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UPDATING OF NON-INDIGENOUS MACROALGAE IN THE ITALIAN COASTS: NEW INTRODUCTIONS AND CRYPTIC SPECIES

AGGIORNAMENTO DELLE MACROALGHE ALIENE DELLE COSTE ITALIANE: NUOVE INTRODUZIONI E SPECIE CRIPTICHE

Abstract - *A revision of the number of NIS in the Italian coasts shows an alarming increase of alien macroalgae: from 35 taxa in 2012 to 52 taxa in 2014, out of which many are invasive, potentially invasive or punctual records, while others are cryptic species requiring further investigation. The Venice Lagoon is the Italian site with more reports accounting for 54% of the total NIS recorded in the Italian coasts and looks like a hotspot from which NIS can be exported in other environments. The decade characterized by higher number of new NIS records was 1991-2000 and the vector responsible of the major number of introductions was aquaculture (mollusc importation for shellfish culture and live seafood trade) followed by vessels.*

Key-words: *alien macroalgae, Italian coasts, new introductions, cryptic species, invasive species.*

Over the last three decades the Mediterranean Sea has been colonized by an increasing number of non indigenous species (NIS) (Zenetos *et al.*, 2010, 2012) and the Italian coasts, especially the transitional systems, are particularly affected by this invasion because they often host human activities associated with the most important pathways of introduction: shipping, shellfish culture, recreational boating and live seafood trade (Occhipinti-Ambrogi *et al.*, 2011; Petrocelli *et al.*, 2013). The number of NIS is continuously evolving, because new species are being introduced or identified and new taxonomical, biogeograhical or molecular evidences demonstrate an exotic origin of species previously believed to be native, or a native origin of formerly known "aliens". The continuous update, check and validation of NIS records is therefore crucial to provide reliable and up-to-date lists of NIS, a requirement of the European Community (2008). The list of non-indigenous macroalgae in Italy, in particular, has been experiencing relevant changes in the very recent years: Occhipinti-Ambrogi *et al.* (2011) provided a list of 32 non-indigenous macroalgae, updated to 2009. One year after, the "Allochtonous Species Group" (GSA) of the SIBM produced a new list, updated to 2012, containing 35 taxa: 3 Chlorophyta, 5 Ochrophyta, 26 Rhodophyta and 1 aquatic angiosperm (GSA-SIBM, 2012). That list included 7 species considered invasive: *Asparagopsis armata* Harvey, *Caulerpa cylindracea* Sonder, *Caulerpa taxifolia* (Vahl) C. Agardh, *Codium fragile* subsp. *fragile* (Suringar) Hariot, *Gracilaria vermiculophylla* (Ohmi) Papenfuss, *Sargassum muticum* (Yendo) Fensholt and *Undaria pinnatifida* (Harvey) Suringar. Other 6 species are considered potentially invasive: *Acrothamnion preissii* (Sonder) E.M. Wollastion, *Hypnea flexicaulis* Y. Yamagishi & M. Masuda, *Grateloupia turuturu* Yamada, *Lophocladia lallemandii* (Montagne) F. Schmitz, *Womersleyella setacea* (Hollenberg) R.E. Norris and *Halophila stipulacea* (Forsskål) Ascherson (Zenetos *et al.*, 2010).

In this account, we present a revision of the non-indigenous macrophytes in Italy with additions up to March 2014 (Tab. 1, Fig. 1). The updated list shows that the number of NIS has strongly increased, although some species present in the

2012 list have now been deleted because either cryptogenic: *Apoglossum gregarium* (E.Y. Dawson) M.J. Wynne; *Palisada maris-rubri* (K.W. Nam & Saito) K.W. Nam, *Chondria polyrhiza* F.S. Collins & Hervey, or possible misidentification: *Hypnea valentiae* (Turner) Montagne.

At present the number of non-indigenous macroalgae in Italy is 52, accounting for 8 Chlorophyta, 9 Ochrophyta, 34 Rhodophyta and 1 aquatic angiosperm. Records of other new species not yet accompanied by a published reference were provisionally not included such as the Rhodophyta *Galaxaura rugosa* (J. Ellis & Solander) J.V. Lamouroux.

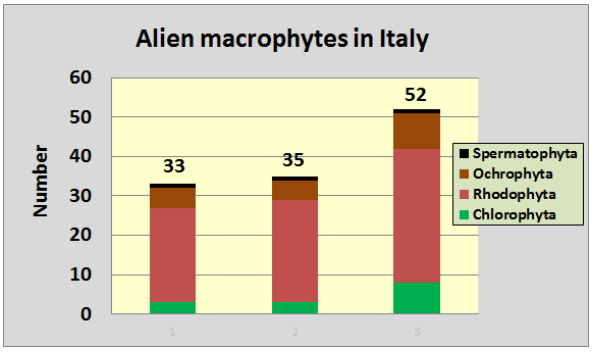

Fig. 1 - Updating of alien macrophytes in 2009 (Occhipinti-Ambrogi *et al.*, 2011), in 2010 (GSA-SIBM, 2012) and in 2014.
Aggiornamento delle macrofite aliene nelle coste italiane nel 2009 (Occhipinti-Ambrogi et al.*, 2011), nel 2010 (GSA-SIBM, 2012) e nel 2014.*

Other species require confirmation of identification, such as the Rhodophyta *Spermothamnion cymosum* (Harvey) De Toni recorded in the Lagoon of Venice in 2010 (Armeli-Minicante, 2014) and *Polysiphonia paniculata* Montagne reported in Sardinia and Sicily (Verlaque *et al.*, 2009).

Finally, the insufficient information on some cryptic species justifies their temporary exclusion from the list of NIS of the Italian coasts, until new evidence will eventually clarify their identity and their non-indigenous status. Out of these doubtful records: *Apoglossum gregarium* (E.Y. Dawson) M.J. Wynne, reported from the Tuscan Archipelago (Sartoni & Boddi, 1993) in deep waters, which might have been present there for a long time, but never being reported as it is a diminutive species. Another example is *Grateloupia minima* P.L. Crouan & H.M. Crouan, a red alga, found in the Mar Piccolo of Taranto in March 2010 (Petrocelli *et al.*, 2012) and earlier (2008) in the Thau Lagoon, France. It is a species from the Atlantic coasts of France, Spain and Portugal (De Clerck *et al.*, 2005) that might have entered naturally in the Mediterranean Sea for simple natural range extension. In addition, *G. minima* is very similar to its Mediterranean congeneric *Grateloupia filicina* (J.V. Lamouroux) C. Agardh, from which it was only recently distinguished after molecular analysis (De Clerk *et al.*, 2005).

Punctaria tenuissima (C. Agardh) Greville is another species that requires a confirmation. It has been recently put into synonymy with *Punctaria latifolia* Greville, the latter being a native macroalga of the Mediterranean Sea.

Among the new entries: *Ascophyllum nodosum* (Linnaeus) Le Jolis was recorded in the coasts of Tuscany and in the Mar Piccolo of Taranto. The likely pathway of

Tab. 1 - List of non indigenous species (NIS) in the Italian coasts updated up to March 2014.

Lista delle specie non indigene (NIS) nelle coste italiane aggiornata a marzo 2014.

	Taxa	First record		Vectors	Condition	Origin	References
		Italy	Venice				
1	*Acrothamnion preissii* (Sonder) E.M. Wollastion	1966		Vessels (Fouling)	Established	Indo-Pacific	Cinelli & Sartoni (1969)
2	*Agardhiella subulata* (C. Agardh) Kraft & M.J. Wynne	1987	2003	Aquaculture	Established	Circumboreal	Cecere (1989)
3	*Aglaothamnion feldmanniae* Halos	1975	2003	Vessels (Fouling)	Established	Boreo-Atlantic	Sartoni & Sarti (1976)
4	*Antithamnion amphigeneum* A.J.K. Millar	1996		Vessels (Fouling)	Established	Pacific	Rindi *et al.* (1996)
5	*Antithamnion hubbsii* E.Y. Dawson as *A. pectinatum* (Montagne) J. Brauner	1994	1994	Aquaculture, Vessels	Established	Pacific	Curiel *et al.* (1996a)
6	*Antithamnionella boergesenii* (Cormaci & G. Furnari) Athanasiadis	1991		Unknown	Casual	Indo-Pacific	Cormaci & Furnari (1988)
7	*Antithamnionella elegans* (Berthold) J.H. Price & D.M. John	1882	1980	Unknown	Casual	Unknown	Berthold (1882)
8	*Antithamnionella elegans* var. *sublittoralis* (Setchell & Gardner) Athanasiadis	1980		Unknown	W Atlantic	Unknown	Cormaci & Furnari (1988)
9	*Antithamnionella spirographidis* (Schiffner) E.M. Wollaston	1995	1995	Aquaculture, Vessels	Established	Indo-Pacific	Curiel *et al.* (1996b)
10	*Ascophyllum nodosum* (Linnaeus) Le Jolis	2009		Culture	Casual	North-Atlantic	Petrocelli *et al.* (2013)
11	*Asparagopsis armata* Harvey	1955		Vessels (Fouling)	Established	Cosmopolitan	Funk (1955)
12	*Asparagopsis taxiformis* (Delile) Trevisan de Saint-Léon (lineage 2)	1993		Unknown	Established	Pantropical	Ní Chualáin *et al.* (2004)
13	*Bonnemaisonia hamifera* Hariot	1973	1995	Aquaculture, Vessels	Occasional	Circumboreal	Curiel *et al.* (1996b)
14	*Botryocladia madagascariensis* G. Feldmann	1991		Vessels (Fouling)	Established	Indian	Cormaci *et al.* (1992)
15	*Botrytella parva* (Takamatsu) Kim	1996	1996	Aquaculture	Established	Pacific	Curiel *et al.* (1999)
16	*Caulerpa cylindracea* Sonder	1993		Unknown	Established	Pantropical	Alongi *et al.* (1993)
17	*Caulerpa taxifolia* (Vahl) C. Agardh	1992		Aquaculture (Monaco Aquarium)	Established	Pantropical	Relini & Torchia (1992)
18	*Caulerpa taxifolia* var. *distichophylla* (Sonder) Verlaque *et al.*	2008		Unknown	First record	Unknown	Jongma *et al.* (2013)
19	*Ceramium strobiliforme* G.W. Lawson & D.M. John	1991		Vessels (Fouling)	Casual	Atlantic boreal	Cormaci *et al.* (1992)
20	*Chondria pygmaea* Garbary & Vandermeulen	1976		Vessels (via Suez)	Established	Indo-Pacific	Cormaci *et al.* (1976)
21	*Codium fragile* subsp. *fragile* (Suringar) Hariot	1973	1978	Aquaculture	Established	NW Pacific	Sfriso (1987)
22	*Colaconema codicola* (Børgesen) H. Stegenga *et al.*	1978	1978	Aquaculture	Established	NW Pacific	Sfriso *et al.* (2002)
23	*Colpomenia peregrina* (Sauvageau) Hamel	1969		Aquaculture	Established	Subcosmopolitan	Boudouresque & Boudouresque (1969)
24	*Gracilaria vermiculophylla* (Ohmi) Papenfuss	2008	2008	Aquaculture	Established	NW Pacific	Sfriso *et al.* (2010)
25	*Grateloupia turuturu Yamada* as *Grateloupia doryphora* (Mont.) Howe	1989	1989	Aquaculture	Established	NW Pacific	Tolomio (1993)
26	*Grateloupia yinggehaiensis* H.W. Wang *et* R.X. Luan	2008	2008	Aquaculture	Established	Indo-Pacific	Wolf *et al.* (2014)
27	*Halothrix lumbricalis* (Kützing) Reinke	1978	1992	Vessels (Fouling)	Casual	N Atlantic/N Pacific	Cormaci & Furnari (1979)
28	*Heterosiphonia japonica* Yendo as *Dasysiphonia* sp.	1999	1999	Aquaculture	Established	NW Pacific	Sfriso *et al.* (2002)
29	*Hypnea cornuta* (Kützing) J. Agardh	2000		Aquaculture	Established	Pantropical	Cecere *et al.* (2004)
30	*Hypnea flexicaulis* Y. Yamagishi & M. Masuda	2009	2009	Aquaculture, Vessels	Established	Indo-Pacific	Wolf *et al.* (2011)
31	*Hypnea spinella* (C. Agardh) Kützing	1985		Vessels (Fouling)	Established	Atlantic-Indopacific	Cecere *et al.* (1996)
32	*Laurencia caduciramulosa* Masuda & Kawaguchi	1991		Vessels (Fouling)	Established	Indo-Pacific	Furnari *et al.* (2001)
33	*Leathesia marina* (Lyngbye) Decaisne	1996	1996	Aquaculture	Casual	Cosmopolitan	Bellemo *et al.* (1999)
34	*Lomentaria hakodatensis* Yendo	2000	2000	Aquaculture	Established	Pacific	Curiel *et al.* (2006)
35	*Lophocladia lallemandii* (Montagne) F. Schmitz	1969		Vessels (via Suez)	Established	Indo-Pacific	Cormaci & Motta (1985)
36	*Neosiphonia harveyi* (J. Bailey) M.S. Kim *et al.*	1969	1998	Aquaculture	Established	NW Pacific	Bellemo *et al.* (1999)
37	*Padina boergesenii* Allender & Kraft	1963		Vessels (via Suez)	Established	Pantropical	Sortino (1967)
38	*Plocamium secundatum* (Kützing) Kützing	1991		Vessels (Fouling)	Casual?	Subantarctic	Cormaci *et al.* (1991)
39	*Polysiphonia morrowii* Harvey	1999	1999	Aquaculture	Established	NW Pacific	Curiel *et al.* (2002)
40	*Polysiphonia paniculata* Montagne	2010		unknown	Casual	Indo-Pacific	Furnari *et al.* (2010)
41	*Pyropia yezoensis* (Ueda) M.S. Hwang & H.G. Choi	2010	2010	Aquaculture	First record	Pacific	Armeli-Minicante (2014)
42	*Sargassum muticum* (Yendo) Fensholt	1992	1992	Aquaculture	Established	NW Pacific	Gargiulo *et al.* (1992)
43	*Scytosiphon dotyi* M.J. Wynne	1978	1996	Aquaculture	Established	NE Pacific	Giaccone (1978)
44	*Solieria filiformis* (Kützing) Gabrielson	1922	2003	Aquaculture	Established	N Atlantic	Cecere (1989)
45	*Symphyocladia marchantioides* (Harvey) Falkenberg	1984		Aquaculture, Vessels	Established	Indo-Pacific	Sartoni (1985/1986)
46	*Ulva australis* Areschoug as *Ulva pertusa*	2011	2011	Aquaculture, Vessels	Established	Indo-Pacific	Manghisi *et al.* (2011)
47	*Ulva californica* Wille in F.S. Collins, Holden & Setchell	2011	2011	Aquaculture, Vessels	Established	Pacific	Wolf *et al.* (2012)
48	*Ulvaria obscura* (Kützing) Gayral	2000	2000	Aquaculture	Established	NW Pacific	Sfriso *et al.* (2002)
49	*Undaria pinnatifida* (Harvey) Suringar	1992	1992	Aquaculture	Established	Pacific	Rismondo *et al.* (1993)
50	*Uronema marinum* Womersley	2008	2008	Aquaculture	Established	Pacific	Sfriso *et al.* (2014)
51	*Womersleyella setacea* (Hollenberg) R.E. Norris	1986		Vessels (Fouling)	Established	Indo-Pacific	Benedetti-Cecchi & Cinelli (1990)
52	*Halophila stipulacea* (Forsskål) Ascherson	<1980		Vessels (via Suez)	Established	Red Sea	Villari (1988)

introduction for this species is live seafood trade: *A. nodosum* is usually employed to keep the imported mollusk *Pecten jacobeus* Linnaeus "Cappasanta" fresh. As it was observed in the fish markets of both Chioggia and Venice, where residues of sales are often thrown in the canals at the end of the day, in the next future this species is expected to be found in the Venice Lagoon as well.

Caulerpa taxifolia var. *distichophylla*, another recent introduction, was introduced from Australia to Sicily (Jongma *et al.*, 2013) and is exhibiting a rapid spread along the coasts of the island (Musco *et al.*, 2014).

A new invasive species recorded in all the lagoons of the Veneto and Emilia-Romagna regions, already reported in the list of 2012 (GSA-SIBM, 2012), is *Gracilaria vermiculophylla* (Ohmi) Papenfuss (Sfriso *et al.*, 2010). Probably introduced from the North-East Atlantic by oyster importations, it soon became a species of concern because of its extremely rapid spread (Rueness, 2005; Thomsen *et al.*, 2005). In fact, it is one of the most widespread species in Europe, having been reported from more than 10 countries along the European Atlantic and Baltic coasts (Galil *et al.*, 2014). Its first Mediterranean record was in 2008 in the Po delta Lagoons and ponds, in the Venice Lagoon and in Pialassa della Baiona in Emilia-Romagna region. *G. vermiculophylla* can reach very high biomasses (up to 15 kg m^{-2} fwt) in confined and eutrophic areas where other two non-indigenous species have also spread, i.e. *Agardhiella subulata* (C. Agardh) Kraft & M.J. Wynne and *Solieria filiformis* (Kützing) Gabrielson.

Gracilaria vermiculophylla presents a higher spreading potential than other invasive species, because it is able to grow detached from the bottom in free-floating status, colonizing eutrophic and confined environments. It is also a species with high tolerances of low salinities, turbidity, sedimentation, desiccation, grazing and nutrient enrichment (Thomsen & McGlathery, 2007; Weinberger *et al.*, 2008). These traits explain its invasive success in transitional environments and estuaries, and also its ability to replace the Ulvaceae, although the latter exhibit higher growth rates. In fact, the grazing impact of crustaceans and gastropods that affect Ulvaceae (Sfriso, 1995; Sfriso & Marcomini, 1996; Balducci *et al.*, 2001) reducing their biomass during the warm season and overcoming the species growth rates, is not present in this species (Nejrup *et al.*, 2012).

Grazers, usually prefer native species with low structural complexity and higher nitrogen content (Geertz-Hansen *et al.*, 1993; Cebrián & Duarte, 1994). *Gracilaria vermiculophylla* has also a high resistance to temperature and sedimentation (Thomsen & McGlathery, 2007) growing even in conditions prohibitive for *Ulva* which, at high temperatures (>28-30 °C), rapidly collapses. Very similar ecological characteristics has *Agardhiella subulata* that in Venice Lagoon coexists in the same environment. However, this species lives attached to the bottom and is not able to grow free-floating.

In spring 2014 both these species have replaced *Ulva rigida* Linnaeus and *Ulva laetevirens* Areschoug in the area at North of the translagoon bridge (Ponte della Libertà) where the abundant May-June biomass production triggered a complete collapse in July 2013 (Bastianini *et al.*, 2013). A rapid increase in temperature above 30 °C caused a dystrophic crisis with the complete degradation of ca. 10,000 tonnes (fresh biomass) of macroalgae in a few days and the death of fish and benthic fauna, causing the concern of the Venice people. In early June 2014 water temperature increased up to 32.5 °C but *G. vermiculophylla* has not suffered from these extreme temperatures. In this sense, the replacing of Ulvaceae by an invasive species such as *G. vermiculophylla*, better adapted to survive in extreme environmental conditions, should be seen in a positive way. Moreover, this species may have a commercial interest. Currently, studies for its employment in agar, sugar and alcohol production are ongoing.

The Chlorophyta *Uronema marinum* Womersley, a small species of Australian origin and the Rhodophyta *Grateloupia yinggehaiensis* H.W. Wang et R.X. Luan in D. Zhao *et al.* are the most recent species recorded in the Venice Lagoon. *U. marinum* is so small that probably has long been disregarded because of its similarity to the juvenile stages of other species such as *Ulothrix implexa* (Kützing) Kützing. That species has rapidly colonized all the Venice Lagoons, the lagoons of the Po Delta and Pialassa della Baiona pond (Sfriso *et al.*, 2014), probably as epiphyte on *Gracilaria vermiculophilla* and *Solieria filiformis* which have the same native origin (Pacific coasts of Korea, Japan and China) and the same vector of introduction (aquaculture).

Grateloupia yinggehaiensis is a termophilic species coming from the Hainan Province, China, that in the Venice Lagoon has colonized the area close to the thermal power plant of Fusina where cooling waters are discharged (Wolf *et al.*, 2014). No thalli have been found more than 1 km away from the Fusina power plant.

The Venice Lagoon is the Italian hotspot area where the majority of non-indigenous macroalgae recorded in the Italian coasts are present (ca. 54%, Fig. 2). The highest number regards Phaeophyceae (67%), followed by Chlorophyceae (63%) and Rhodophyceae (50%). The only allochthnous angiosperm: *Halophila stipulacea* is confined to the coasts of Sicily (Di Martino *et al.*, 2006).

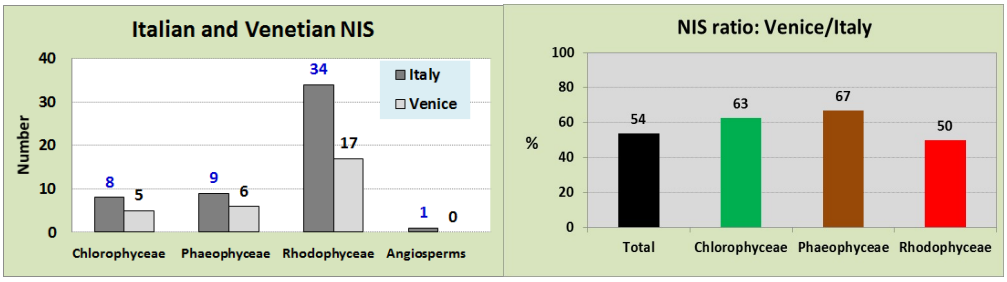

Fig. 2 - Number of NIS per taxon recorded in the Italian coasts and in Venice Lagoon and percentage of NIS that colonize the same lagoon.

Numero di NIS per taxon rinvenute nelle coste Italiane e nella laguna di Venezia e percentuale di NIS presenti in questa laguna.

The highest number of introductions was recorded in the decade 1991-2000 (Fig. 3), both in the Italian coasts (21=40%) and in the Venice Lagoon (14=50%).

The most likely vector for macroalgal introduction is aquaculture (Fig. 4), especially shellfish culture. The decade between 1990 and 2001 corresponds to the period of the most intensive shellfish culture in the lagoons of the North-western Adriatic Sea (Orel *et al.*, 2000), which have also exported live molluscs to other Italian farming sites (Prioli, 2008). Then the number of new records progressively decreased, although the number of studies has increased, as an effect of the implementation of the WFD (2000/60/EC) both in marine coastal areas and transitional waters.

Aquaculture, likely responsible for the introduction of 23 taxa out of 52 (44.2%), is the most important vector for macrophytes in the Italian coasts (Fig. 4). Vessels by fouling on hulls of ships and ballast waters account for other 11 taxa (21.2%). Another 7 taxa were considered to be introduced by multiple vectors (e.g. aquaculture combined to vessels), whereas 4 taxa have entered the Mediterranean Sea via Suez

Canal and have arrived to our coasts by vessels. Finally, the vectors of 7 taxa remain unknown.

The vector aquaculture includes also live seafood trade, responsible of many introductions both in the Venice Lagoon and the Mar Piccolo of Taranto. One species (i.e. *Caulerpa taxifolia*) escaped from the aquarium of Monaco and further spread to the Italian coasts either naturally or favoured by recreational boating (Meinesz *et al.*, 2001).

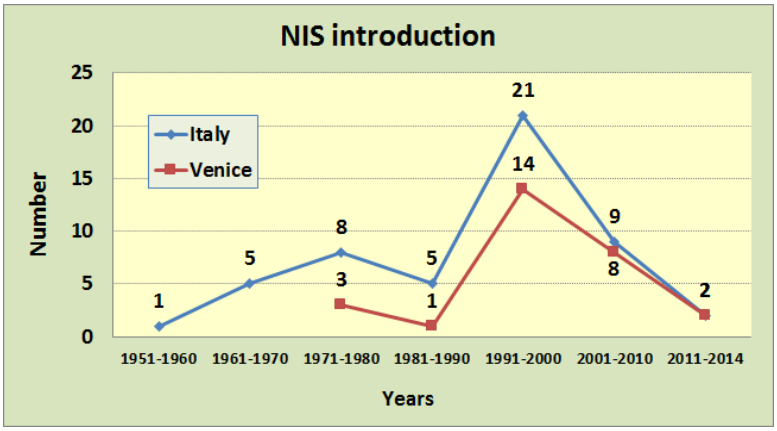

Fig. 3 - Number of NIS recorded in the recent decades by considering the year of the first record.
Numero di NIS rinvenute nelle ultime decadi considerando l'anno del primo rinvenimento.

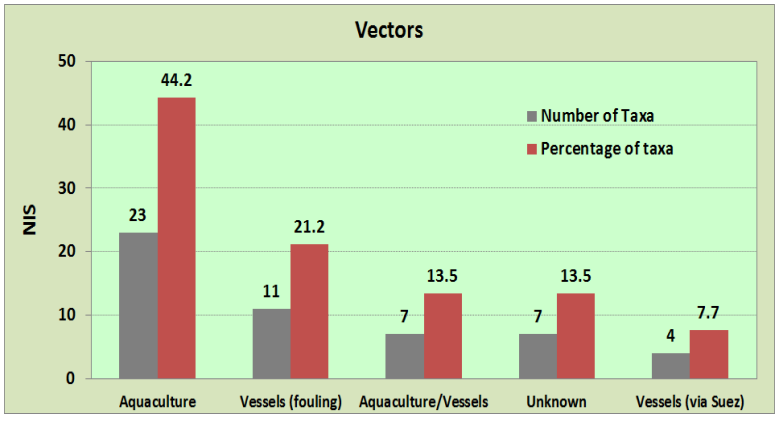

Fig. 4 - Main vectors of macroalgal introduction in the Italian coasts.
Principali vettori di introduzione di macrofite nelle coste italiane.

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