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Additional new records of *Caulerpa cylindracea* Sonder 1845 along the West Algerian Coasts

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Since considered as invasive species, *Caulerpa cylindracea* Sonder 1845 has been the subject of numerous prospecting works aiming its localisation and identification along the western Mediterranean Coasts. In this study, we provide new occurrence of the introduced seaweed *Caulerpa cylindracea* in the West Algerian coasts. *C. cylindracea* has been reported for the first time in Canastel and Zimba (West Algerian coasts) at different density distribution levels. The colonisation level was estimated to Level (I) for Zimba, Canastel and Marsat El Hadjaj sites, which indicated a beginning of spreading. By contrast, in Cap Carbon a Level (II) was recorded suggesting an advanced colonisation of the invasive taxon. Macroalgae and seagrass assemblage characterisation showed low cover for all species in the invasion zone. Accordingly, *Caulerpa cylindracea* is more present in Cap Carbon than in Zimba, Canastel and Marsat El Hadjaj. Considering the observed abundance of macroalgae and seagrasses, *Caulerpa prolifera* seemed to resist the invasion of *C. cylindracea* in Marsat El Hadjaj.

[**Keywords**: Algae, Algeria, Biological invasion, *Caulerpa cylindracea*, Seaweed]

Introduction

A biological invasion consists of a species acquiring a competitive advantage following the disappearance of natural obstacles to its proliferation. This ability allows the invasive species to spread rapidly and conquer novel areas in which it becomes a dominant population[1]. Invasive species are considered as a serious threat to natural ecosystems[2], as well as one of the major drivers of biodiversity loss[3-7]. Invaders are highly competitive and their interaction with native species may cause a global biodiversity decrease[8]. According to Boudouresque & Verlaque[9], the Mediterranean Sea hosts 84 introduced macrophytes that influence the abundance of autochthonous species. This number rose to 110 in 2009[(ref. 10)] and is evaluated, nowadays, to 118 taxa of introduced macrophytes[11,12]. Consequently, the spreading of invasive species can change the structure of native benthic communities affecting the biodiversity of the ecosystems[5], this event has occurred in the northern Mediterranean Sea as consequence of the invasion of *Caulerpa taxifolia* (M. Vahl) C. Agardh[13].

The green algae *Caulerpa cylindracea* Sonder 1845 [formerly *Caulerpa racemosa* (Forsskal) J. Agardh var. *cylindracea* (Sonder) Verlaque, Huisman & Boudouresque] is one of the most invasive seaweeds in the Mediterranean Sea[5-7,14,15]. The species, endemic to the south-western coasts of Australia, is an Indo-Pacific and termophilic taxon coming from the Suez Canal, able to colonize all kinds of marine bottoms, in exposed and sheltered sites subjected to high light conditions from the surface to more than 40 m depth[16,17]. Besides, this allochtonous and invasive strain prefers coastal water highly eutrophic, close to the tourist and fishing harbour[18] on mobile sediments enriched by organic material[19], but it is also observed in pristine coastal waters characterized by good ecological conditions designed to preserve some important and priority habitats[20]. First invasion records were on the coasts of Libya in the early 1990s[21]. Nowadays, the invasive taxon has been systematically reported in 15 Mediterranean countries[16,22,23] and has become a major component of macroalgal assemblages along most coastlines[24,25].

This invasive taxon was first misnamed as *C. racemosa* var. *occidentalis* (J. Agardh) Borgesen[26], to be renamed later as *C. racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman & Boudouresque[27] through a complex morphological and genetic study[27]. Finally, it has shown the genetic independence of *Caulerpa racemosa* var. *cylindracea*, as an independent taxon and it has been stated the reinstatement of the original name *C. cylindracea* Sonder[28].

Historically, *Caulerpa cylindracea* was discovered in Algeria, for the first time, in 2006 near Algiers harbour[29]. It has been reported in nine localities in central Algerian coasts and in nine localities of West[23,29-34].

The aim of this work is to report and characterise a new record of the invasive *C. cylindracea* in Canastel (district of Oran), and Zimba (district of Ain Temouchent), north-west coasts of Algeria. Moreover, we defined the structure of the benthic macroalgal community in presence of *C. cylindracea*. Accordingly, present studymade use of parametric indexes to perform a static aspect of the behaviour of seaweeds and seagrasses to the presence of the invasive *C. cylindracea*.

Material and Methods

The study was carried out through the west Algerian coasts (Fig. 1). In this area, *Caulerpa cylindracea* was first identified in Marsat El Hadjadj in 2011[(ref. 33)], in Cap Carbon in 2012[(ref. 34)] and in Canastel and Zimba in 2014 (present study).

During mid spring to last summer of 2014 and 2015, *C. cylindracea* dominated assemblages were subjected to several sampling. To estimate species average covering, eight samples were collected in the invaded zone, for each site; using a 20 x 20 cm quadrat (Table 1). The sampling depth of each sampling site is recorded and tabulated in Table 1. The cover of different seaweeds and seagrasses was estimated as the surface covered in vertical projections by each species and expressed in percentage of the sampling surface (400 cm²)

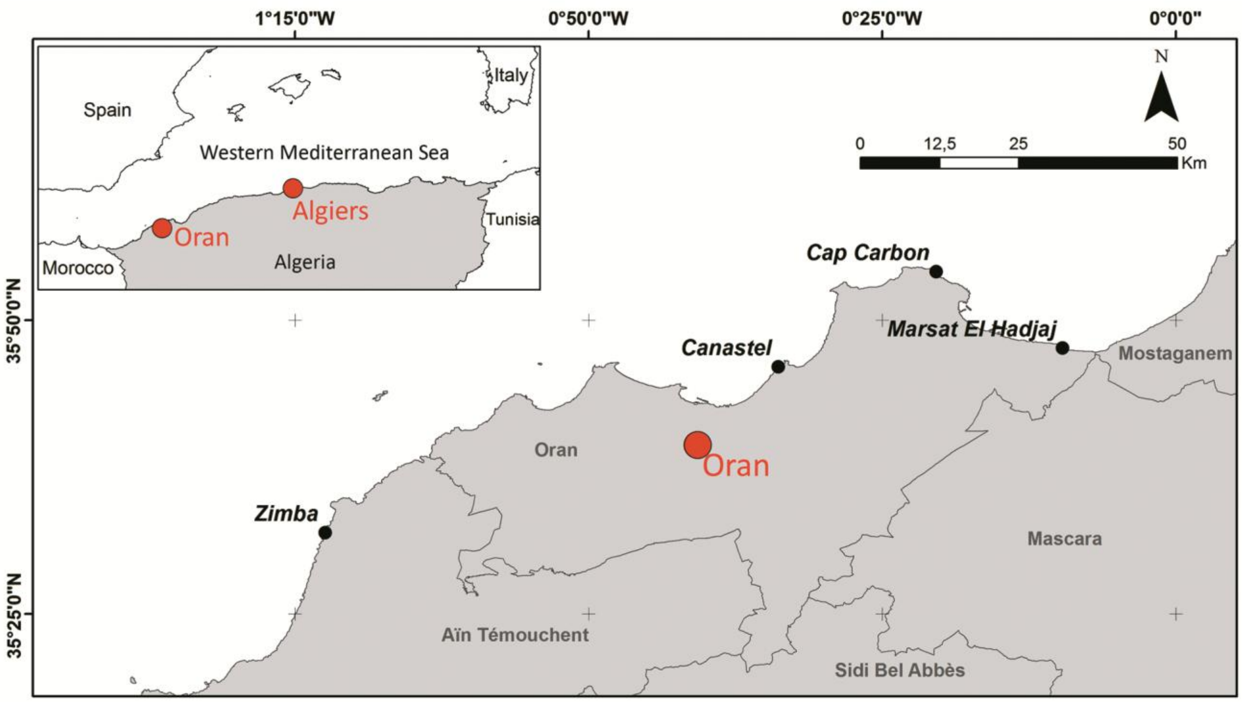

Fig. 1 — Sampling locations (NW Algerian coasts)

Table 1 — Sampling sites geographical coordinates and characteristics.

Sampling sites	Coordinates	Number of quadrats	Depth min.	Depth max.	Substrate	Sampling year
Canastel	0°33'52.26" W 35°46'5.445" N	8	0.1	2.2	Rocky	2014
Zimba	1°12'34.259" W 35°32'0.39" N	8	0.5	1.7	Sandy, rocky	2014
Marsat El Hadjaj	0°9'30.542" W 35°47'36.803" N	8	0.2	2.8	Sandy, rocky	2015
Cap Carbon	0°20'10.044" W 35°54'20.298" N	8	0.2	1.6	Rocky, seagrass	2015

according to Boudouresque[35]. Hierarchical clustering analysis was used to assess the macro-algae behaviour in response to the introduction of the invasive *Caulerpa cylindracea*, using a matrix of covering and species ID data.

To describe the situation of the invasion, all identified *Caulerpa cylindracea* colonies were geo-referenced and surface of each colony was estimated. The collected data has been integrated and treated in a geographical information system (GIS) to project density distribution of the populations of *C. cylindracea* in the study area. The estimated levels of colonisation of the invasive species and the affected coastlines have been performed according to De Vaugelas *et al.*[36]. Levels of colonisation have been evaluated by measuring descriptive parameters as: colonised surface by *Caulerpa cylindracea*, number of colonies located close each other, the affected surface referring to the delimitation of the perimeter in which all colonies are growing (in a convex polygon) and the concerned coastline representing the length of coastline along which one can observe the affected surface. As a result: "Level I refers to a station where one or several colonies less than 100 m apart cover a total surface area inferior to 1000 m²; Level II refers to a station where several colonies less than 250 m apart totally cover more than 1000 m² with fragments and small colonies dispersed over a surface area inferior to 10 ha"[36].

Results and Discussion

Caulerpa cylindracea assemblage characterisation

Caulerpa cylindracea (Fig. 2) is known as a strong competitor. In colonised areas, it tends to eliminate native species and often constitute monospecific beds[16,22,37]. In this case study, *C. cylindracea* was the mean invader of the surveyed assemblages.

Fifteen benthic macrophyte species were found in assemblages colonised by *C. cylindracea*. The number of species per samples varied between 7 and 9. Although the covering of macrophyte species associated to the invasive *C. cylindracea* area showed a significant variability among sites (p = 0.01 in ANOVA; Table 2). The total percent cover of native species is low except for *Caulerpa prolifera* (Forskal) Lamouroux in Marsat El Hadjaj sampling site. Estimated average species covering (Fig. 3) shows a clear spatial dominance of the *C. cylindracea.* Most macrophytes showed low abundance in *C. cylindracea* dominated assemblages suggesting a competitive exclusion by the invasive alga as reported by others[38,39].

From the interspecies hierarchical clustering analysis (HCA; Fig. 4), except *Caulerpa cylindracea*, two species groups are formally distinguished: 1) From 0 to 11.6 Euclidian distance: a group formed of 13 species that seems not to associate the invasiveness of *C. cylindracea* taxon and are less resistant to its presence. 2) Between 19 and 31 Euclidian distance: a group of two species, *Caulerpa prolifera* and *Corallina*

Fig. 2 — *Caulerpa cylindracea* in Cap Carbon (left) and Marsat El Hadjaj (right)

Table 2 — Variance analysis of the ANOVA

Source of variations	*Sum of squares*	*Degrees of freedom*	*Variance estimate*	*F*	*P-value*	*F crit*
Between Groups	3696.09375	3	1232.03125	3.90484613	0.01896572	2.94668527
Within Groups	8834.375	28	315.513393			
Total	12530.4688	31				

elongata, that seems to be closer to *Caulerpa cylindracea* and more resistant to its invasiveness. *C. prolifera* seems able to co-occur with *C. cylindracea*, highlighting similar competitiveness for co-generic species[40]. Some of the species collected in the study sites belong to a vegetal association named *Caulerpetumracemosae* Giaccone and Di Martino already described in the Eastern Mediterranean basin and, then, also spreading in the western one[41].

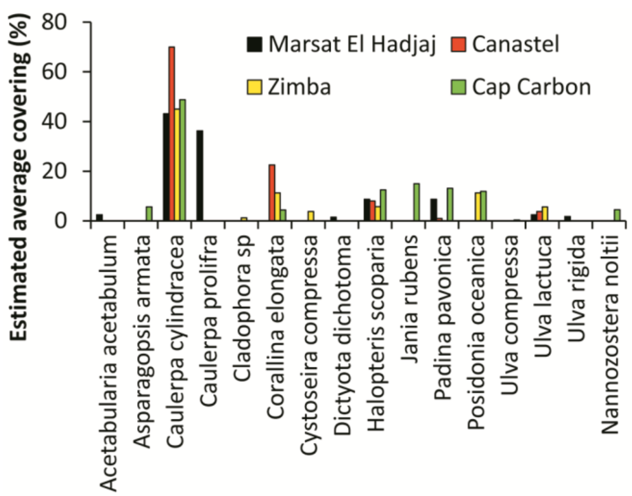

Fig. 3 — Estimated average covering per species and per site

Through all zones, *C. cylindracea* formed a clearly dominant species introducing macroalgae assemblage and seagrass meadows. In the study sites a great cover of turf species, reaching the 37.5 % of the whole, was found in the local macroalgal assemblage. Overall, turf species probably may enhance the settlement of *C. cylindracea* by the entrapment of algal fragments favouring the anchoring of their stolons, as it is well known in scientific literature[4,42,43]. These edaphic conditions cause the development of a multilayered structure trapping sediments and altering the pattern of vegetal associations.

***Caulerpa cylindracea* mapping**

According to our results, data and available references, *C. cylindracea* continues to extend its range on the Algerian coastline. Our results analysis reveals that the spread of *C. cylindracea* is confined to shallow waters, principally between 0-0.5 and 1-1.5 m (Fig. 5), across heterogeneous seaweeds assemblage, through all reported zones. The regression of *Caulerpa cylindracea* populations on deepest water (more than 2 m) has already been reported for the west Algerian coasts for Salamandre and Stidia/ Mostaganem district[31] and Bousfer and Kristel/ Oran district[34].

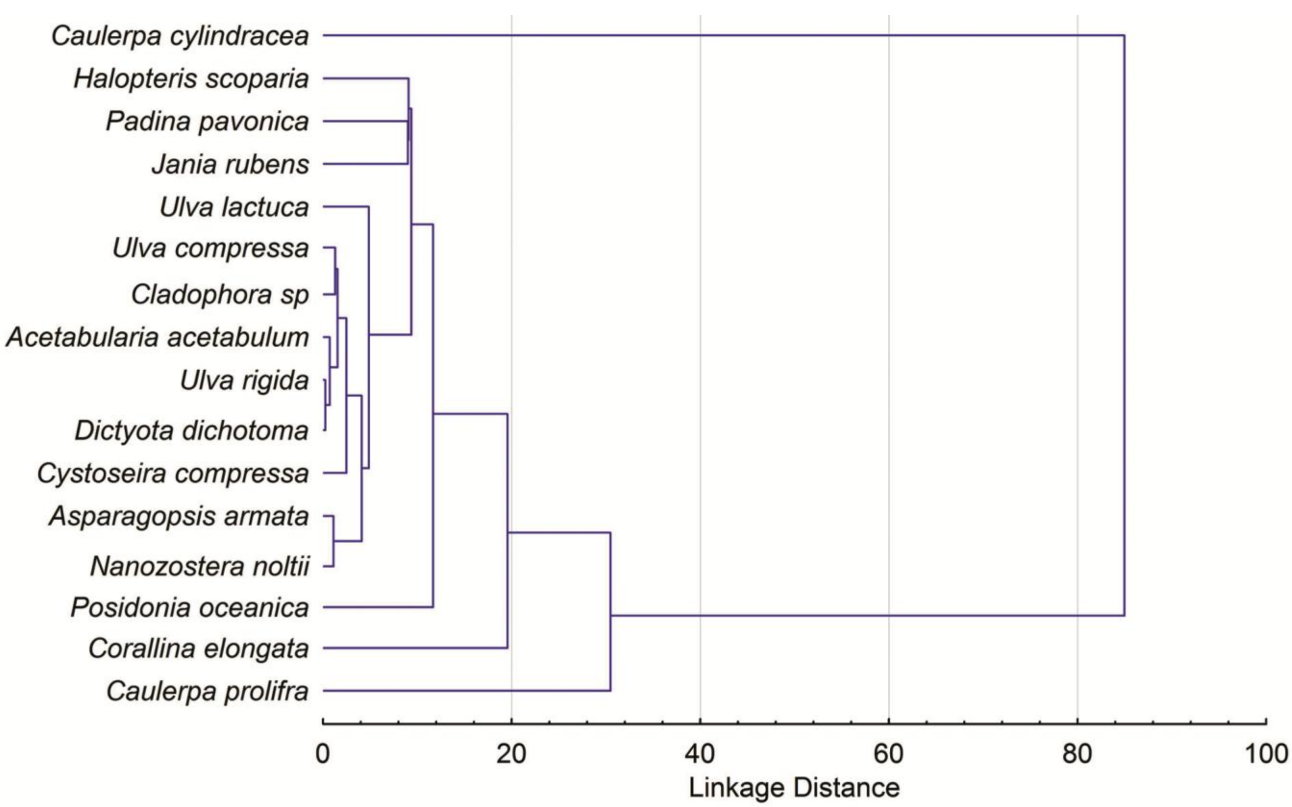

Fig. 4 — Interspecies hierarchical clustering analysis for species average recovery

In terms of spatial presence, the invasive taxon was more present in Cap Carbon than in others studied sites. According to the invasion's cartographic evaluation of the *Caulerpa* genus species, the estimated *C. cylindracea* covered surface and the corresponding affected coastal line are presented in Figure 6. Referring to De Vaugelas *et al.*[36], the colonisation level was estimated to Level (I) for Zimba, Canastel and Marsat El Hadjaj sites, which indicated that the spreading was only at its beginning. The covered surface by *C. cylindracea* in Cap Carbon corresponded to Level (II) that suggested an advanced colonisation of this invasive taxon. This expansion of *C. cylindracea* in the observed sites seems not to be very pronounced in comparison to the other locations of the west Algerian coast such as Stidia and Salamandre[44].

The combination of different localisation's data of *Caulerpa cylindracea* (Sonder) from a vailable references and our survey results (West Algerian coast) contributed to the updated distribution map of the invasive taxon in the Mediterranean Sea (Fig. 7).

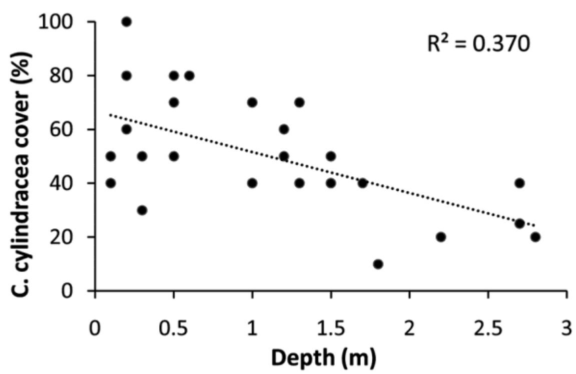

Fig. 5 — Scatter diagram of *C. cylindracea* cover related to depth

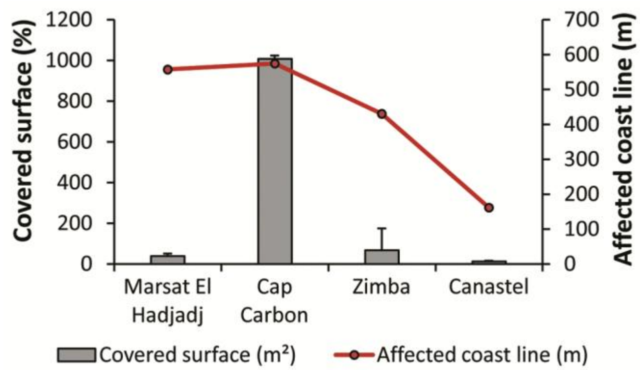

Fig. 6 — Covered surface by *C. cylindracea* and the corresponding affected coast line

Fig. 7 — Geographical distribution of *Caulerpa cylindracea* in the Mediterranean Sea Altamirano *et al.*[22] adapted. The black dots show the locations of *C. cylindracea*; the red dots indicate the newly reported locations for western Algeria

Conclusion

The invasive trend of *Caulerpa cylindracea* is, actually, ongoing in the Western Mediterranean basin and this process could produce, in time, heavy impacts on marine benthic ecosystems[45], supporting conditions of biological pollution. Really, it is impossible to foresee if the spreading of this alien species could produce a better diversification of Mediterranean biota or, instead, a gradual loss in marine biodiversity, affecting the qualitative and quantitative patterns of macro-algal assemblages. So, in these last decades, some experimental plans for the eradication of the species have been performed but the results of these testing trials have highlighted that the recovery process of native vegetal community has been minimal and quite low[38,46-48].

According to our results, we can suggest that the presence of *Caulerpa cylindracea* has no imminent impact and still confined to very shallow water under in the studied sites. Also, the occupied surface of presumed invasive *Caulerpa cylindracea* is very low. According to this, and to the invasion definition, we suggest that the *Caulerpa cylindracea* has not yet reached the invasion stage through the studied sites. So, considering the small area covered by algal spreading, as far as the station of level I, it could be hoped a mechanical eradication of the species by underwater suction pumps or by a simple manual collecting[48]. However, in most of the cases, this invasive taxon was able to quickly colonize wide areas of the Mediterranean basin[49] on all kind of marine bottoms from the surface to more than 40 m depth and, in such ecological conditions, the attempts to eradicate the species were unsuccessful[50] while the process of recovery of the native macro algal assemblage appeared quite slow[38].

Anyway, the conditions of great uncertainty and biological variability suggest the need of monitoring programs and up-to-date mappings of coastal ecosystems so to warrant the survival of endemic species, still living in the Mediterranean Sea, and the protection of its marine biodiversity.

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Conflict of Interest

Authors declare no competing or conflict of interest.

Author Contributions

MEAB conceptualized the paper, wrote the original draft, carried out statistical analysis, and prepared the original illustrations. MEAB & NET carried out the methodology part. MEAB & NC reviewed pertinent literature for the discussion and conclusion part. NET & NC reviewed and commented critically the manuscript.

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