First Report on the Distribution and Impact of Marine Alien Species in Coastal Benthic Assemblages Along the Catalan Coast

María García, Boris Weitzmann, Susana Pinedo, Emma Cebrian, and Enric Ballesteros

Abstract The Mediterranean Sea is especially prone to the introduction of alien species due to an intense marine traffic, the connection with the Red Sea through the Suez Canal and intensive aquaculture. Catalonia, a region in the Northwestern Mediterranean, began an extensive study on the presence, distribution and impact of invasive macroalgae in 1992, which was extended to all macrobenthic alien species by 2007. Gathering all presence and abundance data of introduced species from the monitoring, we also calculated a Biopollution Level (BPL) index to assess the magnitude of the effects of introduced species on the marine biota at a local level (water body) as required by Marine Strategy Framework Directive (MSFD). Seventeen alien species have been identified although only three can be considered so far as threatening in non-modified environments: the green alga *Caulerpa cylindracea* and the red algae *Womersleyella setacea* and *Asparagopsis armata*. These species show an uneven distribution along the coast but sometimes coexist in the same water body. The impact of alien species on native communities was never severe as shown by the low values obtained using the BPL. The only species triggering a moderate to strong impact was *Caulerpa cylindracea* but it only affected a single water body. However, *C. cylindracea* exhibited a great temporal

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variability on its abundance, with sudden collapses of its populations, which also caused a great variability in the BPL. Future monitoring of the coasts of Catalonia is advised as there is an increase in the number of water bodies affected by alien species and an increase in their abundances from 2007 to 2012.

Keywords Alien species, BPL (biopollution level) index, Catalan coast, Invasive species, Littoral rocky shores, Mediterranean Sea, MSFD, Water bodies (WBs)

Contents

1 Introduction

Although much less studied than terrestrial ecosystems, marine habitats are known to hold a great number of alien (=introduced) species [1]. The spread of alien species is considered one of the main threats to biodiversity both in the terrestrial and in the marine realm [2–4]. Inventories of alien species are being published in reports and in the scientific literature as they are useful both for public administrations and for the scientific community. Of special interest are those alien species that behave as invasives, i.e. aliens that undergo a rapid spread and conquer novel areas within recipient ecosystems in which they become dominant [5] because they become major drivers of environmental change and they are the main targets to be monitored and controlled [6].

The Mediterranean Sea is heavily affected by the introduction of alien species [7–9], with almost 1,000 taxa reported in 2012 [10]. Inventories of alien species are only present for certain Mediterranean countries like Turkey [11], Israel [12], Cyprus [13], Italy [14], Greece [15–17] and Libya [18], although they are critical for managing marine ecosystems and providing data for the requirements of major objectives at the European Union level such as the Marine Strategy Framework Directive (MSFD) [19]. In fact, alien species are one of the eleven qualitative descriptors for the assessment of the environmental status of the water bodies according to the MSFD.

Moreover, the descriptor D2 for the assessment of the environmental status according to MSFD requirements states that introduced species have to be “at levels that do not adversely alter the ecosystems” to attain a Good Environmental

Status. This means that presence/absence data has to be available not only on alien species but also on the abundance and impacts of the alien species to the marine habitats. Mediterranean experts know which are the species that are potentially invasive [20–22] and in some cases they also know their spreading rate [16, 23–28]. Moreover, there is plenty of scientific literature dealing with the abundance and effects of invasive species on native Mediterranean assemblages [e.g. 29–43], but they only consider one (or two) species in one or a limited number of habitats. However, as far as we know, there has been no Mediterranean attempt to assess the number of alien species and their effects on the marine biota at a local level, i.e. the level of a water body, as required by MSFD.

Olenin et al. [44] described a methodology specifically focused on the assessment of the magnitude of alien species impacts on native community structure, habitat traits and ecosystem functioning. This methodology uses basic information on abundance and distribution of alien species within a water body (or some other geographical unit) to obtain a score from 0 to 4 at different levels of impact, fitting with the schemes for water quality assessment in the frame of the Water Framework Directive (WFD) [45]. This index was called Biopollution Level (BPL) since, according to Olenin et al. [44], the introduction of alien species is a factor of disturbance that can be viewed as a pollution agent.

The BPL has been first tested in well-studied areas within the Baltic Sea, both in open waters and coastal lagoons, considering also different periods in the same areas to look for changes in the index over time [44, 46]. However the BPL has not been used extensively in other areas although it is easy to apply and compliant with MSFD.

Catalonia is a region situated in the Northwestern Mediterranean with a coastline extending for more than 400 lineal km, whose water bodies are subjected to different pressures and impacts [47]. The regional government from Catalonia initiated in 1992 a monitoring programme to detect the arrival of *Caulerpa taxifolia*, an alien alga that became invasive in southern France [48, 49]. Surveys were carried out by SCUBA diving in 126 stations that were selected to cover the environments where *Caulerpa taxifolia* usually settles at the first stages of colonization. However, in 2006, the monitoring stations were modified in order to cover all kinds of environments, since the programme broadened its aims to make an early detection of other potentially invasive species that were spreading very fast in nearby Mediterranean areas (*Caulerpa cylindracea*, *Lophocladia lallemandii*, *Womersleyella setacea* and *Oculina patagonica*) [28, 37, 38, 40, 42, 50–55]. The methodology was also slightly improved to allow the calculation of BPL because this index was in line with other biotic indexes used in Catalonia for the implementation of the WFD.

The objectives of this work are twofold: (1) to provide a checklist of the main alien species in the coastal waters of Catalonia at the end of 2014, with references to their extension ranges and relative abundances, if available, and (2) to calculate the BPL index at each coastal water body of Catalonia as an indicator of the additive impacts of invasive species during the period 2007–2012.

2 Material and Methods

2.1 Field Procedures

The study area covers the coastal waters of Catalonia (Northwestern Mediterranean) from Punta de l’Ocell (42° 51′ 45,97″N) to Platja de Sòl de Riu (40° 31′ 27,56″N). These coastal waters have been divided into 34 sectors or water bodies according to their geomorphological features, water basins and anthropogenic pressures, as required by the WFD (Fig. 1). The monitoring was exclusively focused on rocky bottoms and was initiated in 1992. The number of sampled stations has been increasing until 2007, when a total of 188 locations were monitored in a 2-year basis, with the sampling dates concentrated between May and October, the period of the year when the sea conditions are more suitable for diving operations.

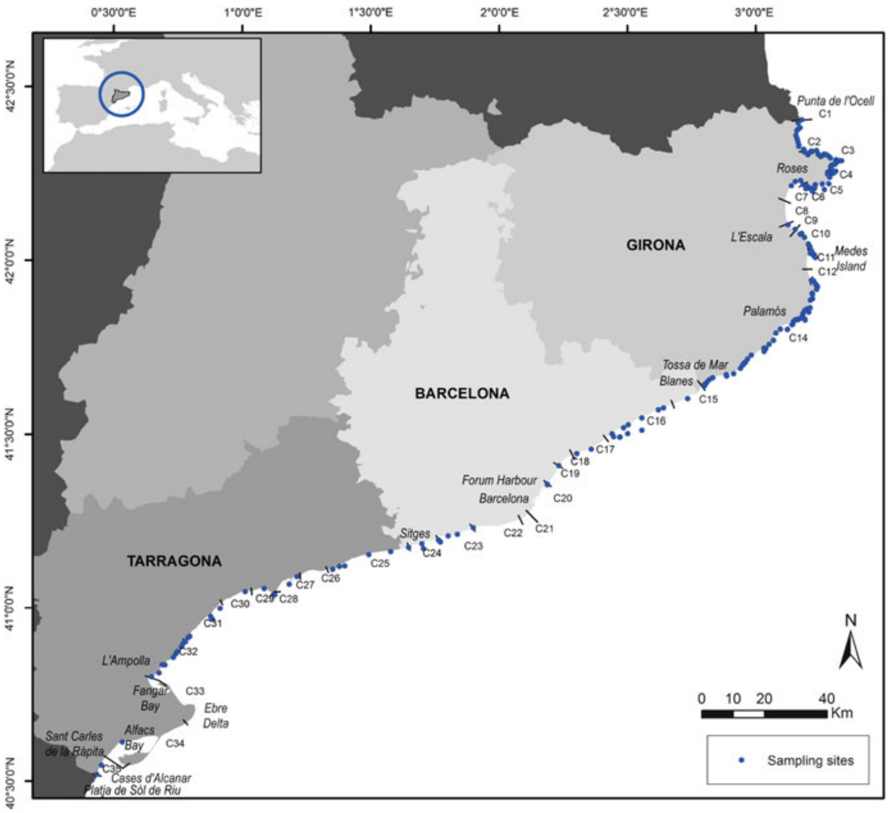

Fig. 1 Coastline of Catalonia with indication of the three provinces, the different water bodies and the sampling stations

Sampling locations were selected to include the geographical range of Catalonia and the environmental diversity of its seabeds, covering all kinds of rocky bottoms and ranges of wave exposure, water quality, depth and orientation. However, water bodies C08, C19, C21, C26 and C34 were not surveyed since they were completely devoid of rocky bottoms. Transects of different lengths according to the bathymetric profile of each station were surveyed by two divers. Surveys covered a width of 10 m (5 m at each side of the transect line) of seabed and crossed different habitats. Main habitats were characterized by native species abundances using a semi-quantitative index widely used in phytosociology (Braun-Blanquet index) [56–58]. Every habitat was checked for over 10 min to make the list of the native species but also to record the abundances of the alien species using the same semi-quantitative index. Moreover, accurate data on alien species' distribution along the bathymetric range, physical appearance, degree of epiphytism and other relevant aspects were recorded. Qualitative samples of unidentified or doubtful species were collected for accurate identification in the laboratory.

There are two alien species that have been detected only outside the monitoring stations. We report these species but we do not provide any indication of its progression.

2.2 Data Analyses

The BPL index [44] was calculated for each water body taking into account the data collected at all the stations situated inside each water body. The assessment was obtained for every 2 years (2007–2008, 2009–2010 and 2011–2012) and was performed using the criteria stated in the BPL calculation. The presence (presence/absence), distribution range (one, several, many, all localities) and abundance (low, moderate, high) of each alien species were analysed at each water body, and all the species were considered to evaluate the impacts. The BPL at each water body was set according to the greatest impact level of alien species found in the water body [44]. BPL ranges from 0 to 4, with five categories indicating no biopollution (BPL = 0) or different levels of biopollution: weak (BPL = 1), moderate (BPL = 2), strong (BPL = 3) and massive (BPL = 4) [44].

3 Results

3.1 Alien Species

A total of 17 alien species, including two green algae, one brown alga, three red algae, one sponge, two cnidarians, two molluscs, one crustacean, four tunicates and one fish, have been recorded in the Catalan coast during this study (1992–2012). Their first record and their invasive potential are summarized in Table 1. Species

Table 1 Main introduced species reported from 1992 to 2012, with indications on the year of first record and their invasive behaviour in Catalonia during the period 2007–2012. Further explanations on invasive behaviours included in the main text

Species	Group	Year	Reference	Invasiveness
Caulerpa cylindracea	Chlorophyta	2008	Ballesteros et al. [51]	Invasive
Codium fragile	Chlorophyta	1981	Ballesteros [59]	Opportunistic
Acrothamnion preissii	Rhodophyta	2006	Ballesteros et al. [60]	Non-invasive
Asparagopsis armata	Rhodophyta	1955	Thomas [61]	Invasive
Womersleyella setacea	Rhodophyta	2006	Ballesteros et al. [60]	Invasive
Dictyota cyanoloma	Ochrophyta	2004	Rull et al. [62]	Non-invasive
Paraleucilla magna	Porifera	2006	Frotscher and Uriz [63]	Non-invasive
Pennaria disticha	Cnidaria	1986	Gili [64]	Non-invasive
Oculina patagonica	Cnidaria	1992	Ballesteros et al. [65]	Opportunistic
Percnon gibbesi	Crustacea	2003	Abelló et al. [66]	Non-invasive
Crassostrea gigas	Mollusca	2010	Ballesteros et al. [67]	Non-invasive
Bursatella leachii	Mollusca	2007	Weitzmann et al. [68]	Non-invasive
Polyandrocarpa zorritensis	Tunicata	1987	Turon and Perera [69]	Opportunistic
Ciona intestinalis	Tunicata	1916	Maluquer [70]	Non-invasive
Microcosmus squamiger	Tunicata	1978	Turon [71]	Opportunistic
Styela plicata	Tunicata	1905	Harant [72]	Non-invasive
Fistularia commersonii	Vertebrata	2007	Pontes (unpublished)	Non-invasive

have been designated as "invasives" if they show an invasive behaviour in natural environments, as "opportunistic invasives" if they behave as invasives only on artificial substrates and anthropogenic environments or as non-invasives if they do not behave as invasives at all. Comments on the impacts and distribution of each species are reported below.

Codium fragile (Suringar) Hariot is common across Catalonia, where it mostly grows on sheltered shallow rocky environments like the entrance of the harbours and some coves with an enhanced nutrient input. It was first reported in Tossa de Mar [as ssp. *tomentosoides* (van Goor) P. C. Silva; [59]]. It was probably present before 1981 since it has been largely misidentified with *Codium tomentosum*, a species that was widely reported before (see Ballesteros and Romero, 1982 [73]). *Codium fragile* can make dense populations in reduced areas, where it covers big patches of the sea bottom but this behaviour is not widespread.

Caulerpa cylindracea Sonder was first reported in 2008 growing between 20 and 50 m in lower infralittoral to circalittoral bottoms from the central coast [51], where it was first detected by artisanal fishermen (Andreu Núñez, personal communication). It invades both rocky and sedimentary bottoms and it even grows over dead *Posidonia oceanica* rhizomes. The species quickly spread and increased its density making dense carpets around 20 m depth offshore Sitges. However, the population collapsed in February 2012 for unknown reasons and recolonized the bottom again after August 2012 (author's unpublished data). At present (September 2014), the species has spread to 5 m depth (Eduard Llorente, personal communication) and has been found at other distant localities (Blanes, 2013; Aurora Martínez-Ricart and Bernat Hereu, personal communication).

The presence of *Acrothamnion preissii* (Sonder) E. M. Wollaston is anecdotal since only two small thalli have been reported in 2010 (Palamós, Conxi Rodriguez-Prieto, personal communication; l'Escala, Marc Terradas, personal communication). It has never been recorded again.

Both the gametophyte and the tetrasporophyte [*Falkenbergia rufolanosa* (Harvey) F. Schmitz] of *Asparagopsis armata* Harvey were already reported by Thomas (1955) [61]. The distribution of the gametophyte seems to be restricted from the northern coast southward till Blanes, always on moderately exposed shallow waters. It attains large coverages from late winter to early spring (March to May) on rocky bottoms north of Medes Islands [74]. The tetrasporophyte is present everywhere but never abundant. The gametophyte, however, shows an invasive behaviour only in spring and in the northernmost part of the Catalan coast.

Womersleyella setacea (Hollenberg) R. E. Norris was first found in 2006 from at Palamós [60] and has expanded northwards and southwards. Its distribution is always restricted to the northern part of Catalonia, where it thrives on coralligenous outcrops. It shows an invasive behaviour everywhere.

Dictyota cyanoloma Tronholm, De Clerck, Gómez Garreta and Rull Lluch was first collected in 2004 and misidentified with *D. ciliolata* [62] before it was described as a new species [75]. It has been found all along the coast and prefers shallow, slightly polluted waters, growing on rocky bottoms and artificial substrates, mainly in small harbours and nearby areas.

The calcareous sponge *Paraleucilla magna* Klautau, Monteiro and Borojevic, 2004, was first reported in 2006 [63] and is currently found all along the coast on shallow water rocky bottoms. It usually grows as an epiphyte of different seaweeds.

Pennaria disticha Goldfuss, 1820, was first reported as *Halocordyle disticha* at Tossa and Sant Carles de la Ràpita [64] and remained unnoticed until the year 2011, when it appeared again in several areas of the central and southern coasts. It colonizes shallow water environments, always on rocky bottoms in moderately exposed conditions.

A single colony of the zooxanthellate coral *Oculina patagonica* de Angelis, 1908, was found in the breakwater of the southernmost harbour in Catalonia (Cases d'Alcanar) in 1992 [65]. Its distribution has expanded northwards since then [28] and at present is common in the southern and central coasts. Some scattered colonies have been also detected in the northern coast. It grows on shallow rocky bottoms and has a special preference for breakwaters and other artificial habitats.

The crab *Percnon gibbesi* was first reported in the coast of Barcelona [66]. It has been found intermittently in our surveys, always in low abundances, on shallow rocky bottoms and artificial substrates.

The Japanese oyster, *Crassostrea gigas*, has been cultured for a long time in the bays of the Ebre Delta, southern Catalonia. We have reported it growing attached to rocks on the breakwaters of the harbours of l'Ampolla and Cases d'Alcanar, situated at the entrances of Ebre Delta bays [67]. *Crassostrea gigas* seems to be restricted to closed bays and lagoonal environments, not expanding abroad.

The sea slug *Bursatella leachii* (de Blainville, 1817) was detected in Alfacs Bay (Ebre Delta) in 2007 growing on muddy bottoms with *Caulerpa prolifera* at 2 m depth [68]. Besides this station, *Bursatella leachii* has been found intermittently at the Fòrum harbour, close to Barcelona.

One colony of the sea squirt *Polyandrocarpa zorritensis* (Van Name, 1931) was first reported in Fangar Bay in 1986 [69]. It is now common in Alfacs Bay where it grows abundantly on artificial substrates and upper infralittoral rocky bottoms.

Ciona intestinalis is a solitary sea squirt that has been found exclusively in harbours and closed bays, where it grows mainly on artificial substrates. It is common in Ebre Delta bays [71].

Microcosmus squamiger Michaelsen, 1927, is a solitary sea squirt present all along the coast, always growing on rocky and artificial substrates from harbours, marinas and enclosed bays. It can colonize all available substrate in harbours where it behaves as invasive but always restricted to these environments. First reported by Turon (1987) [71] from several localities as *Microcosmus exasperatus*, a closely related lessepsian migrant with which it has been usually misidentified [76, 77].

Styela plicata (Lesueur, 1823) is a solitary sea squirt found all along the coast in enclosed bays (Alfacs, Fangar), harbours and nearby areas, growing particularly on artificial substrates. Already reported from Catalonia by Harant (1927) [72].

Fistularia commersonii Rüppell, 1838, is the first lessepsian fish that has established an enduring population in Catalonia. It was first detected in Palamós in 2007 (Miguel Ponte, personal communication) and its sight by SCUBA and free divers is becoming not exceptional.

3.2 BPL Application

Here we present the results of the application of BPL index along the coast of Catalonia during the periods 2007–2008, 2009–2010 and 2011–2012. Some water bodies have not been evaluated since they have not been surveyed (Table 2).

During the period 2007–2008 (Fig. 2, Table 2), eight alien species were recorded (*A. armata*, *B. leachii*, *C. cylindracea*, *C. fragile*, *D. cyanoloma*, *O. patagonica*, *P. gibbesi* and *W. setacea*) but only *W. setacea* and *C. cylindracea* showed an invasive behaviour in natural environments during our surveys. *Womersleyella setacea* partially covered coralligenous assemblages on the water body C14 but with a weak impact. *Caulerpa cylindracea* colonized coastal detritic bottoms in water body C24 but without causing major impacts. *Oculina patagonica* also displayed weak impacts on artificial substrates of water bodies C27, C32, C33 and C35.

During the period 2009–2010 (Fig. 3, Table 2), thirteen alien species were recorded (*A. preissii*, *A. armata*, *B. leachii*, *C. cylindracea*, *C. fragile*, *C. gigas*, *D. cyanoloma*, *M. squamiger*, *O. patagonica*, *P. magna*, *P. gibbesi*, *S. plicata* and

Table 2 Presence (+) of the main introduced species (A.a., *Asparagopsis armata*; A.p., *Acrothamnion preissii*; B.l., *Bursatella leachii*; C.c., *Caulerpa cylindracea*; C.f., *Codium fragile*; C.g., *Crassostrea gigas*; D.c., *Dictyota cyanoloma*; M.s., *Microcosmus squamiger*; O.p., *Oculina patagonica*; P.m.; *Paraleucilla magna*, P.d., *Pennaria disticha*; P.g., *Percnon gibbesi*; P.z., *Polyandrocarpa zorritensis*; S.p., *Styela plicata*; W.s., *Womersleyella setacea*) recorded during the three studied periods (1, 2007–2008; 2, 2009–2010; 3, 2011–2012) in each water body. Water bodies shaded in grey have never been evaluated

	WB	A.a.*			A.p.			B.l.			C.c.			C.f.		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
GIRONA	C01			+										+	+	+
	C02													+	+	+
	C03													+	+	+
	C04													+	+	+
	C05	+														
	C06	+												+	+	+
	C07			+										+	+	+
	C08															
	C09			+										+	+	+
	C10	+	+	+		+								+	+	+
	C11		+	+										+	+	+
	C12													+	+	+
	C14	+	+	+		+								+	+	+
BARCELONA	C15															
	C16													+	+	+
	C17															
	C18															
	C19															
	C20									+						
	C21															
	C22															
	C23													+	+	+
	C24										+	+	+	+	+	+
TARRAGONA	C25													+	+	+
	C26															
	C27													+	+	+
	C28															
	C29															
	C30															
	C31													+	+	+
	C32													+	+	+
	C33													+	+	+
	C34															
	C35							+	+					+	+	+

	WB	C.g.			D.c.			M.s.			O.p.			P.m.		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
GIRONA	C01				+		+									
	C02															
	C03															
	C04															
	C05															
	C06															
	C07									+			+		+	+
	C08															
	C09											+				+
	C10														+	+
	C11															
	C12														+	+
	C14				+						+	+	+		+	+
BARCELONA	C15				+	+	+						+			+
	C16				+	+	+				+	+	+		+	+
	C17															
	C18										+	+	+			
	C19															
	C20				+	+	+									+
	C21															
	C22								+	+		+	+			
	C23				+	+	+								+	+
	C24				+	+			+	+					+	
TARRAGONA	C25											+	+		+	+
	C26															
	C27										+	+	+			
	C28				+	+	+			+	+	+	+		+	+
	C29										+	+	+			+
	C30								+	+	+	+	+			
	C31										+	+	+			+
	C32										+	+	+			+
	C33		+	+					+	+	+	+	+			
	C34															
	C35		+	+					+	+	+	+	+		+	+

	WB	P.d.			P.g.			P.z.			S.p.			W.s.		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
GIRONA	C01															
	C02															
	C03													+	+	+
	C04															
	C05														+	
	C06															+
	C07															
	C08															
	C09															
	C10															+
	C11											+	+			
	C12															
	C14													+	+	+
BARCELONA	C15															
	C16			+												
	C17															
	C18											+	+			
	C19															
	C20															
	C21															
	C22			+									+			
	C23			+												
	C24															
TARRAGONA	C25															
	C26															
	C27			+												
	C28				+											
	C29												+			
	C30			+												
	C31															
	C32			+												
	C33				+											
	C34															
	C35									+		+	+			

*Records of the gametophyte only

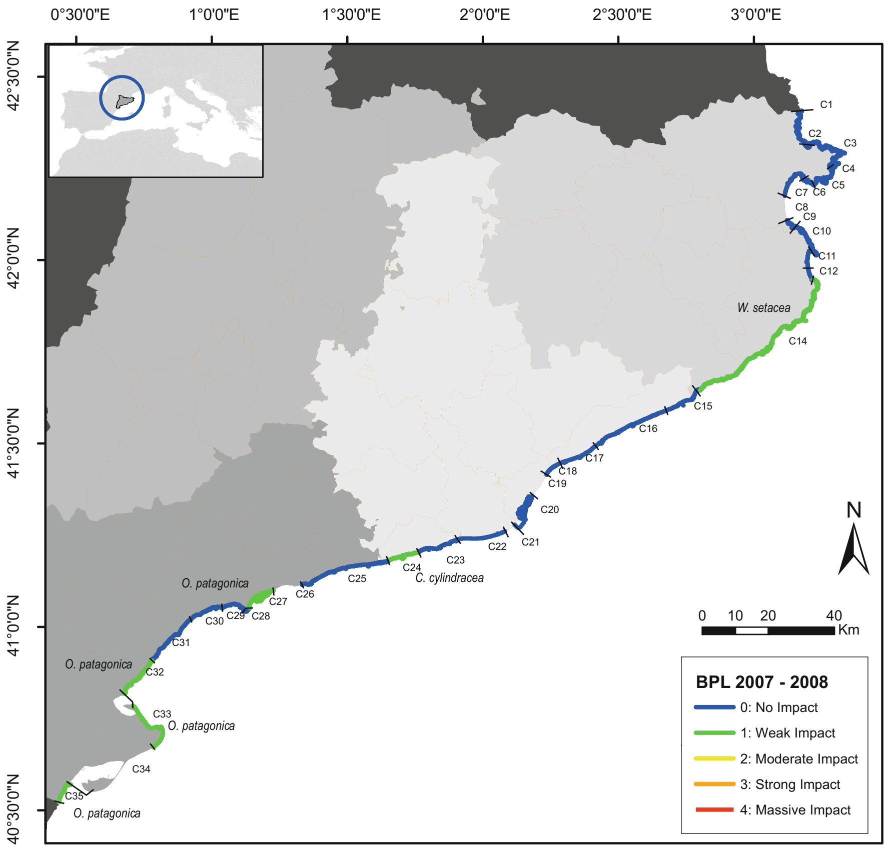

Fig. 2 BPL index for the different water bodies during the period 2007–2008

W. setacea). BPL values ranged between no impact and moderate impact. A moderate impact was produced by *C. cylindracea* in water body C24 since *C. cylindracea* covered large areas of detritical coastal bottoms with densities around 4,500 fronds m^{-2} during fall. *W. setacea* also became more abundant at infected locations and increased its distribution depth; it also colonized some nearby areas in water body C14 and spread to some distant locations (water body C03) but always showed a weak impact on colonized environments. *O. patagonica* generated a weak impact on artificial substrates of water bodies C27, C31, C32, C33 and C35.

Fourteen alien species were recorded during the period 2011–2012 (Fig. 4, Table 2) (*A. armata*, *B. leachii*, *C. cylindracea*, *C. fragile*, *C. gigas*, *D. cyanoloma*, *M. squamiger*, *O. patagonica*, *P. magna*, *P. disticha*, *P. gibbesi*, *P. zorritensis*, *S. plicata* and *W. setacea*), but only *C. cylindracea* and *W. setacea* showed invasive

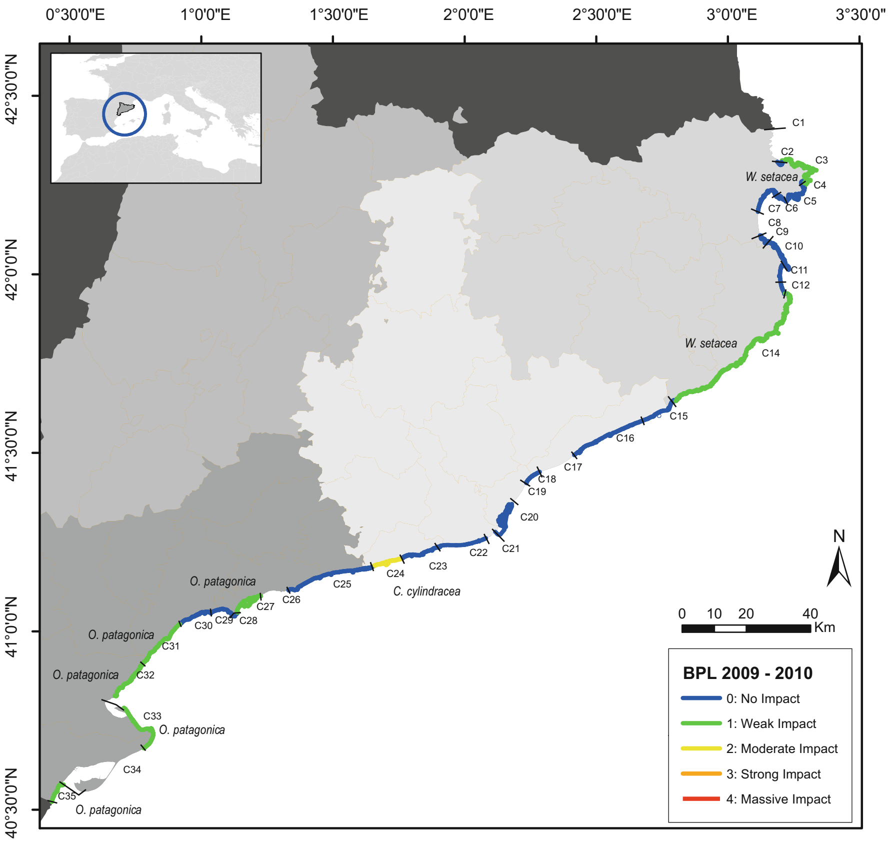

Fig. 3 BPL index for the different water bodies during the period 2009–2010

behaviour on natural environments during the surveying period. *Caulerpa cylindracea* attained frond densities up to 10,000 fronds m^{-2} in the water body C24 during 2011 and displayed a strong impact before totally collapsing in late winter 2012. *Womersleyella setacea* expanded its distribution range to water body C06 but was always showing a weak impact on coralligenous outcrops. *Microcosmus squamiger* constituted monospecific beds in the harbours of Roses (water body C07) and Sitges (water body C22) but its distribution was restricted to the breakwaters and thus having a weak impact at the level of the water body. *Oculina patagonica* expanded its distribution to four new water bodies (C27, C28, C29, C30) but its impact was always weak and restricted to artificial substrates. The sponge *Paraleucilla magna* was detected in 15 water bodies but never showed an invasive behaviour.

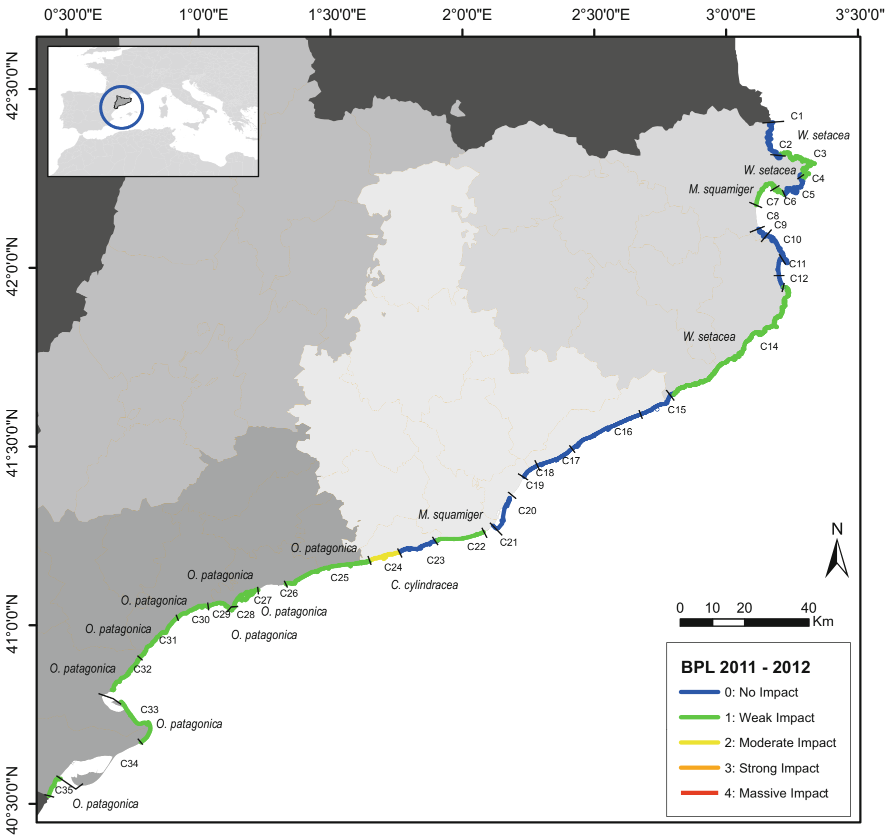

Fig. 4 BPL index for the different water bodies during the period 2011–2012

4 Discussion

Even we have not intensively surveyed areas with high propagule supply in the coasts of Catalonia, the number of detected alien species is still rather low when compared to other Mediterranean areas. The high geographical distance between Catalonia and the Suez Canal, by far the main vector of species introduction in the Mediterranean Sea [7], may explain, at least in large part, the big difference in the number of alien species between Catalonia and Eastern Mediterranean countries [11–13, 16, 17]. The relatively low temperature of the coastal waters of Catalonia [78, 79] should act also as a protection against the colonization of warm-water lessepsian immigrants, as suggested by the data provided by Galil [7] and Zenetos et al. [10]. On the other hand there is a striking difference in the number of alien species present in the neighbouring French Mediterranean coast, where the total number of aliens is enhanced by the large amount of exotic macroalgae arrived by oyster aquaculture [80, 81]. Shellfish farming is also important in the bays of the

Ebre Delta [82], but they are not colonized by the exotic macroalgae that are so common in French Mediterranean lagoons. Globally, the situation in the coasts of Catalonia is much more similar to that found in western Sardinia or the Ligurian Sea coast, where 13 and 38 alien species have been reported, respectively [14]. Comparisons within other Spanish regions are not available since there is no published literature on this issue.

All the alien species reported here were already known from other Mediterranean areas. The species with the lowest number of reports were *Polyandrocarpa zorritensis*, which had been found in two Italian harbours [83], and *Dictyota cyanoloma*, a species that is suspected to be an introduction but that the region of origin is still unknown. Other Mediterranean localities for *D. cyanoloma* outside Catalonia are Izmir (Turkey) [84] and Split (Zuljevic, personal communication).

Tunicates are the taxonomic group holding the highest number of alien species. However, the species reported here are always confined to artificial substrates in highly modified environments, such as harbours, marinas and aquaculture facilities, or to estuaries and bays, as it is usually the case for invasive tunicates [85, 86]. They do not seem to be of great concern outside these environments, although they can generate economic problems in shellfish farms and in harbours as fouling organisms. Breakwaters and aquaculture facilities in the Ebre Delta bays host great numbers of *Crassostrea gigas*. *Bursatella leachii* is exclusively found in enclosed bays and highly modified environments. *Oculina patagonica* also prefers man-made structures such as breakwaters [28, 87, 88] although in the long term may become also abundant in natural environments [40].

Preference for natural environments is evident for the three seaweeds that show an invasive behaviour in Catalonia: *Womersleyella setacea*, *Caulerpa cylindracea* and *Asparagopsis armata*. *Womersleyella setacea* thrives in well-developed coralligenous bottoms [89–93] and also on macroalgal beds and seagrass meadows [93–97]. It has deleterious effects on the suspension feeders living in coralligenous assemblages [53, 98] and on the crustose calcareous macroalgae that build up the outcrops [92].

Caulerpa cylindracea probably is the most aggressive invasive macrophyte in the Mediterranean as it has spread very fast both at a regional level and at the local level across different depths and because its colonization changes the species composition and the structure of the assemblages [25, 26, 34, 54, 99–102]. Consumption of *C. cylindracea* reduces the performances of the herbivores [103–106] but, in any case, herbivory does not affect the ability of *C. cylindracea* to invade [107, 108]. Moreover, *C. cylindracea* is known to show large temporal, not necessarily seasonal, changes in its abundance [37, 109], which explains the sudden collapse and subsequent recovery of *C. cylindracea* in the water body C24.

Asparagopsis armata, a species whose gametophytic stage invades shallow rocky environments in northern Catalonia [75], has not been considered in the calculation of the BPL index because its abundance strongly decays in spring and it has never been found abundant during the surveys. However, even if its abundance only blooms during a short period of time, we agree with Boudouresque and Verlaque [20] in considering it invasive. Further studies have to be performed to account for the real impact of *A. armata* in shallow water assemblages from northern Catalonia.

In our opinion, both *C. cylindracea* and *W. setacea* are the two invasive species that will be most probably threaten the species composition and functioning of benthic assemblages in Catalonia in the long term and at a wide extent. Aside from these two species, *Lophocladia lallemandii* is another candidate to threaten Catalonia's benthic marine assemblages in the near future. It has already been reported to be invading the rocky reefs in the Columbretes Islands [54, 55], an archipelago that is only 35 nautical miles southeast from the southernmost sector of the Catalan coast. *Lophocladia lallemandii* shows a highly invasive behaviour [20, 38, 52, 110–113] with severe affectations on several key Mediterranean ecosystems and species [32, 52, 114, 115].

The application of the BPL index to benthic Mediterranean assemblages has been performed easily. Each station was surveyed by a team of two divers and all the information required by the index could be obtained in a single dive lasting up to 1 h. The assessment of overall water body information obviously depends on the number of dives required to have a good representation and a proper station replication. However, in any case, the time needed is not longer than the time used for other assessments of environmental quality that require SCUBA diving [e.g. 116–121].

There is a clear increase on the alien species impact on shallow benthic assemblages in Catalonia during the last 6 years, with higher number of alien species present and higher coverages for some species. This implies a worsening on the BPL index, with 15 of the 29 water bodies surveyed having a weak impact by alien species and one water body having a moderate impact during the period 2011–2012, versus only six water bodies with a weak impact during the period 2007–2008. The spread of *W. setacea* is driving this worsening in northern shores, while the spread and increasing abundances of *C. cylindracea* and to a lesser extent *O. patagonica* are driving the deterioration in southern shores.

It is hard to compare these BPL values and the deterioration trend with other Mediterranean regions as this is the first time that the BPL has been applied in the Mediterranean. However, available data on the literature related to the current abundances of invasive species and its spread suggests that Catalonia has a lower affectation compared with other countries. We have already pointed out the extended colonization by alien macroalgae in bays and lagoons from the Gulf of Lions (France) [82] and the high level of colonization by *C. cylindracea*, *L. lallemandii* and *W. setacea* in the Balearic Islands [37, 38, 52, 91], which would probably give BPL values ranging from moderate to strong impact in most water bodies of these areas. The spread of *C. cylindracea* [122, 123] and *O. patagonica* [28, 89] in Spanish regions south of Catalonia also suggests weak to moderate values of BPL in these areas. And for sure the situation deteriorates when we move towards the Southeastern Mediterranean where the impacts of invasive species completely transform the whole ecosystem structure and dynamics [e.g. 39, 43, 124–128].

The conjunction of a relatively low water temperature that hinders the settlement and growth of warm-water aliens, the long distance to the Suez Canal and the existence of natural barriers between the lagoons from southern France and those from Ebre Delta bays seem to account for the present generalized weak impact of invasive species in most of the coastal water bodies from Catalonia. However, predicted sea warming following the current scenarios of temperature increase in the Mediterranean region [129], the expected expansion of the Suez Canal [130] and the current spread rates of species such as *C. cylindracea*, *W. setacea*, *O. patagonica* and *L. lallemandii* reported here do not provide any hope for this situation to be maintained or improved, neither in the short or in the long term. Thus, future monitoring for marine species introductions and invasions in the Catalan coast is strongly advised.

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