

Spreading and autoecology of the invasive species *Gracilaria vermiculophylla* (Gracilariales, Rhodophyta) in the lagoons of the north-western Adriatic Sea (Mediterranean Sea, Italy)

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ABSTRACT

Gracilaria vermiculophylla (Ohmi) Papenfuss, an invasive Rhodophyta recently recorded in the Po Delta lagoons (May 2008), was also found in the Venice lagoon in March 2009 and successively in Pialassa della Baiona (Emilia–Romagna Region) in May 2009. The species has colonized the eutrophic and confined areas of Venice by pleustophytic tangled populations (5–15 kg fw m⁻²), replacing the allochthonous species whereas it is absent in the areas characterized by low nutrient availability and high water exchange. In contrast, in the Po Delta lagoons and in Pialassa della Baiona it is present everywhere, also with high water renewal, because of the eutrophication caused by the Po river and the industrial area of Ravenna. This study presents the autoecology and distribution of *G. vermiculophylla* in the above environments, according to their different eutrophication status, showing its relationship with physico-chemical parameters and nutrient concentrations in water column, pore-water, surface sediments and particulate matter collected by traps in a station of the Venice lagoon (Teneri) sampled monthly during one year. Furthermore, we give new information on its morphology and the high dimorphism between female and male gametophytes and tetrasporophytes.

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1. Introduction

The Venice lagoon is one of the Mediterranean transitional environments considered to be a prime area for the introduction of alien species, especially macrophytes (Verlaque, 1994; Boudouresque and Verlaque, 2002; Occhipinti-Ambrogi, 2002; Sfriso and Curiel, 2007). A revision of the allochthonous species, updated December 2010 (Zenetos et al., 2010), shows that there are 33 non-indigenous species (NIS) of macroalgae recorded in the Venice lagoon, ca. 80% of the number (49 taxa) recorded in the Adriatic Sea and 39% of those (125 taxa) found in the whole Mediterranean Sea. Among them some are considered invasive or potentially invasive: i.e. *Codium fragile* subsp. *fragile* (Suringar) Hariot (Sfriso, 1987), *Sargassum muticum* (Yendo) Fensholt (Gargiulo et al., 1992), *Grateloupia turuturu* Yamada (Tolomio, 1993, as *Grateloupia doryphora* (Montagne) M.A. Howe), *Undaria pinnatifida* (Harvey) Suringar (Rismondo et al., 1993), *Heterosiphonia japonica* Yendo (Sfriso et al., 2002) and *Gracilaria vermiculophylla* (Ohmi) Papenfuss (Sfriso et al., 2010a) due to their worldwide spread, but some of them have spread largely only in the

lagoons of the North Adriatic and particularly in the Venice lagoon: i.e. *Sargassum muticum*, *U. pinnatifida* and *G. vermiculophylla*. Other NIS, such as *Agardhiella subulata* (C. Agardh) Kraft & M.J. Wynne and *Solieria filiformis* (Kützinger) P.W. Gabrielson are highly invasive, but only in our lagoons.

Gracilaria vermiculophylla, a species native from Japan and Korea, is the most recent introduced species (Sfriso et al., 2010a). It was firstly recorded in the northern coasts of the Atlantic Sea in 2002 (Rueness, 2005; Thomsen et al., 2007) and has rapidly colonized many European coasts and the transitional systems of the Adriatic Sea. The first record in the Venice lagoon was in March 2009, but in the following months many populations were recorded both in the central and southern basins (Sfriso et al., 2011). In May 2009, high biomasses (5–15 kg fw m⁻²) of this species were also found at Pialassa della Baiona (Ravenna), where *G. vermiculophylla* covered a large part of the southern basin.

This paper maps the presence of this species (Venice lagoon, transitional systems of the Po Delta and Pialassa della Baiona) and analyses the different morphology of non-reproductive and reproductive thalli and their correlation with some physico-chemical parameters and nutrient concentrations in water column, pore-water, surface sediments and particulate matter collected by traps.

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2. Materials and methods

2.1. Sampling areas

Samples were collected during national and regional programmes carried out in order to monitor the ecological status of the Italian transitional environments according to the requirements of the European Water Framework Directive (2000/60/EC) for the “Macrophytes” biological element (macroalgae and aquatic angiosperms). The Po Delta lagoons were monitored in 2008, 2009, 2010 in late spring and autumn of each year (Sfriso, 2010, 2011; Sfriso et al., 2011 and references therein). Pialassa della Baiona was sampled in the same seasons in 2009 whereas macrophytes have been recorded in Venice lagoon also in other periods, within both the European WFD and the study of alien species since 2008.

Gracilaria vermiculophylla was collected monthly in one locality of the Venice lagoon (Teneri) during one year (March 2010–February, 2011) in order to assess the seasonal changes affecting biomass and cover percentage and the relationships with the main environmental parameters. Fig. 1 shows the lagoon sites where *G. vermiculophylla* was recorded.

2.1.1. Venice lagoon

The Venice lagoon (45°34′–45°12′N; 12°09′–12°36′E) is the largest transitional system of the Mediterranean Sea. It is subdivided into 4 basins connected to the sea by three large (400–900 m) and deep (10–20 up to 50 m) port-entrances (Lido, Malamocco and Chioggia). The total surface is of ca. 549 km², of which ca. 432 km² are exposed to the tidal ranges. On average the mean depth is ca. 1 m, but deep canals (>5 m) occupy ca. 5% of its surface. Water exchange with the sea is high and ca. 60% of the water is renewed on any tidal cycle (12 h). The lagoon presents a range of morphological and physico-chemical characteristics that favour the growth of a rich flora (Sfriso and Curiel, 2007) composed of wide meadows of aquatic angiosperms and beds of macroalgae (Sfriso and Facca, 2007).

2.1.2. Po Delta lagoons

The Delta of the Po river (45°08′–44°48′N; 12°16′–12°34′E) is composed of many small basins covering a surface of ca. 200 km²,

out of them ca. 100 km² are open to the tidal ranges. The mean depth of some of the basins ranges between 0.5 and 1 m: Barbamarco, Caleri, Canarin, Marinetta, Vallona and 2–3 m: Goro and Scardovari. The last two exhibit a high water exchange because of their large sea inlet. The others show both confined and highly renewed areas. All exhibit high trophic levels and turbidity. No aquatic angiosperms are present, the flora is scarce and dominated by opportunistic species, especially Gracilariaceae, Solieriaceae and Ulvaceae.

2.1.3. Pialassa della Baiona

Pialassa della Baiona (44°31′–44°28′N; 12°14′–12°16′E) is a small shallow basin located to the South of the Po Delta near the port of Ravenna in the Emilia–Romagna Region. Its surface is only ca. 10 km² and its depth ranges between 0.6 and 1.4 m. In the southern part of the lagoon water exchange with the sea is high because of the presence of many small (10–20 m wide) artificial canals which are ca. 3–6 m deep, whereas in the north it is more reduced. Nutrients are relatively high but their concentration is strongly influenced by the seasonal production of high biomasses of Gracilariaceae and Ulvaceae that hamper sediment resuspension thus producing clear waters. Because it lacks artificial hard substrata, such as the ones that characterize the Venice lagoon, marine algae are rare and mostly present under a pleustophytic form, similarly to the ones in the Po Delta.

2.2. Sampling procedures

The presence/absence of *Gracilaria vermiculophylla* during the spring and autumn macroalgal sampling was determined by testing the bottom surface with a rake (20 sub-samples at each sampling site). This procedure also allows the coverage of each species to be determined with an accuracy of >95%. The population was monthly sampled in 2009–2010 at Teneri (Venice lagoon) by means of an aluminium box of 71 × 71 cm (0.5 m²) repeatedly plunged in an area of 15 × 15 m, according to the procedure set up by Sfriso et al. (1991) to determine the algal pleustophytic biomass on soft substrata in transitional systems. The biomass weight was the mean of 3–6 sub-samples according to the algal abundance in order to obtain a measurement accuracy of ≥95%. Samples were preserved in 4% formaldehyde neutralized with hexamethylenetetramine up to

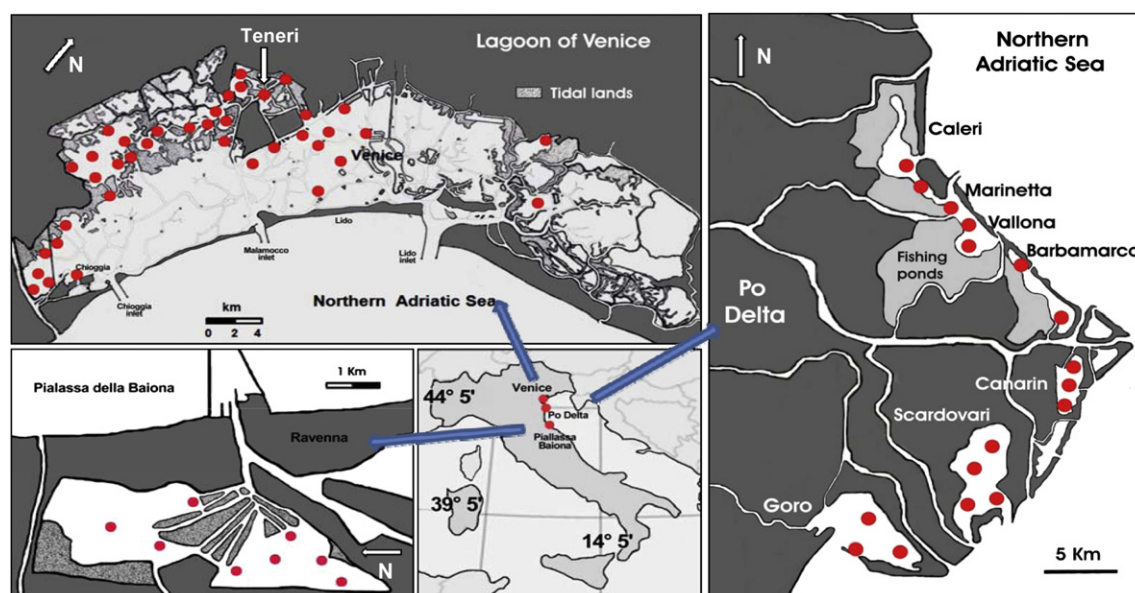


Fig. 1. Maps of the lagoon of Venice, Pialassa della Baiona and Po Delta transitional systems with indication of the *Gracilaria vermiculophylla* presence.

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