

Remains of a fringing *Posidonia oceanica* reef, near Toulon, eastern Provence, hitherto unnoticed

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Abstract. The fringing reefs and barrier reefs of the seagrass *Posidonia oceanica* constitute formations that are both emblematic of the Mediterranean (natural monuments) and strongly threatened by human activities (coastal development, marinas, boating, sand replenishment, sea level rise, etc.). The discovery of what the authors interpret as the remains of a fringing reef of *P. oceanica*, in the Gulf of Toulon, comes as a welcome surprise. This fringing reef should be studied in detail in order to be able to propose protective measures.

Keywords: fringing reef, *Posidonia oceanica*, Provence.

Résumé. Découverte des restes d'un récif frangeant de *Posidonia oceanica*, dans le golfe de Toulon, Provence orientale. Les récifs frangeants et récifs barrières de la magnoliophyte marine *Posidonia oceanica* constituent des formations à la fois emblématiques de la Méditerranée (monuments naturels) et fortement menacées par les activités humaines (urbanisation, ports de plaisance, navigation, re-ensablement des plages, élévation du niveau marin, etc.). La découverte de ce que les auteurs interprètent comme les restes d'un récif frangeant de *P. oceanica*, dans le golfe de Toulon, constitue une heureuse surprise. Il conviendra d'étudier en détail ce récif frangeant, afin de proposer des mesures de protection.

Mots-clés : *Posidonia oceanica*, Provence, récif frangeant.

Mediterranean marine habitats are subject to strong anthropogenic pressures, mainly coastal development, overfishing, biological invasions and anchoring, to which we can add pollution (in decline), global warming and the rise in the sea level (on the increase) (Meinesz, 2021; Boudouresque and Perret-Boudouresque, 2022). These pressures have paramount effects on the *Posidonia oceanica* (Linnaeus) Delile seagrass meadows (Boudouresque *et al.*, 2009, 2012; Pergent *et al.*, 2014), and on their ecosystem services such as the protection of beaches from erosion, a sand factory providing sand for beaches and a habitat supplying resources for artisanal fishery (Vassallo *et al.*, 2013; Boudouresque *et al.*, 2016; El Zrelli *et al.*, 2016; De Falco *et al.*, 2017; Borrello *et al.*, 2019; Rigo *et al.*, 2021).

Posidonia oceanica thrives between the sea level and 20-45 m depth, depending upon the water transparency. Rhizomes and leaf shoots can grow horizontally, to colonize the substrate (plagiotropic rhizomes). The leaf canopy traps autochthonous sediment, e.g. remains of calcareous organisms living within the meadow, and allochthonous sediment, e.g. mineral particles transported by currents and biogenic particles from the pelagic ecosystem. To resist being buried, rhizomes can also grow vertically (orthotropic rhizomes). The structure constituted by live and dead parts of rhizomes and roots, together with the sediment that fills the interstices, is called *matte*. Sediment trapping and orthotropic rhizome growth result in the rise of the *matte* and therefore of the sea bottom over time. The rise of the *matte* can bring the meadow close to the sea surface. Under sheltered conditions, especially in the innermost part of bays, the rise of the *matte* can continue right up to the sea surface. At low tide, the *P. oceanica* leaves spread out on the surface. In the first stage, the emersion of the tips of the leaves occurs very close to and parallel to the coast. This formation is known as a fringing reef. Then, the continuing rise of the *matte* widens the fringing reef. Between the coast and the *P. oceanica* emersion front, the leaf shoots die, and a lagoon is formed. The *P. oceanica* emersion front thus constitutes a barrier reef (Molinier and Picard, 1952; Boudouresque and Meinesz, 1982; Bonhomme *et al.*, 2015).

The *P. oceanica* reefs, located in shallow water (< 1 m depth) are particularly sensitive to human impact (e.g. anchoring, trampling, erosion caused by boats, sea level rise), and also to natural factors (e.g. temperature and salinity variations). They are considered natural monuments and threatened landscapes (Unesco, 1972; Boudouresque *et al.*, 1990). But we only protect well what we know well. For this reason, the *P. oceanica* reefs, in particular the fringing reefs, have been inventoried and mapped along all the French Mediterranean coast (Occitania, Région Sud and Corsica) (Rouanet *et al.*, 2019, 2022).

Here, we describe a previously unnoticed fringing reef, located near the mouth of the Gulf of Toulon (eastern Provence), at a site known as La Vieille beach (Fig. 1).

Material and methods

The study site (La Vieille beach) is located near the mouth of the inner Gulf of Toulon, at Saint-Mandrier-sur-Mer (43°05'01.28 N, 5°55'17.37 E) (Fig. 1).

The site was studied by snorkelling and *via* aerial photographs from the French agency IGN (*Institut Géographique National*), taken on May 4th, 2020, with a resolution of 20 cm. This beach is framed by rocky groynes to the north and south, sheltering it from the strongest waves

during the Mistral wind episodes. The reef is located at a depth of less than 1 m, 3 m off the edge of the beach.

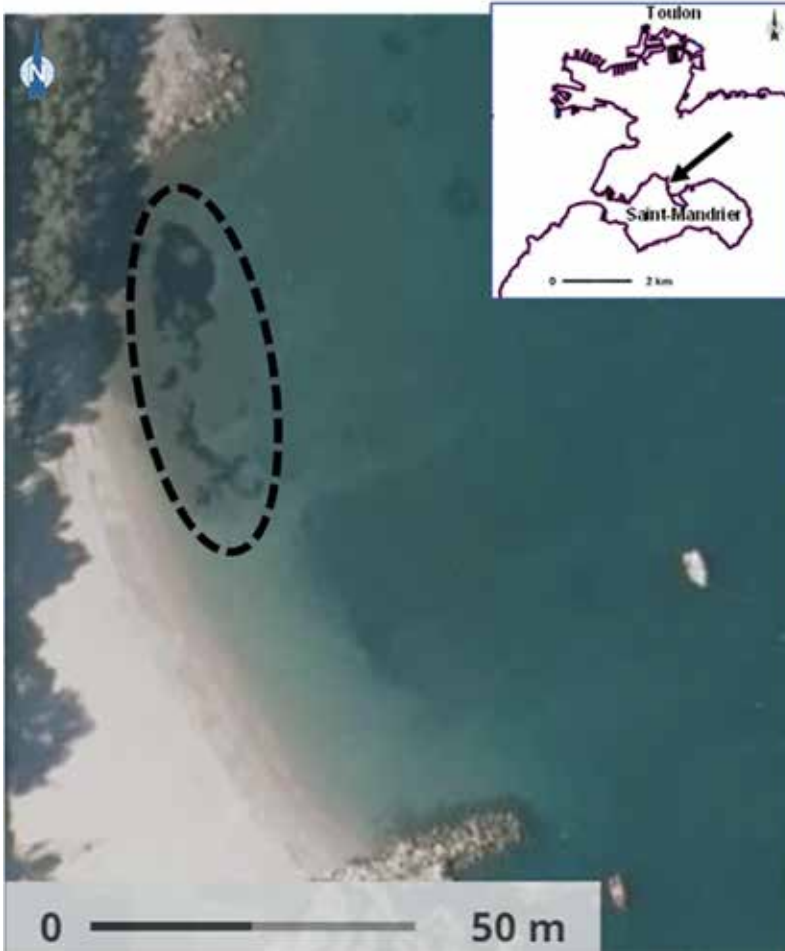


Figure 1. Location of the *Posidonia oceanica* fringing reef (dashed oval), off La Vieille beach (arrow), Saint-Mandrier-sur-Mer. @ IGN.

Results and discussion

The *P. oceanica* reef is easily located by observing the tips of the leaves very close to the sea surface or which rise above it at low tide (Fig. 2). The proximity to the beach, together with the emergence of the leaves at low tide, are clearly characteristic of a fringing reef (Boudouresque and Meinesz, 1982; Bonhomme *et al.*, 2015).

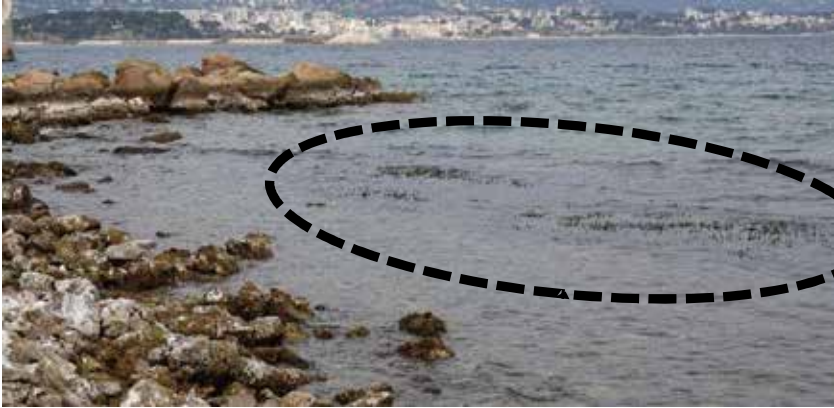


Figure 2. Views of the fringing reef of *P. oceanica* (dashed oval), off La Vieille beach, when the tips of the leaves protrude above the sea surface. Top: general view. Bottom: close-up view. Shooting date: February 20th, 2023. © Dominique Calmet.

The fringing reef consists of three patches. The main one, to the north, has a surface area of 110 m² (Figs. 1, 3). The patches of live *P. oceanica* are surrounded, separated and interspersed with dead *matte*, which is an indication of degradation of the reef.

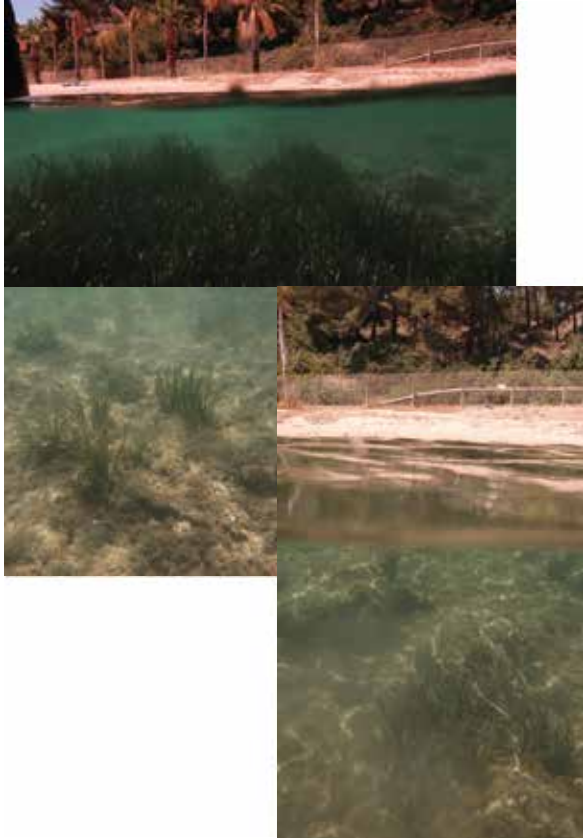


Figure 3. Top: underwater views taken in the middle of the fringing reef, off La Vieille beach. Bottom left and right: isolated rhizomes in front of the beach. Shooting date: June 1st, 2022. © Dominique Calmet.

Live patches of *P. oceanica* develop at the edge of a rocky bottom, on a substrate composed of small rock blocks, gravel with a grain size between 1 to 3 cm and sand from the beach, which has been replenished by quarry sand for several years. In fact, it is an artificial sandy beach, because the original beach consisted only of pebbles. Isolated patches (a few shoots) of *P. oceanica* were observed by scuba diving south of the fringing reef close to the shore, but also at greater depth (2 m) (Fig. 3).

This *P. oceanica* fringing reef, naturally very close to the beach (which is the rule for a fringing reef), is directly impacted by activities linked to mass tourism with the annual replenishment of the beach with quarry sand and the trampling of the seagrass by bathers.

The La Vieille fringing reef, located near the mouth of the Toulon Gulf, was not noticed by Andromède Oceanologie (2014) and Rouanet *et al.* (2022). Andromède Oceanologie and Agence de l'Eau RMC (2020) only mapped there a dead *P. oceanica matte*. In the absence of previous data, we interpret the observed reef as the remnants of a once more extensive fringing reef.

Posidonia oceanica fringing and barrier reefs were probably common in the past along Mediterranean coasts. Their location in bays, strongly impacted by coastal development, marinas, boating and beach replenishment, has undoubtedly resulted in the destruction of a large number of them (Molinier and Picard, 1952; Boudouresque *et al.*, 1975; Boudouresque and Meinesz, 1982). The discovery of what we consider to be the remains of a fringing reef, in a gulf heavily impacted by humans for several centuries, is therefore both an interesting and a unexpected find.

Conclusions

The discovery of what we consider to be the remains of a fringing reef of *P. oceanica*, in a region, the Gulf of Toulon, both strongly impacted by man and well explored, constitutes a welcome and unexpected surprise.

Following this discovery, it will be necessary to study this *P. oceanica* reef in more detail, and to propose protective measures. The very questionable practice of beach replenishment, widespread throughout the Mediterranean (Boudouresque *et al.*, 2017), deserves to be reconsidered, in particular in the Gulf of Toulon.

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