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From mechanical to chemical impact of anchoring in seagrasses: The premises of anthropogenic patch generation in *Posidonia oceanica* meadows

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ABSTRACT

Intensive anchoring of leisure boats in seagrass meadows leads to mechanical damages. This anthropogenic impact creates bare mat patches that are not easily recolonized by the plant. Several tools are used to study human impacts on the structure of seagrass meadows but they are not able to assess the indirect and long term implication of mechanical destruction. We chose to investigate the possible changes in the substrate chemistry given contrasted boat impacts. Our observations show that hydrogen sulfide concentrations remain high at 15 and 20 m depth (42.6 μM and 18.8 μM) several months after the highest period of anchoring during the summer. Moreover, our multidisciplinary study reveals that anchoring impacts of large boats at 15 and 20 m depth can potentially change the seascape structure. By taking into account both structural and chemical assessments, different managing strategies must be applied for coastal areas under anthropogenic pressures.

1. Introduction

Over the last decades, marine ecosystems all around the world have been facing impacts of human activities at various extents (Halpern et al. 2008; Jorda et al. 2012). This statement is particularly observed in the Mediterranean Sea at the level of the coastal habitat formed by seagrass meadows (Grech et al. 2012; Giakoumi et al. 2013). Seagrasses play a major ecological and economical role at the level of the global ocean, covering an area reaching up to 500,000 km^2 (Costanza et al. 1997; Short et al. 2007; Cullen-Unsworth and Unsworth 2013). Thus, they constitute a nursery (Beck et al. 2001), a large carbon sink (Fourqurean et al. 2012), as well as a protection against coastal erosion by attenuating waves and currents (Ondiviela et al. 2014). Among Mediterranean seagrasses, *Posidonia oceanica* (L.) Delile is the most studied due to its major ecological and economical role (Ruíz et al. 2009; Vassallo et al. 2013). The meadows it forms are observed from the surface to 40 m depth and are subject to the impact of human activities like coastal development, eutrophication, trawling, fish farms and anchoring (Boudouresque et al. 2009; Giakoumi et al. 2015b).

Along the French Mediterranean coasts, the main substrate affected by boat anchoring appear to be *Posidonia oceanica* (Holon et al. 2015). Anchoring inside *P. oceanica* meadows seems to have various degrees of impact according to its density, frequency, the type of anchor and the depth as well as the size of boats (Boudouresque et al. 2012). Thus, repeated anchoring of cruise ships, at depths greater than 15 m, causes large-scale degradations of the meadows (Ganteaume et al. 2005b; Abadie et al. 2015). In the same way small units, less than 10 m long, can have an important impact at a local scale (Francour et al. 1999; Milazzo et al. 2004; Ceccherelli et al. 2007).

At the present day, studies mainly targeted the degradation of small boats at shallow depths i.e. less than 10 m. Few works treat the effects of larger pleasure ships anchoring which can measure more than 80 m long and have an important impact in confined areas (Abadie 2012). In order to assess their impact, several parameters are classically measured: the meadow density, the mat structure and the bottom cover (Boudouresque et al. 1995; Francour et al. 1999; Pergent-Martini et al. 2005). However, some of these metrics seem not relevant enough to assess the damages observed on *P. oceanica* meadows. More specifically, classical indicators can indicate a good state of conservation of the meadow with no anthropogenic impact when tracks of bare mat (Fig. 1a) are clearly observed (Milazzo et al. 2004; Ganteaume et al. 2005a).

Intensive anchoring can lead to modifications of substrate qualities, passing from meadows to large bare mat areas in which anchoring tracks are visible (Fig. 1b). This phenomenon also induces a change in sediments nature going from carbonate sediments possibly oxygenized by the living plant to fine particles filling crevices inside decomposing

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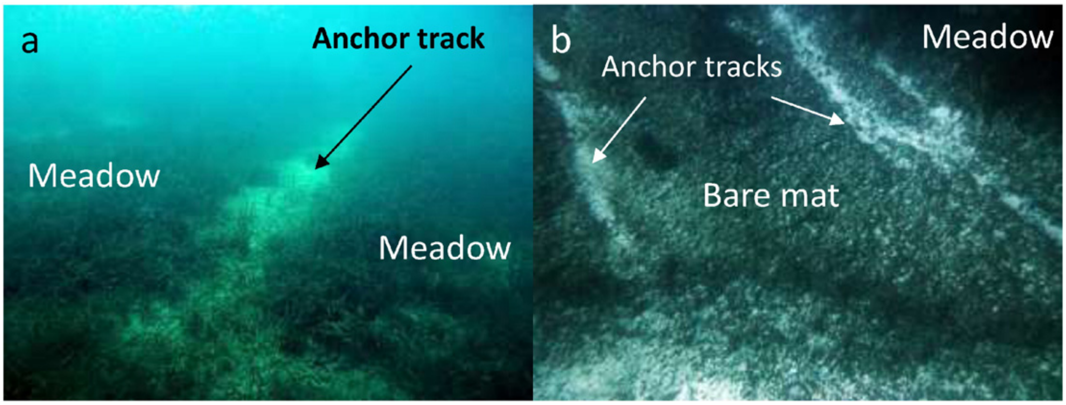

Fig. 1. a) Anchoring track inside a *P. oceanica* meadow at 30 m depth in Calvi Bay (Corsica, France); b) Bare mat of *Posidonia oceanica* generated by intensive anchoring at 18 m depth in Calvi Bay (Corsica, France) with furrows dug by large ships (photos: Arnaud Abadie).

organic tissues forming an anoxic bare mat (Mateo and Romero 1997). Such evolution of the substrate qualities can lead to the hydrogen sulfide (H_2S) intrusion in healthy meadows of the area, limiting the plant development (Holmer et al. 2003; Marbà et al. 2006). Thus, it has been observed that in carbonate sediments H_2S concentrations higher than 10 μM can cause a limitation of *P. oceanica* growth (Calleja et al. 2007).

This study aims to trigger a new way to approach the study of the anchoring impact on seagrass meadows by (1) testing the relevance of the classical structural tools (e.g. meadow density and cover, mat compactness); (2) exploring the relevance of chemical properties of the sediment as a new tool; and by extension; (3) assessing the impact of large leisure ships in a confined area; and lastly, (4) investigating the possible consequences for management and conservation of the areas concerned correlated with anchoring pressure.

2. Material and methods

This study was conducted in Alga Bay (8°43′52″ E; 42°34′20″ N), an area of 1 km^2 of intensive anchoring in Calvi Bay (Corsica, France), colonized by a *P. oceanica* meadow covering 0.78 km^2 (Fig. 2). This site encompasses a particular structure called "return river", a large sand patch where no seagrass meadow can grow, possibly due to strong bottom currents deriving from the surface ones reflected by the coast as described by Boudouresque and Meinesz (1982).

Six stations on two different sites in Calvi Bay were studied at three different depths, i.e. 10 m, 15 m and 20 m. Three stations were chosen as control in a continuous meadow with no traces of impact from human activities near the research facility of STARESO (C10, C15 and C20). Three stations were sampled at Alga Bay in areas of intensive anchoring (A10, A15 and A20) where it can generate anthropogenic patches.

2.1. Anchoring pressure assessment

A boat counting in Alga Bay was daily performed in the afternoon from May to October 2014 (the touristic period in Corsica) where anchoring frequency is the higher. Ships sizes were classified in three categories according to their length: <10 m; 10–20 m; and >20 m. In parallel, the substrate of anchoring (meadow, rock or sand) was assessed. Moreover, the spatial distribution of boats anchored in the area was investigated by using AIS positioning system of leisure boats (www.marinetraffic.com) from 2012 to 2014 as well as direct catches obtained between 2012 and 2014. These observations were inserted in the GIS software ArcGis® 10 coupled with a map of *P. oceanica* meadows in the area from previous studies (Michel et al. 2012; Jousseaume et al. 2013; Richir et al. 2015).

2.2. Meadow structure

The impact of anchoring on the *P. oceanica* meadows was assessed using six metrics commonly used in the study of its impact on seagrass meadows, i.e. the density, the proportion of orthotropic/plagiotropic rhizomes, the mat compactness, and the rhizomes baring. Ten replicates of the meadow density were randomly counted using quadrats of 25 cm × 40 cm and classified according to the grid of UNEP-MAP-RAC/SPA (2011). Assessment of the proportion of orthotropic/plagiotropic rhizomes was performed during density measures and interpreted thanks to the classes made by Charbonnel et al. (2000) (Table 1). Mat compactness was investigated given the method and classification of Francour et al. (1999) using a 1 m long rod and a 5 kg weight, repeating ten times the measure for each station (Table 1). Twenty replicates per station of the rhizomes baring, i.e. the distance between rhizome and substrate, were measured and classified according the protocol of Boudouresque et al. (1980). Meadow cover was measured using a 30 cm × 30 cm quadrat hold at arm-length 3 m above the meadow (Gravez et al. 1995). Thirty replicates were performed for this measure and results were interpreted given the scale of Charbonnel et al. (2000) (Table 1). This measure was standardized by keeping the same observer for all measures and placing a depth gauge on the quadrat in order to avoid a distance variation from the vegetation. Finally, 20 longest standing leaves per station (corresponding to the canopy height) were measured in September after the touristic period).

2.3. Conservation Index (CI)

The Conservation Index (CI) was used as a reflection of damages in *P. oceanica* meadows visually observed by scuba diving. Triplicate transects were made to calculate the CI for each station according to the process of Moreno et al. (2001):

$$CI = L/(L + D)$$

where L (%) corresponds to the proportion of living *P. oceanica* and D (%) the percentage of bare mat. Four intervals were calculated to assess the meadow's state of conservation on each station:

1. $CI < (x_{mean} - 1/2\ s)$
2. CI from $(x_{mean} - 1/2\ s)$ to x_{mean}
3. CI from x_{mean} to $(x_{mean} + 1/2\ s)$
4. $CI > (x_{mean} + 1/2\ s)$

where mean (x_{mean}) and standard deviation (s) were calculated from all CI values of the study.