ISSN: 0001-5113 AADRAY	ACTA ADRIAT., 51(2): 195 - 202, 2010	UDC: 582.273 : 581.9 (262.3)

Distribution of invasive red alga *Womersleyella setacea* (Hollenberg) R.E. Norris (Rhodophyta, Ceramiales) in the Adriatic Sea

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Womersleyella setacea *(Hollenberg) R.E. Norris (Rhodophyta, Ceramiales) is an invasive macrophyte in the Mediterranean Sea, first recorded from the coast of Italy in 1986. This is a review of the geographic distribution and depth limits of* W. setacea *invasion in the Adriatic Sea since its first record in 1997. Algal turfs were collected and examined from different locations in the Croatian part of the Adriatic Sea from 2005 to 2009 by SCUBA diving and grab sampling. A total of 50 sites invaded by* W. setacea *were recorded in the Adriatic Sea; 40 new sites in this research and 10 from the literature records.* Womersleyella setacea *was recorded from 7 to 72 meters depth. Only sterile specimens without any reproductive structures were found. The magnitude of the invasion is discussed.*

Key words: *Womersleyella setacea*, distribution, biological invasion, Adriatic Sea

INTRODUCTION

Womersleyella setacea (Hollenberg) R.E. Norris (Rhodophyta, Ceramiales) is an invasive macrophyte in the Mediterranean Sea, first recorded from the coast of Italy in 1986 (BENEDETTI-CECCHI & CINELLI, 1989). The origin and way of introduction remain unknown, but a suggested vector for its introduction is fouling on ship hulls (VERLAQUE, 1994; CIESM, 2002).

Womersleyella setacea is native to tropical areas of the world's oceans. It has been recorded in the tropics of the Atlantic Ocean, Costa Rica and El Salvador (HOLLENBERG, 1968), Bermudas (OLIVEIRA-FILHO & CORDEIRO-MARINO, 1970), Pacific Ocean, Hawaii, Johnston Islands, Society Islands, American Samoa, Fiji Islands, Marshall Islands, Caroline Islands, Philippines and Indonesia (HOLLENBERG, 1968), Thailand (EGEROD, 1971) and Columbia (SCHNETTER & BULA-MEYER, 1982). The detailed biogeographical range of this species is still unknown. More reports on its distribution were published recently for the eastern Atlantic Ocean where it is still unclear whether *W. setacea* is an introduced or a native species (ROJAS-GONZÁLEZ & AFONSO-CARILLO, 2000). Recent molecular studies aimed to verify the establishment of the genus *Womersleyella* and position it in relation to other clades of the *Polysiphonia* group (CHOI *et al.*, 2001).

In the Mediterranean Sea, *W. setacea* has been first recorded in 1986 in Italy as *Polysiphonia* sp. (BENEDETTI-CECCHI & CINELLI, 1989) and on the coast of France in 1987 as *Polysiphonia setacea* Hollenberg (VERLAQUE, 1989). Later it was reported for most of the Mediterranean

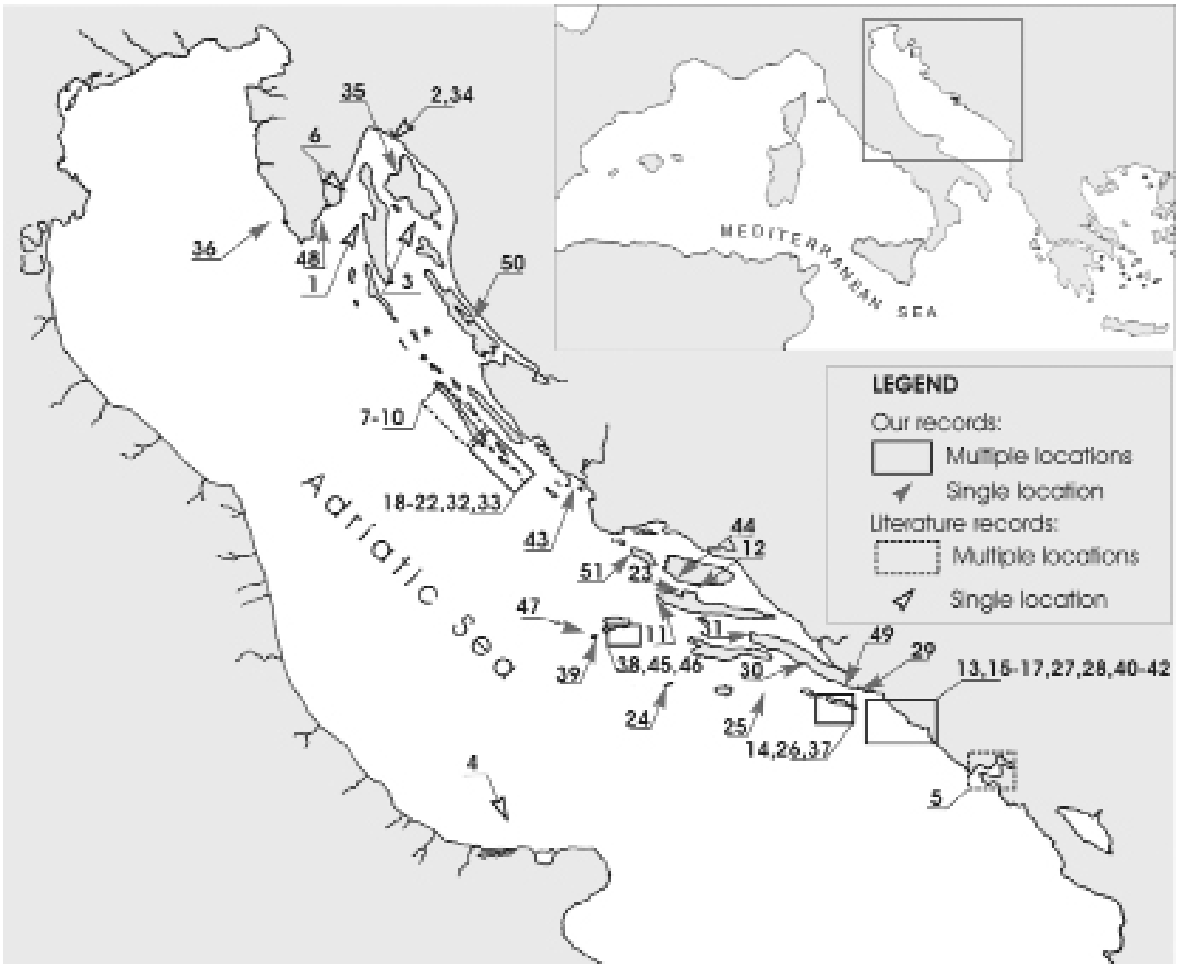

Fig. 1. A map of Womersleyella setacea *distribution in the Adriatic Sea. Literature records: 1 – Cres Island, 2 – Cape Oštro, 3 – Kvarner Gulf, 4 – Tremiti Islands, 5 – Boka Kotorska Bay, 6 – Rabac, 7 – Veli Rat, Dugi Otok, 8 – Sakarun, Dugi Otok, 9 – Mežanj, Dugi Otok, 10 – Brbinjščica, Dugi Otok; Our records: 11 - Marinkovac Island, 12 - Jelsa, 13 - Lokrum Island, 14 – Cape Lenga, 15 – Šipan Island, 16 – Bobara Island, 17 – Cape Orsula, 18 – Islet Purara, 19 – Mali Obručan Island, 20 – Islet Mana, 21 – Klobučar Island, 22 – Mrtovnjak Island, 23 – Stari Grad, 24 – Sušac Island, 25 – Islet Smokvica, 26 – Sobra, 27 – Kupari, 28 – Dubrovnik, 29 – Cove Priježba, 30 – Žuljana, 31 – Lovišće, 32 – Cape Raknić, 33 – Mali Garmenjak Island, 34 – Cape Oštro, 35 – Malinska, 36 – Veli Brijun, 37 – Pomena, 38 – Ravnik Island, 39 – Cove Mezuporat, 40 – Jakljan Island, 41 – Lopud Island, 42 – Sv. Andrija Island, 43 – Šibenik, 44 – Cove Grška, 45 – Vis Island, 46 – Islet Greben, 47 – Biševo Island, 48 – Cove Budava, 49 – Cove Prapratno, 50 – Pag Island, 51 – Islet Kamik (sites 11-13 recorded in 2003, 14-37 in 2005, 38 and 39 in 2006, 40 to 44 in 2007, 45 to 47 in 2008 and 48 to 51 in 2009)*

Sea from Greece to Spain (AIROLDI *et al.*, 1995; ATHANASIADIS, 1997; BALLESTEROS *et al.*, 1997; GÓMEZ GARRETA *et al.*, 2001; PIAZZI & CINELLI, 2001). STREFTARIS & ZENETOS (2006) classify it among the 100 worst marine alien species in the Mediterranean.

The first records of this alien invasive species in the Adriatic Sea were in 1997 in the area of Cres island in the northern Adriatic (SARTONI & ROSSI, 1998), Tremiti Island in Italy (FURNARI *et al.*, 1999; CORMACI *et al.*, 2000) and Oštro cape in the northern Adriatic (BATELLI & ARKO-PIJEVAC, 2003, 2005), followed by records in 2003 in Boka Kotorska Bay in the southern Adriatic, in 2004 for Rabac in the northern Adriatic (BATELI & RINDI, 2008) and Dugi Otok Island in the middle Adriatic (KRUŽIĆ, 2008). There was no record of *W. setacea* in historical surveys of algal flora in the Croatian part of the Adriatic Sea for the period from the 1970s to the 1990s, though it

remains a possibility that it was overlooked or misidentified due to its small size. Formation of extensive and thick turfs made of filamentous red algae at depths below 15 m was never reported for the eastern coast of the Adriatic Sea until the appearance of *W. setacea*. This suggests that it was probably a recent introduction, as proposed by ATHANASIADIS (1997). Here we review the geographic distribution and depth limits of the invasion of *W. setacea* in the Adriatic Sea since its first record.

MATERIAL AND METHODS

Algal turfs were collected and examined from various locations in the Croatian part of the Adriatic Sea during our scientific missions. Samples of algal material were collected from 2003 to 2009 by SCUBA diving and grab sampling. The presence of invasive alga *W. setacea* was confirmed after microscopic analysis and its thalli were occasionally examined for the presence of reproductive structures. Depth range of the visible turf formation was recorded when possible.

RESULTS AND DISCUSSION

To the end of 2009, a total of 50 sites invaded by *Womersleyella setacea* were recorded in the Adriatic Sea: 40 new records have been reported in this study and 10 citations come from the literature. Seven sites have been recorded in the northern Adriatic, 24 in the central Adriatic and 19 in the southern Adriatic Sea (Fig. 1). Forty eight sites are reported from Croatia, one from Montenegro and one from Italy. Information on the presence of extensive turfs throughout the Adriatic Sea was received from recreational and professional divers, though none of the reported sites were controlled and included in this study. Divers often report extensive turf formations and these can also be recognized from underwater amateur and professional photographs and videos. Therefore, the current area invaded by this alga should be far larger than recorded in this research.

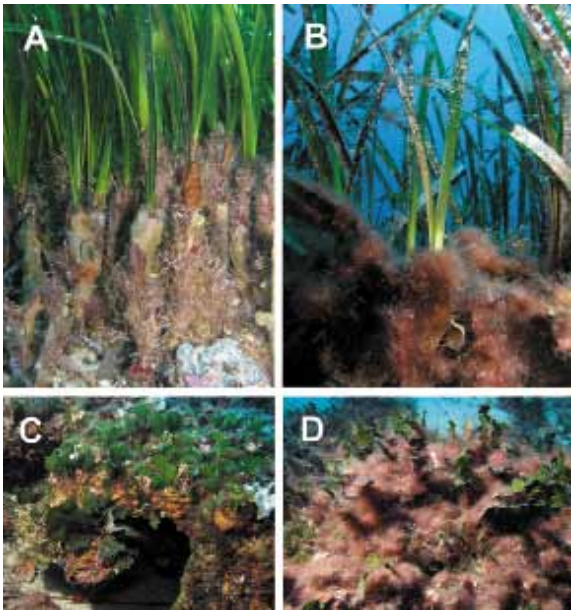

Fig. 2. Natural communities and Womersleyella setacea *turfs in the Adriatic Sea. A – Natural community on rhizomes of* Posidonia oceanica*; B – Rhizomes of* P. oceanica *invaded by* W. setacea*; C – Natural circalittoral rocky bottom community; D – Circalittoral bottom community after* W. setacea *invasion*

Womersleyella setacea was recorded from 7 to 72 m depth. The deepest record was obtained with a grab from a circalittoral plain near Biševo Island (location nr. 47, Fig. 1). The most extensive turfs were recorded between 15 and 40 meters depth. The surface area of invaded rocky bottom was often so large that it could not be surveyed in just one dive. *Womersleyella setacea* grows on almost all available substrates, both on rocky and sandy bottoms, as an epiphyte of other macroalgae or over *Posidonia oceanica* (L.) Delile rhizomes (Fig. 2). The only erect species noticeable in the invaded circalittoral communities are usually green algae *Halimeda tuna* (J. Ellis & Solander) J.V. Lamouroux and *Flabellia petiolata* (Turra) Nizamuddin (Fig. 2). Inclination of the invaded rocky substrate ranged from horizontal to completely vertical. PIAZZI *et al.* (2002a) also recorded *W. setacea* on a vertical cliff. The turf thickness measured in the Adriatic Sea was usually up to five centimeters, consisting of interlaced algal filaments and a very large quantity of deposited sediment. *Womersleyella setacea* enhances sedimentation rates which has a substantial influence on species

diversity of the algal community (AIROLDI *et al.*, 1995). Sediment deposition also implies reduced availability of firm substratum for settlement and recruitment of native algae. *Womersleyella setacea* is thought to inhibit recruitment of corallines and other algae (e.g. *Cystoseira* spp.) (BALLESTEROS *et al.*, 1998, 2009; BALLESTEROS, 2006). Further research is needed to investigate these impacts on Adriatic algal communities.

Uniform size and extent of turf formations were recorded at surveyed locations irrespective of the season of the year. As shown by AIROLDI *et al.* (1995) the mean percentage cover of *W. setacea* did not show seasonal variation and was never lower than 80%, although biomass and turf thickness changed in different seasons or following severe weather conditions or sediment movement. This pattern of continuous vegetative propagation throughout the year is not characteristic for native algae which always proliferate in their favoured vegetative seasons and stagnate in the others. Stability of populations through all seasons is perhaps the strongest invasive characteristic of this turf-forming species.

In the Adriatic Sea we found only sterile specimens without any reproductive structures. Tetrasporangia are the only reproductive structures noted so far for this species (HOLLENBERG, 1968). Despite the weekly and biweekly sampling of *W. setacea* during one year (AIROLDI *et al.*, 1995), frequent sampling in all seasons by RINDI & CINELLI (2000) and growing in culture in a variety of conditions (RINDI *et al.*, 1999) the authors did not find any reproductive structures. It is still uncertain that sporangial or sexual reproduction exists in the Mediterranean Sea and therefore it is assumed that the successful spread of this invasive alga is only due to vegetative propagation. However, the wide geographical range of its distribution (eastern and western Mediterranean) might suggest the existence of more successful spreading vectors such as sea currents. Specimens of Mediterranean *W. setacea* were grown in culture in order to measure their responses to environmental factors (RINDI *et al.*, 1999). Results proposed the existence of a Mediterranean thermal ecotype which is somewhat different from tropical populations. Cultured plants showed the upper thermal limit at 28°C and survived at a temperature as low as 5°C over a period of four weeks without showing any damage. Mean winter temperatures in the open waters of the Adriatic Sea range from 13 to 15°C in the southern, and from 6 to 13°C in the northern, Adriatic Sea (BULJAN & ZORE-ARMANDA, 1971). In the area of the northern Adriatic, IVEŠA & DEVESCOVI (2006) recorded that temperature ranged between 7.7 and 10°C for 35 days and for 110 days the sea temperature remained below 12°C. The existence of well developed *W. setacea* turfs in the cold northern Adriatic further supports the theory of the existence of a Mediterranean thermal ecotype.

The subtidal habitat of *W. setacea* Mediterranean populations, as opposed to its intertidal habitat in the tropics, is further confirmed in this research. *Womersleyella setacea* was never found in the shallows or in the intertidal zone. ROJAS-GONZÁLEZ & AFONSO-CARILLO (2000) report *W. setacea* from the Canary Islands growing in tidal pools and on anchor ropes and not exhibiting massive turf formations. Whether the Canarian population belongs to the supposed tropical ecotype and therefore is not invasive should be elucidated with comparative molecular methods.

The invasive character of *W. setacea* has been well documented. Its turfs significantly reduce diversity of the epiphytic community on *P. oceanica* rhizomes (PIAZZI & CINELLI, 2000; PIAZZI *et al.*, 2002b). PIAZZI & BALATA (2008) recorded lower values of diversity and significant differences in species composition and abundance in the invaded shallow and deep rocky bottom habitats and dead matte of *P. oceanica*. The loss of seasonality in the zoobenthic community was noted by ANTONIADOU & CHINTIROGLOU (2007). *Womersleyella setacea* changes the assemblage structure and reduces species richness in coralligenous communities, particularly decreasing the diversity and abundance of other turf algae (PIAZZI *et al.*, 2007). The negative effect of this invasive species on Adriatic benthic assemblages is suggested by the dominance of turfs (Fig. 2), but specific studies should be undertaken to evaluate these effects.

A comparison between the level of an eventual impact with data reported from other Mediterranean regions may represent an interesting topic for further investigations.

In a number of areas in the Adriatic Sea, *W. setacea* was recorded together with *Caulerpa racemosa* var. *cylindracea* (Sonder) Verlaque, Huisman and Boudouresque. *Caulerpa racemosa* is mostly spread from the surface to 30 meters, while the most extensive turfs of *W. setacea* were detected from 15 to 40 meters. This situation will probably become more common as both species seem to be spreading continuously over the past decade. Their synergic interactions and influence on the native communities have yet to be closely studied (for the latest studies see CECCHERELLI *et al.*, 2002; PIAZZI *et al.*, 2003; BULLERI & BENEDETTI-CECCHI, 2008). Recent studies show that the co-occurrence of invasive species *Caulerpa taxifolia* (Vahl) C. Agardh, *C. racemosa*, *W. setacea* and *Acrothamnion preisii* (Sonder) E.M. Wollaston does not limit their total cover and they can reach similar values independently of the dominant species (PIAZZI & CINELLI, 2003).

We can now assume that the entire coastline of the Adriatic Sea is severely affected by invasive alga *W. setacea* and that invaded surfaces probably greatly exceed the ones invaded by *Caulerpa racemosa* var. *cylindracea* (http://jadran.izor.hr/kaulerpa/). If the impact of *W. setacea* turfs on native benthic communities will prove to be destructive, this species could be assigned the status of the worst alien macrophyte in the Adriatic Sea.

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Received: 18 April 2010

Accepted: 28 June 2010

Rasprostranjenost invazivne crvene alge *Womersleyella setacea* (Hollenberg) R.E. Norris (Rhodophyta, Ceramiales) u Jadranskom moru

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SAŽETAK

Womersleyella setacea (Hollenberg) R.E. Norris (Rhodophyta, Ceramiales) je invazivna crvena alga, koja je u Sredozemnom moru prvi put zabilježena u Italiji 1986. godine. U ovom radu prikazana je geografska i dubinska rasprostranjenost ove invazivne vrste u Jadranskom moru od prvog nalaza na području sjevernog Jadrana 1997. godine. Uzorci zajednica alga su sakupljeni na različitim postajama u hrvatskom dijelu Jadranskog mora u razdoblju od 2005. do 2009. godine autonomnim ronjenjem i grabilom. Ukupno je zabilježeno 50 lokaliteta s vrstom *W. setacea*, 40 tijekom ovog istraživanja i 10 iz literaturnih podataka. *Womersleyella setacea* je pronađena na dubinama od 7 do 72 metra. Zabilježeni su samo sterilni primjerci bez prisutnih reproduktivnih struktura. U radu se raspravlja o razmjerima invazije.

Ključne riječi: *Womersleyella setacea*, rasprostranjenost, biološka invazija, Jadransko more