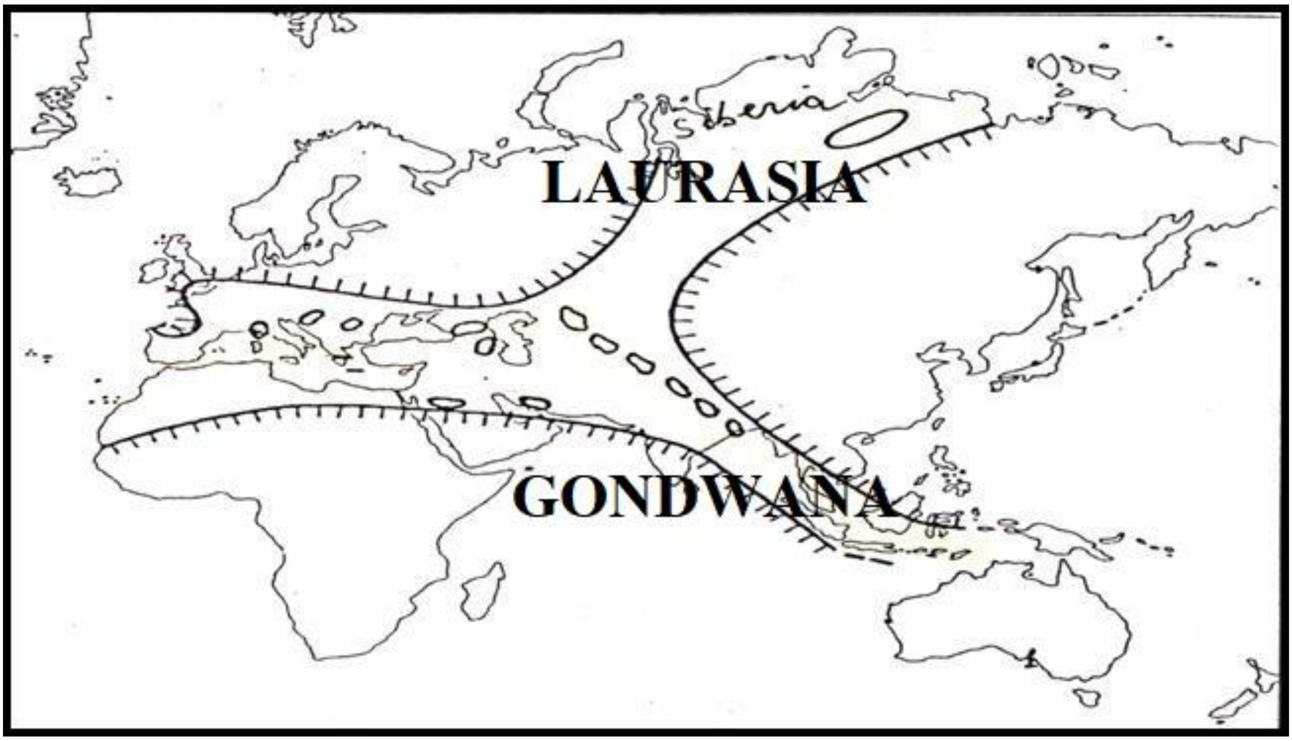

Figure 2 Tethys Sea at the time of Cretaceous period, about 100 million years ago.

Then, *Posidonia cretacea* became well established in the coastal regions of the basin about 63 million years ago, on 26 December, in the middle of the Cenozoic era [19-21]. In the following period of Miocene from 60 to 40 million years ago, on the dates of 27 and 28 December, an impressive geologic event of continental drift happened in the Tethys Sea [9], leading to the geographic separation between Australia and Antartide platforms [22, 23]. Meantime, the Tethys basin began to dry up and break up to originate in its western region, the Mediterranean Sea, for the sliding of the ocean crust under the continental one. During this geologic period happened, a long process of allopatric speciation in separate areas from which eight species of *the Posidonia* genus originated. In this way, *Posidonia oceanica* was established in the northern hemisphere. At the same time, seven species spread in the southern one distinguished into two sets as are *Posidonia australis* and *Posidonia Osterfeld* complexes (Figure 3). This process confirms the hypothesis that the current species of *the Posidonia* genus originated from a single center of radiation. However, presently, the complexes are separated by a distance of about 17.000 km.

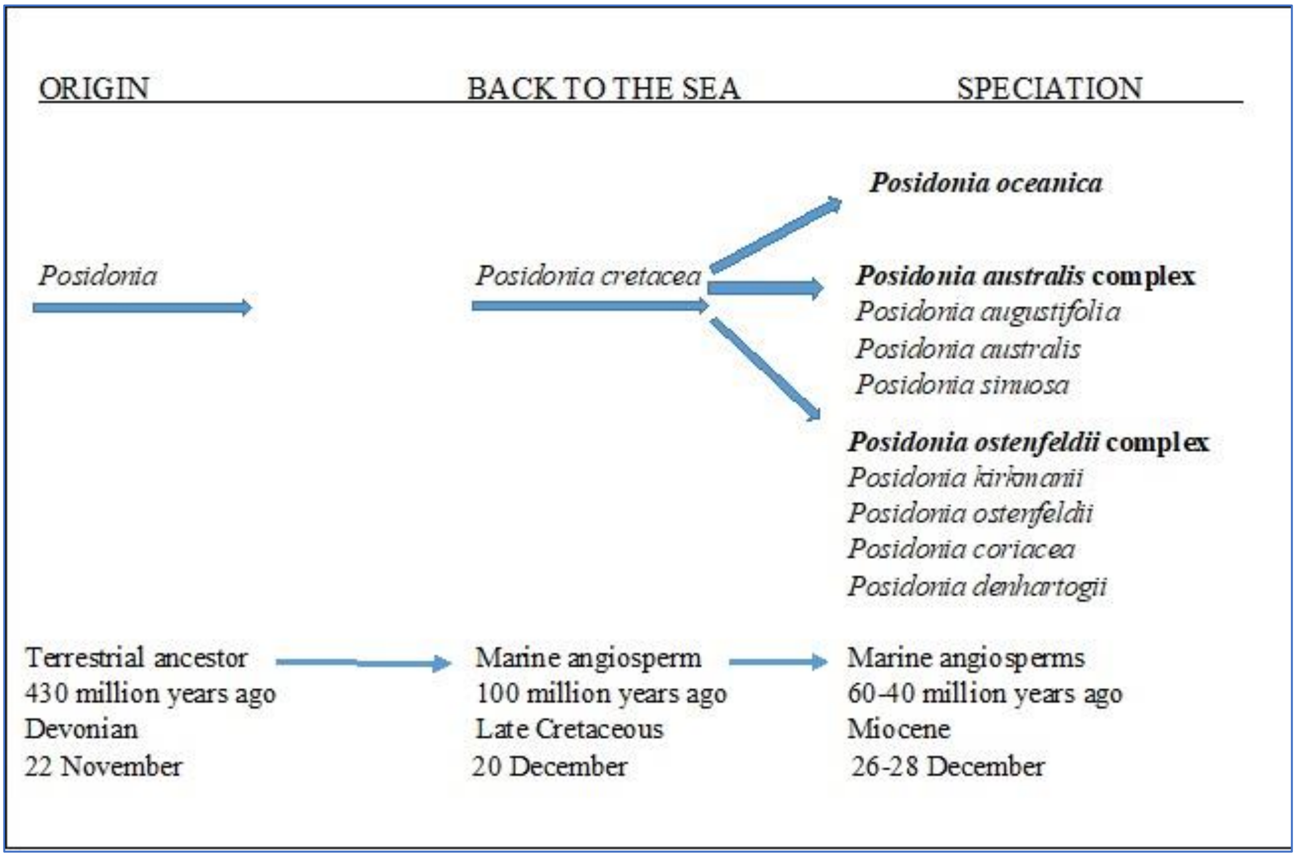

Figure 3 The phylogenetic pathway of *Posidonia* species.

Today, *Posidonia oceanica* is one of the most important endemic species of the Mediterranean Sea. It covers an estimated whole surface area from 2.5 to 5.0 million hectares [13] from the surface to 40 meters depth. In favorable and pristine coastal waters, the species can form large and extensive meadows as the "climax ecosystem" on mobile substrata in the infralittoral bottoms of the basin [24]. However, in the last decades, there has been a widespread regression of the meadows in Mediterranean coastal waters with a declining trend of their global extent variable from 13% to 50% [25]. Therefore, considering their important ecological role, *Posidonia oceanica* meadows have been protected by European legislation through the Habitat Directive 92/43/UE, classified as Priority Habitat and inserted as "Best Concern" within the Red List of the International Union for Conservation of Nature (IUCN) [26]. In these last years, characterized by an increasing trend in marine pollution, the functional role of this seagrass species has become very important not only for biodiversity conservation but also for limiting the present conditions of environmental decay. *Posidonia oceanica* beds perform some important ecosystem services and microplastic removal in the coastal waters of the Mediterranean Sea. The high capacity of the species to store organic carbon is strictly connected to its power to filter out micro-particles from seawater, storing them at the base of the meadows [27]. Firstly, *Posidonia oceanica* plays a leading role in carbon sequestration, removing carbon dioxide from seawater [28]. In such conditions, the carbon bound in these meadows has been termed "blue carbon" [29]. Indeed, *Posidonia* leaves can limit the energy of sea swells and currents, strongly reducing coastal erosion processes [30]. Hence, the meadows are considered of fundamental importance for the coastal sedimentary equilibrium of sandy beaches. Also, *Posidonia* beds act as a "nursery" for many animal species that could be, in prospect, a potential source for fishing and commercial activities [31]. Besides, during its biological evolution, the species performed an important pivotal role in the diversification of some endemic new species, such as Bryozoan and Hydrozoan organisms living on its leaves [32, 33]. In this way, the meadows play a leading role in protecting and improving marine biodiversity in the Mediterranean Sea. Finally, in terms of environmental pollution, the plants of *Posidonia oceanica* can trap plastic litter in their sediments due to sinking processes occurring at the base of the meadows. Hence, *Posidonia oceanica* can promote a trapping process of plastic debris from the water column thanks to the reduced hydrodynamic forces inside the meadows, which promote sedimentation and sinking of plastics [28]. In fact, at the end of the vegetative period, in the Autumn season, the leaf sheaths of the species suffer a process of erosion at the bottoms of the seagrass meadows, releasing part of their fibers and rhizomes to form spheroidal piles, known as "aegagropilae." In detail, the balls are mostly formed by rhizomes with attached sheaths of old leaves that, once detached from the meadow, are eroded and shaped into balls [34]. Afterward, these spheroidal and soft agglomerations are washed by wave climate and settled on sandy beaches as wrack beds. Recently, it has been highlighted that "aegagropilae" are able to extract plastic from seawaters carrying them to the neighboring shores [35]. Therefore, *Posidonia oceanica* meadows play an important role in binding microplastics in the shallow sea floor of the Mediterranean Sea, leaving these mixed remains on lands through beaching processes. Presently, the meadows are declining in Mediterranean coastal waters for increasing marine pollution, mainly due to human pressure on coastal waters and climate changes in the Mediterranean Sea [36]. On the other hand, *Posidonia oceanica* shows an effective acclimatization capacity against the increasing overheating of Mediterranean waters through the high thermotolerance of the species [37, 38]. In such a context, some experimental studies have shown that the present acidification process of coastal waters does not imply negative effects on the species [39, 40]. Finally, the reproductive trends of the species, showing a regular alternation between sexual and asexual reproductive modes induced by the heating of Mediterranean coastal waters, enhances the genotypic diversity of the species and confirms its high tolerance to spatial and temporal variations [41, 42]. Therefore, *Posidonia oceanica* meadows have spread on Mediterranean Sea beds for over 6000 years, achieving millenary life spans. The high phenotypic plasticity of the species allows its strong adaptability to different microhabitats and variable environmental conditions. In this way, the species can counteract the present biotic and abiotic changes, including temperature increase, marine acidification, and growing anthropogenic pressure on coastal waters. In conclusion, the adaptative features of the species and its high resilience against human pressures suggest imagining a positive future for *Posidonia oceanica* meadows.

Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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