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ORIGINAL ARTICLE

Tracking macroalgae introductions in North Atlantic oceanic islands

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Abstract The Azores archipelago was selected as a case study since there are few studies on macroalgae introduction in oceanic islands. While at a global scale, around 3 % of macroalgae are considered non-indigenous; in the remote oceanic islands of the Azores, over 6 % of the marine algal flora is non-indigenous. The taxa distribution pattern of non-indigenous species in the Azores is significantly different from the distribution pattern in the globe. The most representative group was Rhodophyta species, being 84 % of the total non-indigenous macroalgae, mainly introduced via maritime traffic. This study highlights the vulnerability of remote islands to the introduction of macroalgae and the need to develop further studies on other archipelagos to understand whether the observed vulnerability is generally characteristic of oceanic islands. The development of local monitoring and mitigation programs and the necessity of regulatory and preventive measures for the maritime traffic vector are strongly suggested.

Keywords Macroalgae · Maritime traffic · Non-indigenous species · Remote islands · Taxonomic pattern

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Introduction

Macroalgae introductions have been extensively reviewed in the last three decades, especially in the Mediterranean Sea (e.g., Verlaque 1994; Verlaque 2001; Boudouresque and Verlaque 2002; Ribera-Siguan 2002; Klein et al. 2005; Tsiamis et al. 2008; Galil 2009). Although a broad European geographical area was covered by Wallentinus (2002), other studies focus on specific geographical regions in the Atlantic Ocean such as the UK (e.g., Farnham 1980; Minchin 2007), Denmark (e.g., Thomsen et al. 2007), Canada (e.g., Chapman et al. 2002) and Florida (e.g., Jacoby et al. 2004). Specific studies in the Pacific Ocean include California (e.g., Jousson et al. 2000), Mexico (e.g., Miller et al. 2011), Chile (e.g., Castilla et al. 2005), New Zealand (Nelson 1999) and Australia (e.g., Pollard and Hutchings 1990; Lewis 1999; Hewitt et al. 2004). Ruiz et al. (2000) investigated non-indigenous marine invertebrates and algae of the Pacific and Atlantic North America, evaluating some of the emergent patterns and underlying mechanisms of marine invasion. Recently, a global review on macroalgae introductions was reported by Williams and Smith (2007). Nevertheless, to the authors' knowledge, Smith et al. (2002) was the only study specifically targeting non-indigenous macroalgae on oceanic islands, focusing on the five most successful non-indigenous algae in Hawaii.

The uniqueness of oceanic islands with marine introductions is related to the degree of isolation of their shallow-water marine ecosystems, i.e., they are distant from colonization sources. In general, marine ecosystems on oceanic islands are characterized by: (1) small numbers of native species, with a reduced level of competition and few predator species; (2) a small population that is subject to demographic isolation; and (3) limited resources, such as food and space. As a result, oceanic islands are generally poor in species, exhibit simpler trophic webs and have a lower functional diversity than similar mainland ecosystems (Vitousek 1990). The biotic resistance of marine oceanic islands to introduced invaders is therefore limited, and the availability of empty niches is high (Pearson 2009).

Although marine invasions have occurred through time, such as punctuated events in geological time (e.g., changes in climate and dispersal barriers or catastrophic occurrences, see Ruiz and Hewitt 2008), at present a high percentage of biological invasions have a human-mediated origin (Wonham and Carlton 2005). Often, even in cases where invasion was considered to be a natural event, it was subsequently assessed that the expansion was probably due to changes in habitat structuring caused by human intervention (McCulloch and Stewart 1998).

The Azores archipelago is located between latitudes 36°55′ and 39°43′ North and longitudes 24°46′ and 31°16′ West, at the northern edge of the North Atlantic subtropical gyre—the rotor of the North Atlantic circulation (Bashmachnikov et al. 2004). This North Atlantic archipelago comprises nine strongly isolated islands of recent volcanic origin (ages range between 0.3 and 8 million years), which spread over more than 600 km along a northwest–southeast axis (França et al. 2003). The Azores are set apart about 800 km from the archipelago Madeira, 1,500 km from the west coast of Europe and 1,900 km from the east coast of America, across the Mid-Atlantic Ridge (Coutinho et al. 2009). Sea surface temperatures have an annual range between 14 and 23 °C. Tidal amplitudes range from 0.1 to 1.1 m, mediated by the proximity of these islands to the North Atlantic amphidromic point and the absence of complicating continental margins (Ramos et al. 2012). The biogeographically mixed origin of the algal flora characteristic of the Azorean shores (Neto 1997) and the geographical position of the archipelago produce an algal flora on the Azores, which is important for natural heritage and that needs to be preserved.

The aim of this study is to contribute to a better understanding of the vulnerability of oceanic islands to macroalgae introductions through the identification of non-indigenous species (NIS) of macroalgae on the Azores archipelago and assessment of their invasive potential. The taxonomic distribution pattern of NIS on the Azores was contrasted with the known global distribution pattern of algae, in order to reveal possible differences between oceanic islands and continental coasts. Vectors of introduction, invasion status, establishment success and the functional group of NIS of macroalgae were discriminated as a strategy to develop robust management plans. Azores islands were chosen for this case study because of the ecological importance of this archipelago, representing an important geographical link between the NE Atlantic and NW Atlantic coasts (Morton et al. 1998). To the authors' knowledge, the vulnerability of oceanic islands to macroalgae introductions has not yet been addressed in the context of marine introductions.

Methods

The list of algal species of the Azores by Parente (2010) was used as the basis for this work, updated with additional species from recent publications (such as: Rosas-Alquicira et al. 2011; Wallenstein et al. 2010; Wallenstein 2011; León-Cisneros et al. 2012). Records of non-indigenous and cryptogenic species of the Azores were compiled from a wide variety of sources, mainly from literature searches through scientific papers and reports, including recent field and taxonomic studies, and supplemented with existing databases. Information on global algae distribution was taken from works such as Wallentinus (2002) and Nyberg and Wallentinus (2005), for European marine algae, and Goulletquer et al. (2002), for Atlantic marine algae. A chi-squared goodness-of-fit test ($\chi 2$) was used to assess if the known global taxonomic distribution pattern of macroalgal NIS was similar to the Azores macroalgal NIS taxonomic pattern (based on the number of species per taxonomic group).

Subsequently, we discriminated species based on a set of different variables considered important to assess the invasive potential of a species. They were the following: (a) origin; (b) vector of transportation and possible route of entry to the Azores; (c) population status; (d) relative density; (e) functional density; (f) invasive potential. These parameters are further described below.

Origin (native, non-indigenous and cryptogenic species status)

In this study, the International Union for Conservation of Nature (IUCN 2000), definition of "native" (indigenous) was adopted, i.e., a species, subspecies or lower taxon occurring within its natural range and dispersal potential.

In contrast, a "non-indigenous" species was defined as a species that has been intentionally or unintentionally introduced beyond its native range through human activities (Rosenthal 1980; Carlton 1985; Williamson and Fitter 1996; Eno et al. 1997; Williams and Smith 2007). In this study, a species that lacks geographical contiguity with its native range and/or is associated with introduction vectors or pathways (e.g., occurring in ship fouling or ballast water) is considered as "non-indigenous species" (Supplemental Table 1). The classification as a "non-indigenous species" was confirmed through reference to the literature.

Table 1 The different variables considered important to assess the invasive potential of a species and respective categories

Variables	Categories					
Native origin (5)	NE Atlantic		W Atlantic	Indian Ocean	Indo-Pacific	Pacific
Vector (3)	Unknown			Maritime traffic[a]	Fouling (within maritime traffic)[b]	
Status (3)	Not established			Undetermined	Established	
Relative density (6)	Rare	Occasional	Frequent	Abundant	Dominant	Unknown
Functional group (5)	Filamentous	Corticated	Siphonous	Foliose	Corticated foliose	Articulated calcareous
Invasive potential (3)	Not invasive			Unknown	Invasive	

In parentheses is the number of categories considered for each variable

[a] Maritime traffic includes ballast water, hull fouling, sediments in ballast tanks, sediments attached to anchors/chains, commercial fishing nets and gear

[b] Fouling is considered as a subcategory of maritime traffic

Cryptogenic species, i.e., species for which the origin remains unknown, with no definite evidence of their native or introduced status according to Carlton (1996), although reported in the present work, are tabulated separately (Supplemental Table 2) and were excluded from the analyses. The status of some of these species as cryptogenic may change as knowledge of their dispersal mechanisms increases, or when studies with genetic markers allow the origin to be inferred.

To assess patterns of the native ranges of introduced species, five broad geographical regions were defined based on oceanic regions. These are NE Atlantic, W Atlantic, Indian Ocean, Indo-Pacific and Pacific Ocean (see Table 1).

Transportation vectors

There are numerous ways in which human activity results in the introduction of non-indigenous marine species. Although it is not always possible to determine the vector of introduction, the dominant vectors of non-indigenous marine species are maritime traffic and aquaculture (Rilov and Crooks 2009). There is little aquaculture in the Azores. To date, only one bivalve species (*Venerupis decussata*) has been introduced for commercial exploitation in the archipelago. Thus, the majority of introduced species appear to be associated with ship traffic. This study examined the most probable vectors for the introduction of a given species based on the literature and communication with scientific peers (e.g., HELCOM 2008). For some species, many transfer mechanisms are possible, making a specific vector difficult to assign. Two broad categories of vectors were distinguished: *known*, that is maritime traffic (including ballast water, hull fouling and sediments in ballast tanks, sediments attached to anchors/chains, commercial fishing nets and gear) and *unknown* (see Table 1). A subcategory of maritime traffic was also considered—*fouling*.

Population status (success of non-indigenous species)

The establishment of an introduced species is generally related to the survival of the individuals that initially arrive, and their capacity to reproduce and expand their population. Establishment is influenced both by the characteristics of the introduced individuals, as well as the receiving ecosystems (Rilov and Crooks 2009). Population status was determined based on literature data. A species was considered as *established* when there were multiple records. A species was considered as *not established* when there was a historical record, but the species could later not again be detected in the location where it had been identified or in any other location. The population status was considered as *unknown* for introduced species with a single record and where there was no prior surveying.

Relative density

Whenever information could be retrieved from the literature, the relative density of each species in the Azores was adapted from the DAFOR scale, an internationally recognized semi-quantitative scale by Sutherland (2006), which estimates frequency, categorizing species as follows:

Dominant >75 %; Abundant 50–75 %; Frequent 25–50 %; Occasional 5–25 %; Rare <5 % (see Table 1).

Functional group

As pointed out by Williams and Smith (2007), the success of introduced algae may be related to their functional group. Six functional groups, based on algal anatomical and morphological characteristics (see Table 1), were considered in the present study, following Steneck and Dethier (1994).

Invasive potential

The impacts of an introduced species range from insignificant to extremely high and can be difficult to assess. Many organisms that enter a new or endangered area will not establish. Even species that do establish may not become a pest, or may initially have little impact, because the populations remain small (Mmaynard and Nowell 2009).

In this study, the International Union for Conservation of Nature's (IUCN 2002) definition of "invasive" was adopted, whereby an established species is considered to be an agent of ecological change and thus threatens native biological diversity. In addition, a species can be considered invasive if it causes economic damage or negative effects on human health (EPA 2001). Based on these premises, the invasive potential of each introduced species was derived from existing scientific literature and assigned to three categories: (1) no invasive potential, (2) unknown or (3) invasive potential (see Table 1).

Date of First Record

The first date of collection was used as the date of the first record. If this was not available, the date of the first written report was used instead (Supplemental Table 3).

Results

In the Azores archipelago, a total of 26 NIS of macroalgae were recorded (Supplemental Table 1), São Miguel Island with the highest number of NIS of macroalgae (18 species) and Corvo Island with the lowest number (2 species) (Supplemental Table 3). Along the archipelago, a total of 20 NIS of macroalgae appear to have established and 7 species have an invasive potential impact. Additionally, 40 species are identified as cryptogenic (Supplemental Table 2).

Table 2 Comparison between observed data and expected data (χ^2 test), based on the proportions between macroalgae species

	χ^2 value	*Df*	*P*
Global			
Total spp. versus NIS	4.86	2	0.0900
Global versus Azores			
Global spp. versus Azores (total) spp.	0.99	2	0.9800
Global NIS versus Azores NIS	25.49	2	**0.0001**
Within Azores			
Native spp. versus NIS	17.25	2	**0.0002**
Native spp. versus cryptogenic spp.	0.10	2	0.9500
Cryptogenic spp. versus NIS	29.56	2	**0.0001**

Significance levels in bold

Origin (native, non-indigenous and cryptogenic species status)

The global occurrence of macroalgae species consists of 65 % Rhodophyta, 16 % Chlorophyta (Bryopsidophyceae, Dasycladophyceae, Siphonocladales and Ulvophyceae) and 19 % Ochrophyta (Phaeophyceae) (Guiry 2012). This pattern is similar to the observed global pattern of NIS of macroalgae, 60 % Rhodophyta, 24 % Chlorophyta and 16 % Ochrophyta (see Williams and Smith 2007, a global review which encompasses recently published reviews on seaweed introductions, case histories on specific species and regional reviews) (Table 2: global spp. vs. global NIS—(χ^2–$P < 0.0900$)).

In the Azores archipelago, about 439 species of marine macroalgae have been detected, of which 6 % (26) are probably introduced (Supplemental Table 1, Azores NIS) and 9 % (40) are considered cryptogenic (Supplemental Table 2, cryptogenic species). The percentage of global NIS macroalgae is 3 %, while this value is double in the Azores (6 %). The pattern of taxonomic distribution of NIS of macroalgae in the Azores includes 84 % Rhodophyta, 8 % Chlorophyta and 8 % Ochrophyta. This Azores NIS pattern is significantly different from the known global taxonomic pattern (χ^2—$P < 0.0001$), and it also contrasts with the native regional pattern of macroalgal species composition: 65 % Rhodophyta, 17 % Chlorophyta and 18 % Ochrophyta (Table 2). The main difference is in the proportion of Rhodophyta.

The native origin of the 22 macroalgal NIS recorded in the Azores is the Indian and/or Pacific Oceans, while only three species originate from the western Atlantic and one species from the northeast Atlantic (Fig. 1). The majority of the Azores NIS of macroalgae belongs to the Rhodophyta phylum (84 %), and their native range does not seem to be a factor affecting their distribution (Fig. 2), although

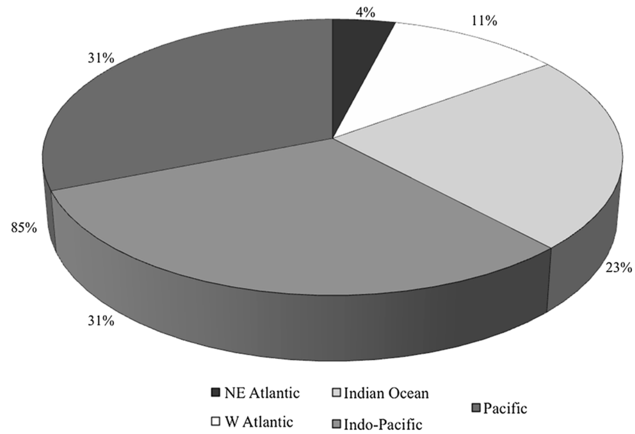

Fig. 1 Native range relative percentage of non-indigenous macroalgae in the Azores

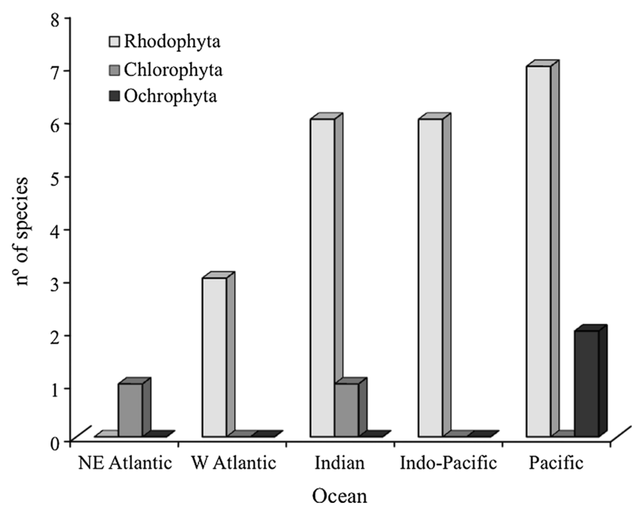

Fig. 2 Number of non-indigenous macroalgae in the Azores, presented by phylum

one exception was detected: *Codium fragile* ssp. *fragile* from the NE Atlantic belongs to the Chlorophyta (Fig. 2).

Among the 40 cryptogenic macroalgae, 64 % are Rhodophyta, 18 % are Chlorophyta and 18 % are Ochrophyta, which is very similar to the Phyla proportion of the native regional pattern but contrasts with the regional pattern of NIS of macroalgae (Supplemental Table 2). This suggests that the majority of cryptogenic species may in fact be native (Table 2).

Transportation vectors

Maritime traffic seems to be the most prevalent vector for macroalgae introductions in the Azores, representing 69 % of the introduced macroalgae, with hull fouling corresponding to at least 56 % of this transportation vector. There is a lack of information regarding the transportation vector for 31 % of all macroalgal introductions (Fig. 3). There is no record of intentional introductions of macroalgae species in the Azores.

Population status (success of non-indigenous species) and density

From the 26 NIS macroalgae in the Azores, at least 77 % seem to be established since they spread to more than one island (Fig. 3, Supplemental Table 3). These NIS exhibit the capacity to overcome abiotic factors and to adapt to a new niche. Relative densities are unknown for 55 % of the established species (Fig. 3).

Functional group

Anatomical and morphological characteristics were determined for each non-indigenous algal species. Around 46 % of all NIS are filamentous, and 38 % are corticated, followed by siphonous (8 %), and finally foliose (4 %) and corticated foliose species (4 %). Within the Rhodophyta phylum, 55 % of the introduced species are filamentous and all Chlorophyta are siphonous. Filamentous and corticated Rhodophyta is mainly transported in fouling communities (Fig. 4). Even among those macroalgae whose introduction vector is unknown, filamentous and corticated species are the most representative functional groups.

Invasive potential

Of the 20 established NIS of macroalgae, 7 are in the invasive category for their potential impact (Fig. 5). The species *Asparagopsis armata*, *Asparagopsis taxiformis*, *Bonnemaisonia hamifera*, *Codium fragile* subsp. *fragile*, *Grateloupia turuturu* and *Symphyocladia marchantioides* are established in the Azores and present on more than one island (Supplemental Table 3). *Caulerpa webbiana* is also established, has been recorded on only one island and is known as a successful invasive species in the Azores. An invasive potential was found in practically all foliose and siphonous species (Fig. 5). Most of the filamentous and corticated foliose NIS of the Azores has an unknown invasive potential.

Discussion

The NIS of macroalgae in the Azores showed a taxonomic composition pattern that is significantly different from the known global pattern. Rhodophyta was the dominant phylum of NIS macroalgae in the archipelago (84 %). This pattern could be related to the ability to reproduce by

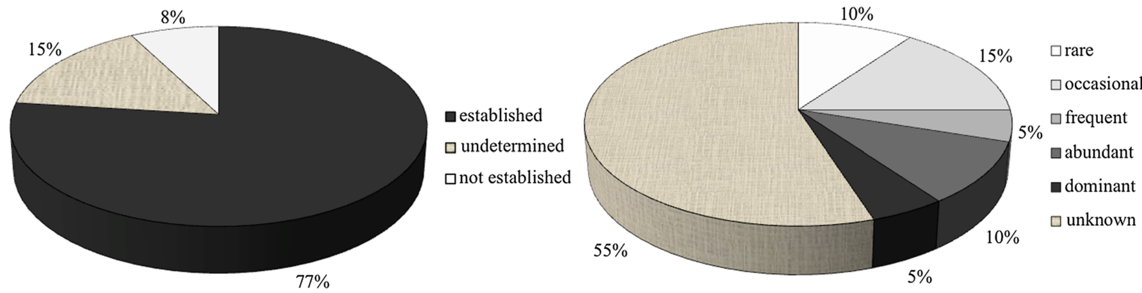

Fig. 3 Relative percentage of introduction success for non-indigenous macroalgae in the Azores and their relative densities, categorized using the DAFOR scale (Sutherland 2006)

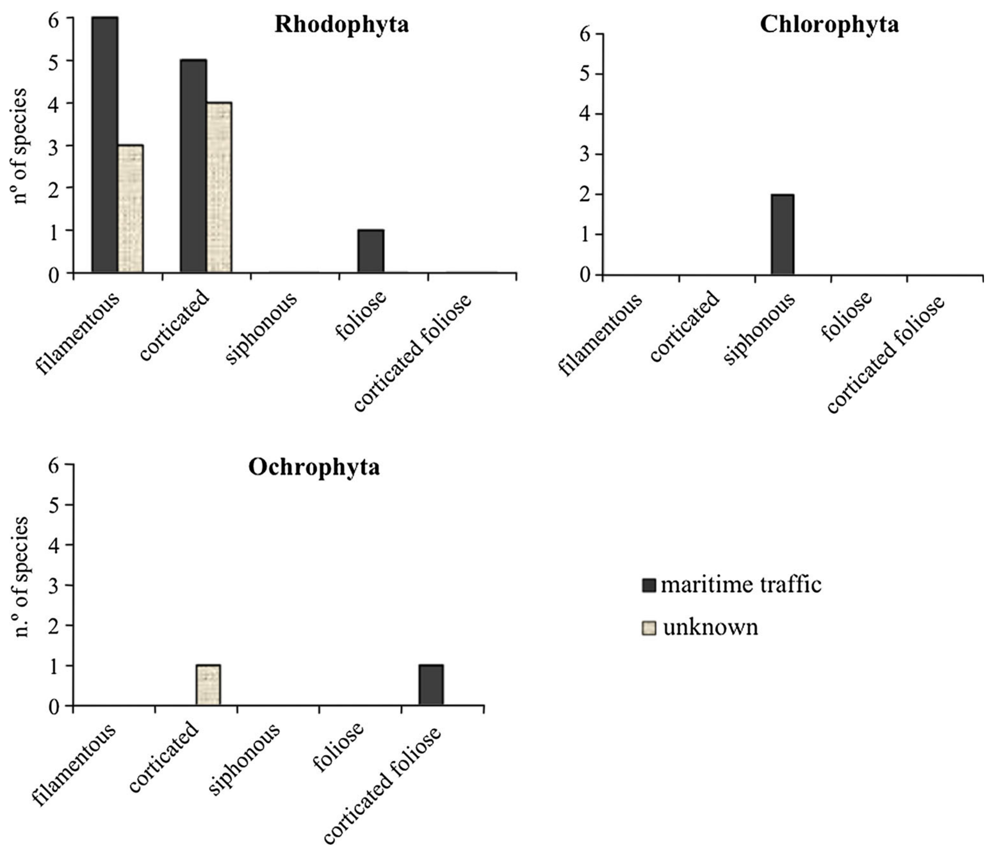

Fig. 4 Number of non-indigenous macroalgae in the Azores, presented by functional group

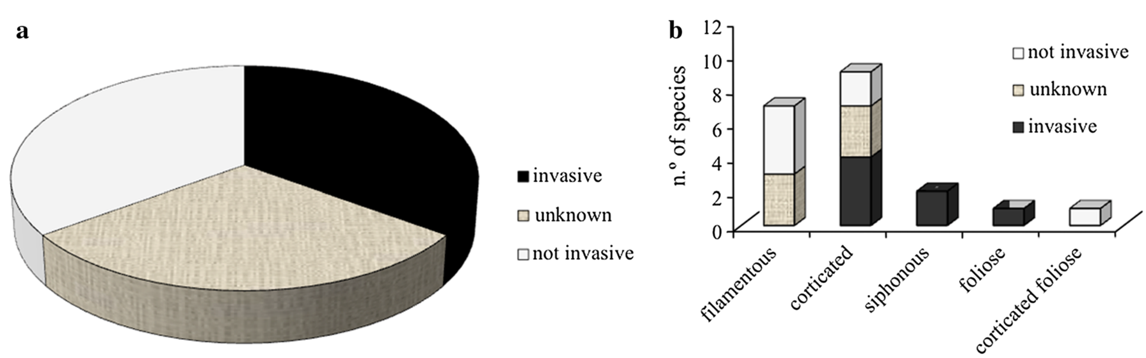

Fig. 5 Number of non-indigenous macroalgae in the Azores, presented by functional group and transportation vector

fragmentation that is inherent to most species in this group (Williams and Smith 2007). Most NIS of macroalgae in the Azores were filamentous early colonizers, which are known to be found in disturbed environments such as harbors (Williams and Smith 2007). The corticated morphotype was also well represented among the NIS in the Azores and is characteristic of habitats with low physical disturbance (Steneck and Dethier 1994).

The Mediterranean Sea has been recognized as the region with the highest number of introduced species worldwide with 126 NIS macroalgae so far (Boudouresque and Verlaque 2005; Williams and Smith 2007) and including known NIS geographical areas such as the Thau Lagoon (Hérault, France—Mediterranean sea) with 45 species (Verlaque 2001) and the Italian coast with 33 species (Occhipinti et al. 2011). The NE Atlantic (the European Atlantic coasts) has about 76 NIS of macroalgae (Williams and Smith 2007). Australia so far counts 39 species, and other vast geographical areas such as the NE Pacific, the central Pacific and the NW Atlantic each account between 20 and 32 NIS of macroalgae (Williams and Smith 2007). The 26 NIS of macroalgae documented in the Azores are of particular relevance if one considers the small coastal extension of this region of about 844 km (Borges 2003), the narrow intertidal strip and the almost absent euphotic subtidal on these oceanic islands, characterized by cliffs lunging straight into the sea (Morton et al. 1998). As emphasized by Williams and Smith (2007), the documented patterns of macroalgal distribution observed in the different geographical areas of the globe may be related to the history of research and phycological expertise in a given region and may not correspond to the actual patterns of distribution. In the northern coast of continental Portugal, for example, in a coastal extension of approximately 250 km (one-third of the Azores coastal extension), 320 macroalgae are recorded. To the area in question, the number of NIS of macroalgae corresponds to 3 % (see Aráujo et al. 2009), equivalent to the percentage of global NIS of macroalgae (Williams and Smith 2007). The high number of NIS of macroalgae observed in the Azores clearly contrasts with other geographical areas in the globe, and this phenomenon could indicate a vulnerability of oceanic islands to the introduction of species, enhanced by simplified trophic levels and a high availability of empty niches in islands' marine ecosystems.

The majority of successful introduced species in the Azores are native to the Indo-Pacific, an area containing the highest level of biodiversity for a number of different taxonomic groups, including macroalgae (Kerswell 2006; Williams and Smith 2007). This Indo-Pacific origin is similar to the native origin of NIS of macroalgae globally. Determining transportation vectors for NIS of macroalgae is difficult due to a lack of research focusing on this issue (Occhipinti et al. 2011). Also, separating macroalgae from other groups is difficult since marine flora and fauna are usually grouped together in NIS studies. Nevertheless, depending on the geographical location, type of local industries, the availability of the history of introduction for a given species and the probability of marine entry vectors can be tracked back with confidence. Although 31 % of macroalgae introductions have an unknown transportation vector in the Azores, there seem to be strong evidences that these species were indeed introduced. This idea has as a premise the characteristics suggested by Williams and Smith (2007) to explain the known global pattern of macroalgae introductions, e.g., discontinuous distribution in relation to the native range or introduced elsewhere in the European Atlantic coast.

In the Thau Lagoon, one of the hot spots of marine species introductions in Europe, the most probable vector of macroalgae introductions is aquaculture (through oyster transfers) (Verlaque 2001). The importance of this vector is re-enforced by the Mediterranean Sea data of Boudouresque and Verlaque (2005). However, the Azores are isolated oceanic islands with no significant aquaculture or aquarium trade, so the most likely entry vector for marine organisms is maritime traffic (passive transport on the hull, in ballast water or dry ballast, in or on cargo, on deck and on anchors). Moreover, as the Azores islands are more a "commercial products importation" region rather than a "commercial products exportation" one, meaning that ballast water generally is not discharged in Azores, the hull fouling pathway may be considered as the most likely dominating vector for macroalgae introductions in the Azores. The number of macroalgae NIS will probably increase in the near future due to the recent ban of tributyltin (TBT), the main active component in antifouling paints for vessels. Tributyltin has been discontinued and marked to be globally phased out by 2008 for environmental reasons (International Convention on the Control of Harmful Antifouling Systems on Ships 2012). The discontinuation of TBT is still not effective, as the stocks have not diminished; however, Schaffelke et al. (2006) predicted that the TBT ban, together with the marked increase in maritime traffic (type, speed, number and dimension of vessels), will contribute to a higher incidence of hull fouling, likely increasing at both the regional and global scale. To counteract this tendency, the International Maritime Organization (IMO) has developed several recommendations to address biofouling of ships and to minimize the transfer of aquatic species (IMO-MEPC62 2011).

Within the Azores archipelago, the first record of an introduced species has occurred in São Miguel island for 69 % of the NIS of macroalgae. This is not surprising since São Miguel not only is the biggest and the main island of the archipelago, with higher maritime traffic movement, but also is located in the closest geographical group of the archipelago to the mainland. Faial, a known sailing stop-over accounts with 15 % of first records. Corvo, the smallest Island of the archipelago, almost 600 km apart from São Miguel has no first records of NIS of macroalgae and only accounts with 8 % for the total Azores NIS of macroalgae. An intensive campaign should be developed along each island, employing the same sampling effort, in order to observe the development of these species within the Azores archipelago.

As emphasized by Occhipinti et al. (2011), the arrival of any NIS to a new biogeographical area has a significant ecological impact on the ecosystem by directly or indirectly affecting the different levels of biological organization, i.e., genetics, integrity of the organism, population, community and habitat/ecosystem, albeit the fact that in many cases the effects may be cryptic and go unnoticed (Carlton 2002). Invasive species may play a conspicuous role in the recipient ecosystem, becoming the dominant species or taking the place of keystone species, hence critically impacting the ecological balance of a given area. The impacts are reflected by changes in the diversity, biomass, structure and composition of communities, as well as by changes in food webs, primary production, nutrients cycles and disturbance regimes (Klein et al. 2005). *Asparagopsis armata*, *Asparagopsis taxiformis*, *Bonnemaisonia hamifera,* and *Grateloupia turuturu* are established and have been recorded on more than one island of the Azores. Since these species are included in a short list of the 100 worst NIS in the Mediterranean Sea (Streftaris and Zenetos 2006), special attention should be given to their populations in future studies and in local monitoring and mitigation programs, in order to avoid long-term negative ecological impacts.

The study of introduced species in the terrestrial environment produced the generalized “tens rule” (Williamson and Fitter 1996), i.e., on average, 10 % of arriving species will settle upon arrival to a given region, 10 % of these will established and 10 % of the introduced species will become invasive. Invasive macrophytes introduced to the Mediterranean Sea fit well with Williamson and Fitter’s “tens rule” according to Boudouresque and Verlaque (2002). In the Azores, from 26 recorded NIS of macroalgae, 77 % have established, i.e., far more than 10 %. It is likely that the actual number of introduced species that tried to settle in the Azores is underestimated or the empty niches characteristic of oceanic islands allows for increased establishment success. Of 20 known established NIS of macroalgae, only one has been proven to be invasive, *Caulerpa webbiana*. Since its arrival to the Faial Island, this alga has rapidly colonized and dominated the marine bottom, forming mono-species stands in the main harbor of the island, as well as surrounding areas (Amat et al. 2008). Nevertheless, given the high numbers of recent new species with invasive potential and of cryptogenic species found in the Azores, it must be expected that the current scenario of invasion and dispersion will become even more accentuated. Moreover, because ship hull fouling is the most relevant vector for NIS of macroalgae in the Azores, and given that there is a large variety of possible species with a potential to arrive in the region (both small species and large species whose life history may include a microscopic or small phase), the present study unveils the urgent need of regulation and development of preventive measures to accurately monitor this problematic transportation vector and reinforcing the importance of following the IMO guidelines for the control and management of ships’ Biofouling to minimize the transfer of invasive aquatic species (IMO-MEPC62 2011).

The uniqueness of oceanic islands is in part represented by the simplicity of their ecosystems, with typically fewer species per unit area than on the mainland (Whittaker 1998). Also, individual traits such as dispersal capacity, invasive behavior and reproductive output tend to be lower with island species (Whittaker 1998) and may translate into an ecological vulnerability to introduced species. The environmental specificity of insular marine ecosystems, where millions of years of physical isolation have favored the evolution of unique species and habitats, can be easily jeopardized by an increasing number of invasives, threatening native species and even driving some to local extinction.

The authors consider that the approach presented in this work is fundamentally important and should be applied to other oceanic archipelagos in order to discriminate routes of entry and understand the taxonomic distribution pattern of oceanic island macroalgae. Specially, if the different NIS taxonomic pattern of macroalgae observed on the Azores is identical to other similarly isolated archipelagos in the globe, it will corroborate this observed contrast in macroalgae distribution between oceanic archipelagos and global distributions.

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