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A MARINE INVASION STORY: *CAULERPA CYLINDRACEA* (CHLOROPHYTA, ULVOPHYCEAE) IN THE MARINE PROTECTED AREA OF PORTOFINO (LIGURIAN SEA)

STORIA DI UN'INVASIONE MARINA: CAULERPA CYLINDRACEA *(CHLOROPHYTA, ULVOPHYCEAE) NELL'AREA MARINA PROTETTA DI PORTOFINO (MAR LIGURE)*

Abstract *- The green alga* Caulerpa cylindracea*, one of the worst invasive species in the Mediterranean Sea, was first recorded in the Portofino Marine Protected Area (Ligurian Sea, NW Mediterranean) in 2008, where it was more abundant in the circalittoral (21 m to 45 m depth) than in the infralittoral zone (1 m to 20 m). Monitoring between 2012 and 2021 showed that, notwithstanding high yearly variability, it was widespread at all depths, with minor differences between the infralittoral and the circalittoral. However, recent monitoring data showed that the alga decreased its cover at all depths, to virtually disappear in 2023. This temporal pattern recalls that of the congeneric* C. taxifolia*, which – after an impressive initial bloom – did not persist in most of the Ligurian Sea.*

Key-words: *Biological invasion, alien alga, monitoring, rocky reefs, Mediterranean Sea.*

Introduction – With the publication of the seminal book of Elton (1950), a new discipline was born: invasion ecology. For a long time, interest in bioinvasions remained focused on the terrestrial environment only. Working on the introduced invertebrates in San Francisco Bay, Carlton (1979) initiated the marine counterpart of invasion ecology. Due to the intensity of human activities, the Mediterranean is one of the most invaded seas of the world (Streftaris *et al.*, 2005). The two alien green algae *Caulerpa taxifolia* (M.Vahl) C.Agardh, and *Caulerpa cylindracea* Sonder, in particular, are considered among the "worst" invaders (Streftaris & Zenetos, 2006). *C. taxifolia* garnered significant concern because of its rapid initial proliferation and its adverse effects on native ecosystems, whereas *C. cylindracea* received comparatively less attention. Today, the abundance of *C. taxifolia* has significantly declined; on the contrary, *C. cylindracea* has shown a remarkable and consistent expansion since its initial appearance in the Mediterranean Sea (Montefalcone *et al.*, 2015).
First recorded in 1990 off Libya, *C. cylindracea*, of SW Australian origin, reached the Ligurian Sea in 1996 (Montefalcone *et al.*, 2015 and references therein). Its presence remained mostly restricted to anthropized areas until 2008, when the species was observed also in the Marine Protected Area (MPA) of Portofino (Fig. 1), especially on biodetritic bottoms (Morri *et al.*, 2019). A yearly monitoring activity between 2012 and 2017 showed that it was widespread between 1 m and 45 m depth, with the highest substratum cover (up to 25%) at about 20 m (Morri *et al.*, 2019). After 2008, its cover has increased from 4% to about 12% in the infralittoral zone, whereas in the circalittoral decreased from 21% in 2008 to around 15% in 2017 (Mancini *et al*., 2022). Here we update to 2023 the existing data series to reconstruct the whole trend

of colonization of *C. cylindracea*, in Portofino MPA, in order to see whether it has somewhat receded after a first bloom or has remained similarly abundant as in the previous period.

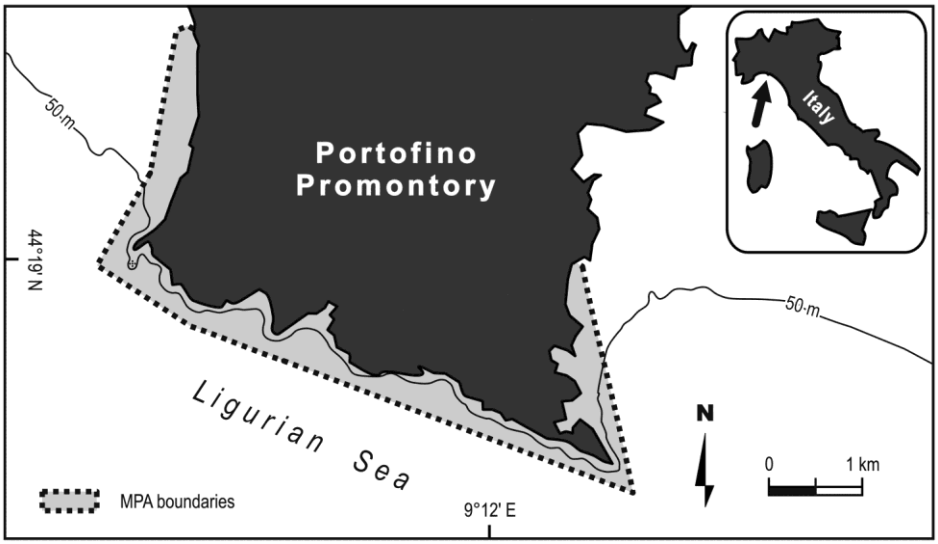

Fig. 1 – The Marine Protected Area (MPA) of Portofino and its geographical location in Italy (black arrow in the inset).
L'Area Marina Protetta (AMP) di Portofino e la sua collocazione geografica in Italia (freccia nera nel riquadro).

Materials and methods - Cover data of *C. cylindracea* were estimated visually by scuba diving between 1 m and 45 m depth, down several vertical transects (9-16, according to the year), randomly located along the southern front of the Portofino Promontory (Fig. 1). Data were analyzed separately according to two different depth ranges: the infralittoral zone, 1 m to 20 m, and the circalittoral zone, 21 m to 45 m. The reconstructed trend will be compared with the two models of invasion kinetics proposed by Boudouresque and Verlaque (2012): the first one, called "natural fluctuation model", envisages a more or less ample yearly fluctuation around a rather stable mean; on the contrary, the second one, called "boom and bust model" predicts a natural collapse to a very low and almost stable level after a period of rapid increase. Both models distinguish four phases: 1) a punctual arrival; 2) a short period of naturalization; 3) a longer expansion phase; 4) a persistence phase (Fig. 2).

Results – Recent monitoring data showed that the percent cover of *C. cylindracea* exhibited again high yearly variability, but diminished to virtually disappear in 2023, when amounted to 0.3% on average (Fig. 3). There was little difference between the infralittoral and the circalittoral zone: in the former, cover reached 1.5% ± 0.31 SE in 2022 and 0.7% ± 0.28 SE in 2023; in the latter, 0.7% ± 0.22 in 2022 and 0.1% ± 0.05 SE in 2023.

Conclusions – Contrarily to the results obtained in the first decade of monitoring (Morri *et al.*, 2019; Mancini *et al.*, 2022), in recent years (mostly after 2018) the cover of *C. cylindracea* decreased drastically with respect to the values of the previous period, both in the infralittoral and the circalittoral zone. Looking at the whole reconstructed trend, 2008 to 2023, it is possible to see both analogies and differences

with the models of Boudouresque and Verlaque (2012). The arrival in 2008 was characterized by a comparatively high cover, especially in the circalittoral zone, rather than the low abundance predicted by the models. On the contrary, the naturalization phase at Portofino, between 2009 and 2010 (in the infralittoral zone) or 2011 (in the circalittoral zone), implied lower values with respect to the arrival, while the models predicted the opposite. Until 2017, the trend conformed to the "natural fluctuation model"; in the last six years, the trend was rather recalling the "boom and bust model" of the same authors.

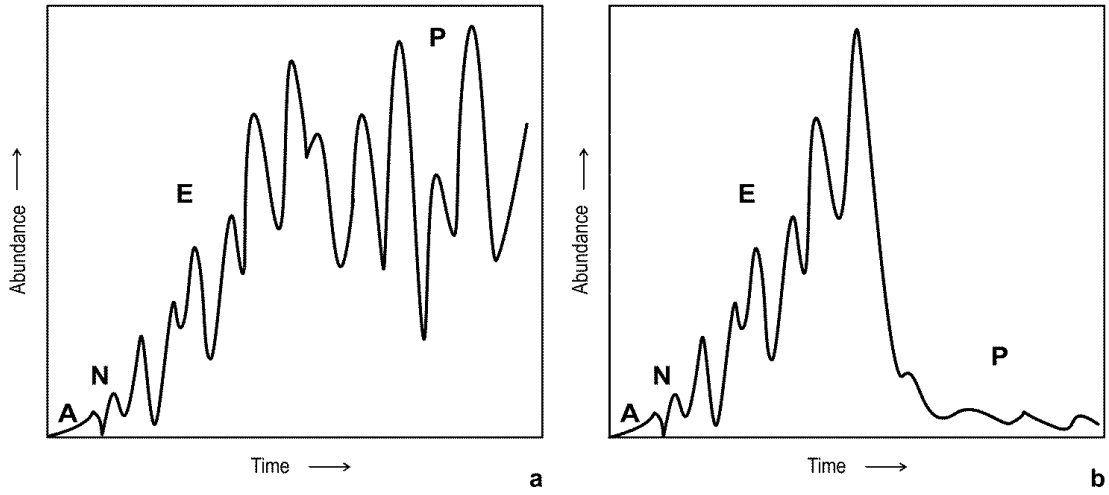

Fig. 2 – Phases in the invasion kinetics of an alien species, according to the natural fluctuation model (**a**) or the boom and bust model (**b**). **A**: arrival; **N**: naturalization; **E**: expansion; **P**: persistence. After Boudouresque and Verlaque (2012), redrawn and modified.
*Fasi nella cinetica d'invasione di una specie aliena, secondo il modello delle fluttuazioni naturali (***a***) o il modello ascesa e crollo (***b***). **A**: arrivo; **N**: naturalizzazione; **E**: espansione; **P**: persistenza. Da Boudouresque e Verlaque (2012), ridisegnato e modificato.*

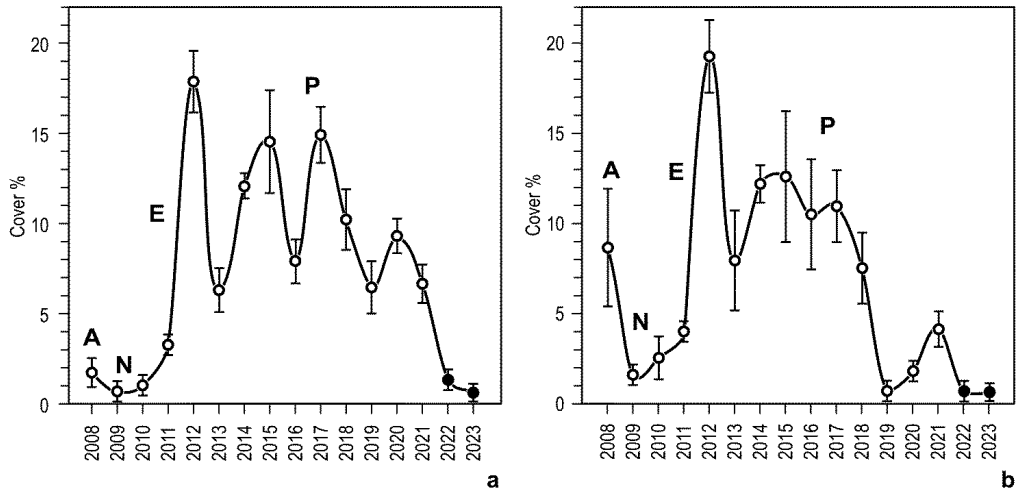

Fig. 3 – Temporal trend of the substratum cover by *Caulerpa cylindracea* (mean ± standard error) in the Marine Protected Area of Portofino in the infralittoral zone (**a**) and in the circalittoral zone (**b**). Open circles are literature data (Morri *et al*., 2019; Mancini *et al.,* 2022), solid circles new data (present paper). **A**: arrival; **N**: naturalization; **E**: expansion; **P**: persistence.
Andamento temporale del ricoprimento di Caulerpa cylindracea *(media ± errore standard) nell'Area Marina Protetta di Portofino nel piano infralitorale (***a***) e nel piano circalitorale (***b***). I cerchietti bianchi sono dati di letteratura (Morri* et al*., 2019; Mancini* et al*., 2022), i cerchietti neri nuovi dati (presente lavoro). **A**: arrivo; **N**: naturalizzazione; **E**: espansione; **P**: persistenza.*

In a study involving the whole Ligurian Sea, Montefalcone *et al.* (2015) distinguished two different kinetics in the invasion of the two alien species of *Caulerpa*: *C. taxifolia* strongly reduced its substratum cover and habitat occupancy after an initial "boom" phase, during which it received the epithet of "killer alga"; on the contrary, *C. cylindracea* was still continuing an impressive and constant expansion. Our results suggest that also *C. cylindracea* is now decreasing, at least in the Portofino MPA. A comparable diminution, however, has similarly occurred in anthropized areas (Author's unpublished observations). Can it be hypothesized that *C. cylindracea* is starting to follow the same route of its congeneric? As a matter of fact, in the Ligurian Sea both species showed an expansion phase that peaked after around 15 years, followed by a decline that lasted for further 15 years, for a total cycle of nearly 30 years (1980s to 2010s for *C. taxifolia*: see Fig. 2 in Montefalcone *et al.*, 2015; 1990s to 2020s for *C. cylindracea*: see Fig. 3 in the present paper).
It has been asserted that the Mediterranean specimens of *C. taxifolia* belong to a clone unable to reproduce sexually (Jousson *et al.*, 1998). The same is possibly true for *C. cylindracea* (Žuljević *et al.*, 2012). Should the lack of sexual reproduction in the two species be confirmed, one might suppose that a clone comes to exhaust its scope for vegetative propagation, and then - without the renewal brought by genetic recombination - degrades and regresses over time. This suggests caution when defining "worst" a clonal (i.e., a plant or colonial invertebrate) invader before waiting for some decades. Similarly, talking about "naturalization" for an alien species that does not reproduce sexually in the invaded area might seem inadequate.

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