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Hitch-hikers of the sea: concurrent morphological and molecular identification of *Symplegma brakenhielmi* (Tunicata: Ascidiae) in the western Mediterranean Sea

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Abstract

We report here one of the first records of the non-indigenous colonial ascidian *Symplegma brakenhielmi* in the western Mediterranean Sea. Colonies of this invasive species were collected in 2014 and 2018 along the North-eastern Sardinia coasts (Olbia, Italy). Further colonies were observed in 2016 in the Mar Piccolo basin (Gulf of Taranto, Italy). Both areas are strongly influenced by anthropogenic activities such as commercial shipping and aquaculture and these human-mediated pathways are the most likely vectors of introduction. In both areas, the colonies present two different color phenotypes, the yellow and the red type, with the yellow coloration never previously found in the Mediterranean Sea. Morphological and DNA barcode analyses of the collected specimens show that both these color types belong to the same species. Phylogenetic and species delimitation analyses based on the DNA barcode confirm our identification as *S. brakenhielmi*, but also indicate a surprisingly high similarity with published sequences of two other species, including the co-generic species *Symplegma rubra* Monniot, 1972. Morphological and molecular examination of a large number of samples of these species is needed in the near future to clarify this issue.

Keywords: *Symplegma brakenhielmi*; non-indigenous; NIS; ascidian; Mediterranean; COI; DNA barcode.

Introduction

The lack of ascidian-specialized taxonomists and the consequent frequent misidentification of samples have been among the major limiting factors in the ability to detect non-indigenous species of ascidians (Izquierdo Muñoz et al., 2009). Systematic knowledge, particularly with respect to accurate species identification, is crucial to clarify causes and consequences of ascidian invasions in marine ecosystems. Defining clear identification keys, correctly revising the taxonomic nomenclature, as well as combining morphological and molecular evidence, are the main components of an integrated approach aimed at solving the problem of ambiguous taxonomy in ascidians (Zhan et al., 2015).

*Symplegma brakenhielmi* is a colonial ascidian, first recorded in the Gulf of Mexico by Michaelsen in 1904, who named it *Diandrocarpa brakenhielmi*. Subsequently, in 1961, Tokioka described a new species from Melanesia, *Symplegma oceania*. Based on the similarity of morphological characters, Kott 1985 considered these two nominal species to be conspecific, retaining the name *S. oceania*. Later, considering the nomenclature rules (ICZN, 1985), Monniot & Monniot 1997 named it as *Symplegma brakenhielmi* (Michaelsen, 1904). This species has a pantropical distribution, having been recorded in Mexico (Michaelsen, 1904), the Western Indian Ocean (Kott, 1964, 1985; Michaelsen, 1904), Melanesia (Kott, 1981; Tokioka, 1961, 1967), Indonesia (Sluiter, 1904), Thailand (Tokioka, 1967), Hong Kong (Kott & Goodbody, 1980), South Korea (Rho & Park, 1998), China (Tokioka, 1967), Sri Lanka (Herdman, 1906), Madagascar (Plante & Vasseur, 1966; Vasseur, 1967), the Arabian Gulf (Monniot & Monniot 1997), California (Lambert & Lambert, 1998), Hawaii (Abbott et al., 1997), Brazil (Rocha, 1991; Rodrigues & Rocha, 1993; Rocha & Barros de Faria, 2005; Ro-
Based on current knowledge, the recorded presence of this species in the Mediterranean Sea has been limited to the eastern basin, along the coasts of Turkey, Israel and Lebanon. More specifically, Bitar & Kouli-Bitar (2001), reported the first occurrence of *S. brakenhielmi* in the Mediterranean Sea, reviewing the list of macrozoobenthos species along the Lebanese coast. Furthermore, Çinar et al. (2006) recorded several red colonies on an artificial substratum during a survey on the presence of alien species along the Turkish Levantine coast. Further colonies have been reported more recently from the same area (Ulman, 2016; Ulman et al., 2017; Halim & Messeih, 2016; Gerovasileiou et al., 2017; Servello et al., 2019). Shenkar & Loya (2009) found this species along the Israel coasts, also reporting only reddish colonies. A recent record of *S. brakenhielmi* in Sicilian waters (Palermo, Italy) was reported by Ulman et al. (2017), but without providing any images or detail about its identification.

This study reports the presence of *S. brakenhielmi* in the western and central Mediterranean Sea, in particular along the North-eastern coasts of Sardinia (Olbia, Western Tyrrhenian Sea) and in the Mar Piccolo basin (Gulf of Taranto, Northern Ionian Sea). Both finding areas are strongly influenced by human activities and pressures (Bracchi et al., 2016; Tursi et al., 2018), such as high maritime traffic, commercial shipping and import/export of living marine species for aquaculture, considered the most important pathways for the introduction of the alien species. Therefore, a hypothesis on the most likely vector of introduction of this non-indigenous species in the western Mediterranean basin is suggested. In both areas the colonies of *S. brakenhielmi* present two different colorations, red and yellow, with the yellow coloration reported here for the first time in the Mediterranean Sea.

A brief review of the genus *Symplegma* and a detailed morphological descriptions of the red and yellow colonies collected are provided, together with their molecular characterization based on the mitochondrial COI gene (Cytochrome Oxidase subunit I) (Hebert et al., 2003) This study represents a contribution to the knowledge of the composition and distribution of alien species in the Mediterranean Sea, and it underlines the importance of a synergistic approach between morphological and molecular analyses, especially in the identification and study of non-indigenous species.

**Material and Methods**

**Survey site**

Red and yellow colonies of *S. brakenhielmi* were collected in the North-eastern Sardinian Sea, along the “Lido del Sole” beach (40.91444° N; 9.56611° E) near Olbia (Italy), at a depth of 3-5 m (Fig. 1) in July 2014 and November 2018. This area is mainly characterized by the seagrass *Cymodocea nodosa* (Ucria) Ascherson, 1870, the bivalve *Pinna nobilis* Linnaeus, 1758, the large solitary ascidians *Phallusia mammillata* (Cuvier, 1815), *Microcosmus* spp. and *Halocynthia papillosa* (Linnaeus, 1767), as well as colonial ascidians belonging to the genus *Clavelina*.

Further red and yellow colonies were observed in August 2016 in the Mar Piccolo basin (Gulf of Taranto, South Adriatic, Italy) (40.47707° N; 17.24627° E). The colonies were attached to glass bottles and other marine litter on a detritic bottom, at a depth of 7 m (Fig. 3), in a military area where sampling is forbidden.

**Fig. 1:** Map of the Mediterranean Sea showing the previous records of *S. brakenhielmi* (black dots) and the two new records (red asterisks).
**Fig. 2:** A) Living yellow colonies of *Symplegma brakenhielmi* sampled in Sardinia (Italy); B) Magnification of a yellow zooids showing the reticulated pattern; C) Living red colonies of *Symplegma brakenhielmi* sampled in Sardinia (Italy); D) Magnification of a red zooid showing the reticulated pattern; E) Detail of the yellow and red colonies on valves of *Pinna nobilis* and leaves of *Cymodocea nodosa.*

**Fig. 3:** A-B) Red and yellow colonies of *Symplegma brakenhielmi* photographed along North-eastern coasts of Sardinia (Olbia, Italy) in 2003 (pictures from Trainito, 2005, reported as *Styelidae* sp.); C-F) Red and yellow colonies *S. brakenhielmi* observed in the Gulf of Taranto (Italy).
Sampling

A total of ten yellow and red colonies were manually collected by SCUBA diving in Sardinia waters. Colonies were settled on different biotic and abiotic substrata, such as leaves of *C. nodosa*, shells of *P. nobilis* and rocks (Fig. 2). The sampled colonies were narcotized with menthol crystals in seawater and preserved in a 4% formaldehyde solution in seawater. Moreover, subsamples of two red and two yellow colonies were preserved in 99% ethanol and in RNA later for molecular investigation.

Molecular analyses

Total DNA was extracted from the four colonies in ethanol or in RNA later (two yellow and two red) using a modified CTAB method (Hirose & Hirose, 2009). In particular, the DNA was extracted from 2-3 zooids isolated from each colony. Molecular characterization was based on the amplification and sequencing of a fragment of the mitochondrial COI (Cytochrome Oxidase subunit I) gene. In particular, the analysed COI fragment is about 850 bp and contains the 650 bp-long barcode region commonly amplified with Folmer’s primers (Folmer et al., 1994). The 850 bp-long amplicon was obtained using the primer pair dinF/Nux1R (Brunetti et al., 1994). The 850 bp-long amplicon was chosen in order to delete regions corresponding to the primers used in amplicon production, often erroneously saved in the public COI sequences. The final alignment, available on request, is 838 nt long and consists of 442 ungapped sites and 19 sequences. The list of analysed sequences is reported in Table 1, together with additional data.

Pairwise identity percentages between sequences were calculated using Geneious ver. 5.5.7 (http://www.geneious.com, Kearse et al., 2012).

Species delimitation analyses were carried out with the Automatic Barcode Gap Discovery method, ABGD, a method that sorts sequences into OTUs (Operational Taxonomic Units), corresponding to hypothetical species, based on the statistical inference of the “barcode gap”, i.e., the gap between intra- and inter-specific diversity (Puillandre et al., 2012). ABGD analyses were performed on the web-based interface (http://wwwabi.snv.jussieu.fr/public/abgd/) using the default values for both the minimum relative gap width (X=1.5) and for the scanned range of prior intraspecific divergence (Pmin – Pmax: 0.001 – 0.1). Three COI alignments, differing in the number of aligned sites and sequences, were tested, i.e., the whole alignment including the B. schlosseri outgroup, and all the 838 gapped and ungapped sites (alnBS_838); the two alignments including only the 442 ungapped sites, with (alnBS_442) or without the B. schlosseri outgroup (aln_442). These alignments were analysed in order to verify possible bias on the barcode gap calculation due to missing data (i.e., gapped sites) or to the presence of the B. schlosseri outgroup. For each analysed alignment, pairwise distances were calculated according to the three models of nucleotide evolution available in ABGD: Jukes-Cantor (JC, Jukes & Cantor, 1969), Kimura 2 parameter (K2P, Kimura, 1980) and uncorrected p-distances (p-dist). These analyses allowed us to exclude possible bias of the selected evolutionary model on the OTU delimitation. Therefore, a total of 12 ABGD analyses were performed.

The phylogenetic reconstruction of Polyzoa was performed on the alnBS_838 alignment according to the maximum likelihood (ML) method using online PHYML v3.0 software, which includes automatic model selection by SMS (Smart Model Selection) (Guindon & Gascuel, 2003) (http://www.atgc-montpellier.fr/phylm-sms/). The best-fit substitution model selected under the Akaike Information Criterion (AIC) was HKY85+I+G. The proportion of invariant sites (I) and the gamma shape parameter (alpha) for the 4 rate categories were estimated due to missing data (i.e., gapped sites) or to the presence of the B. schlosseri outgroup. For each analysed alignment, pairwise distances were calculated according to the three models of nucleotide evolution available in ABGD: Jukes-Cantor (JC, Jukes & Cantor, 1969), Kimura 2 parameter (K2P, Kimura, 1980) and uncorrected p-distances (p-dist). These analyses allowed us to exclude possible bias of the selected evolutionary model on the OTU delimitation. Therefore, a total of 12 ABGD analyses were performed.

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points to the presence of this species along Sardinia coasts as early as 2003 (Trainito, 2005, reported as Styelidae sp., Fig. 3A-B). Since then, the species has been observed in Olbia constantly every year, with the period of greatest abundance between the end of autumn and the beginning of summer (Trainito, personal communication). Moreover, accurate analysis of the photos taken within the military area of Taranto allows the identification of both red and yellow colonies as Symplegma brakenhielmi (Fig. 3C-F).

Material examined
Olbia (North-eastern Sardinian Sea, Italy), (40.91444° N; 9.56611° E), 3-5 m.
Four colonies (two of the red-type and two of the yellow-type), preserved both in 70% ethanol after 4% formalin, and in 99% ethanol, have been deposited in the collection of the Museum of the University of Bari (Code: MUZAC-6326; MUZAC-6327).

External appearance
Living individuals appeared as flat and encrusting colonies, red or yellow in color, up to 30 cm in diameter and about 2 mm thick. Colonies grew freely over any hard substrata, such as large solitary ascidians (e.g., Phallusia mammillata, Microcosmus spp.), bivalve shells (e.g., P. nobilis), seagrass leaves (e.g., C. nodosa) and rocks. Furthermore, in the sampling site, red and yellow colonies were adjacent on the same substratum (Fig. 2E-4F). Zooids were completely embedded in a transparent and jelly-like tunic, more or less crowded and not arranged in systems (Fig. 2A-B). They were different in size, up to

| AC number in the nt-nr | Species | Isolate | Sampling locality | bp | % nt identity to our COI * | Note |
|------------------------|---------|---------|-------------------|----|--------------------------|------|
| LS992554               | Symplegma brakenhielmi | Italy | 834 | 96.9 | This study |
| FJS28648               | Symplegma rubra | Kenya | 620 | 95.5 |
| KX138510               | Symplegma brakenhielmi | DBTIC136 | 676 | 97.8 |
| KT726224               | Symplegma brakenhielmi | DBTIC38 | 567 | 96 |
| KU360802               | Symplegma brakenhielmi | ASC17 | 600 | 96.5 |
| KT726228               | Symplegma brakenhielmi | DBTIC49 | 645 | 96.5 |
| KR815818               | Symplegma brakenhielmi | DBTIC08 | 615 | 53.9 |
| KR815819               | Symplegma brakenhielmi | DBTIC12 | 543 | 26.0 |
| FJS28651               | Stolonica socialis | i69 | Spain | 297 | 96.6 |
| FJS28647               | Polyzoa opuntia | i73 | Argentina | 628 |
| FJS28652               | Distomus variolosus | i84 | UK, Plymouth | 676 |
| FJS28653               | Distomus variolosus | i85 | UK | 679 |
| FJS28654               | Distomus variolosus | i86 | UK | 678 |
| KF309623               | Distomus variolosus | DS-5 | Spain, Catalunya | 586 |
| KF309643               | Polyandrocarpa zorritensis | iSCR-3 | Spain, Catalunya | 586 |
| KY111429               | Polyandrocarpa zorritensis | i29 | USA | 545 |
| KY111428               | Polyandrocarpa anguinea | i28 | USA | 576 |
| KY111427               | Polyandrocarpa anguinea | i27 | USA | 555 |
| KY111426               | Polyandrocarpa anguinea | i26 | USA | 618 |
| KX138505               | Polyandrocarpa zorritensis | DBTIC10 | India | 524 |
| KX138504               | Polyandrocarpa zorritensis | DBTIC09 | India | 523 |
| FM177702               | Botryllus schlosseri | VE | Italy | 1548 |

*: Identity to our COI sequence of 834 bp

Symplegma brakenhielmi (Michaelsen, 1904) Diandrocarpa brakenhielmi Michaelsen, 1904: 50-Mexico.
Symplegma viride: Van Name, 1945: 232-Tropical Atlantic Ocean.
Symplegma oceania Tokioka, 1961: 114-New Caledonia (Noumea Harbour); Symplegma oceania: Kott, 1985:257. Pacific and Indian Oceans.

Table 1. COI sequences of the nt-nr database (NCBI, 10th May 2018) analysed in this study.

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4 mm in length, with the youngest individuals intercalated between adults. Basal stolons and spherical ampullae were evident between the zooids, becoming particularly abundant around the margins of each colony, where they were elongated and parallel to one another (Fig. 4A). The gelatinous tunic of red specimens was slightly tougher than that of yellow ones in preserved colonies. Both red and yellow fresh colonies became uniformly grey in formalin (Fig. 4A).

Zooids

Zooids were dorso-ventrally flattened with the oral and atrial apertures on the upper side of the body, the first one near the anterior end and the second in the middle (Fig. 4A, 4C). Both the apertures opened at the end of a short tubular siphon with a smooth rim. Atrial tentacles, fine and variable in number and length, were arranged around the oral siphon. Both in preserved and in vivo colonies, reddish brown (in red colonies) or yellowish (in yellow colonies) spots were evident on the body wall of zooids, resulting in a reticulated pattern (Fig. 2B-C; Fig. 4A-B). Zooids of the colonies collected during November 2018 appeared smaller than those collected in July 2014.
Branchial sac

The branchial sac was crossed by 10-11 rows of stigmata in both yellow and red colonies (Fig. 4C). Four longitudinal vessels on each side ran through the inner part of the branchial sac (Fig. 4C). The dorsal lamina was arranged in two parallel smooth edged blades.

Alimentary canal

The digestive system occupied the posterior end of the left side of the body. The stomach was pyriform, with 13 to 16 parallel folds. On the distal end its wall presented a blind diverticulum, the pyloric caecum (pc), which was stout and curved. Two connections linked the caecum with the intestinal loop; the first joined the base of the caecum and the descending branch of the gut loop, while the other one was branched, resulting in three connections that joined the curve of the caecum with the ascending limb (Fig. 4E). A notable constriction is placed between the stomach and the intestine (Fig. 4E). The anus, which showed a smooth margin, opened into the atrial cavity (Fig. 4E).

Gonads

The gonads, one on each side, were attached to the inner wall of the body. The right one was placed on the middle of the body, while the left one was located slightly anteriorly, in the middle of the range between the anterior end and the gut loop (Fig. 4F). Each gonad consisted of an ovary with a variable number of eggs (up to 3-4), and a testis divided into two pyriform male follicles sometimes lobed at their distal end, one anterior and the other posterior to the ovary. Male and female gonads were both mature at the same time. The deferens ducts came together in a single vas deferens which opened into the peribranchial cavity (Fig. 4F). Gonads and larvae were only recorded from the colonies collected in July 2014.

Larvae

*S. brakenhielmi* showed an ovoviviparous mode in reproduction, with larvae development occurring in the parental atrial cavity before release. Up to 4 larvae were occasionally found in the peribranchial cavity and were characterized by different development stages. Tadpole larvae were approximately 1.5 mm in total length, with the trunk measuring about 500 µm (Fig. 4G). They were orange in color, like the mature eggs. The trunk had three unstalked adhesive organs, tri-radially arranged, and a single sense organ, the photolith (Fig. 4G).
COI sequence comparisons

The 834-bp long COI sequences obtained from the two yellow and the two red type colonies were identical, thus demonstrating that these colonies belong to the same species. The comparison to the nt-nr db (10th May 2018) showed that our 834-bp sequence is 96.5±0.99% identical to the four shortest (567-676 bp) COI sequences of S. brakenhielmi and, surprisingly, it is also 96.9% identical to a 620-bp long COI sequence of the congenic S. rubra (Table 1). Phylogenetic and species delimitation analyses were performed within the Polypoidea in order to clarify the significance of the molecular similarity between S. brakenhielmi and S. rubra. The COI phylogenetic reconstruction (Fig. 5) strongly supported the clustering of all specimens of the two Symplegma species in a monophyletic clade (100% bootstrap) and identified monophyletic clades for three of the other four analysed species (i.e., Polyandrocarpa anguinea, Polyandrocarpa zorritensis and Distomus variolosus). All 12 ABGD species delimitation analyses (carried out on the three different alignments - alnBS_838, alnBS_442 and aln_442 - using the JC, K-2P and p-dist evolutionary distances) highlighted the existence of a clear barcode gap and showed a perfect match between the initial and the recursive partitions for prior intraspecific divergences ranging from 0.1% to 5.99%. Remarkably, all ABGD analyses indicated S. brakenhielmi and S. rubra sequences in the same OTU, thus suggesting a possible synonymy between S. brakenhielmi and S. rubra (Fig. 5). Apart from the case of Symplegma, each ABGD-identified OTU corresponded to a distinct species, as labeled by the sequence’s author based on morphological identification (Fig. 5), with the only exception being the creation of a singleton OTU for Distomus variolosus “i86” just in the analyses of the alnBS_838 alignment (data not shown). This suggested that the ABGD species delimitation results are mainly correct, in spite of the analysis of a dataset consisting of few sequences per species and only one S. rubra representative. The only available COI of S. rubra (FJ528648) was published without a morphological description of the relative specimen (Perez-Portela et al., 2009), but the Authors confirmed that this specimen had the typical red line encircling the siphons used as species diagnostic character for S. rubra (X. Turon, personal communication). Nevertheless, the possible synonymy between S. brakenhielmi and S. rubra must be further investigated through the concomitant molecular and morphological analyses of additional samples of the two species.

Unexpectedly, our S. brakenhielmi sequence was also 96.6% identical to a very short COI sequence of Stolonica socialis (297 bp) (Table 1). The usage of Symplegma-specific primers to obtain this S. socialis COI (Perez-Portela et al., 2009) raised doubts as to the source of this sequence, which therefore also needs to be confirmed by amplification and sequencing of additional S. socialis specimens. Indeed, we are not aware of ascidians belonging to different genera showing such a high level of similarity in COI barcode fragments.

The nt-nr db also contained two COI sequences of S. brakenhielmi (KR815818-19) having only 26-54% identity to our sequence (Table 1) but with highest and statistically significant similarity to aplousobranch and arthropod COIs according to BlastN results. These two sequences, both unpublished, are clearly the result of errors in db sequence submission or specimen identification.

Discussion

Within the Styelidae family, the Polypoidea subfamily is represented by colonial ascidians with zooids never arranged in systems, characterized by extensive color polymorphism, including pomegranate purple, orange-red, pale lemon, greenish lemon or sulfur yellow (Kott, 1985). In their recent monograph on European Ascidians, Brunetti & Mastrototo (2017) report a key to genera of the subfamily Polypoidea. According to this key, the assignment of the genus Symplegma was here based on the following characteristics: gonads all hermaphroditic with a single pair of male follicles, placed one on each side of the body wall lining the atrial cavity; branchial sac without folds and with four internal longitudinal vessels. Kott has published two different keys to species of the genera Symplegma (Kott, 1964, 1985). In the first key, Kott distinguished the four species Symplegma connectans Tokioka 1949, Symplegma reptans Oka 1927, Symplegma viride Herdman 1886 and S. oceania by the presence and shape of the pyloric caecum, as well as the number of its connections with the intestine loop and the number of rows of stigmata (Kott, 1964). Based on this first key, S. connectans is characterized by zooids without a pyloric caecum, but with a connection that links the stomach directly to the gut loop. S. reptans has a rounded pyloric caecum with 1 or 2 intestinal connections, and only up to ten rows of stigmata. S. viride is characterized by a branchial sac with more than 10 rows of stigmata and a curved pyloric caecum connected through 1 or 2 intestinal connections to the gut loop. S. oceania has a pyloric caecum linked to the gut loop by three intestinal connectives. In the second key, the same author (Kott, 1985), only described the three species Symplegma arenosa Kott 1972, S. reptans, and S. oceania, that can be distinguished by the presence and shape of the pyloric caecum, the position of the zooids and the number of stomach folds. According to this more recent key, S. arenosa is characterized by upright zooids, while those of S. reptans and S. oceania are prostrate and embedded in the common tunic. Moreover S. reptans does not show more than 8 stomach folds, and a short and straight pyloric caecum, while S. oceania has more than 8 folds and with a long and curved pyloric caecum. Subsequently, Monniot & Monniot 1997, as already mentioned, considering the nomenclature rules (ICZN, 1985), recognised S. oceania as a junior synonym of S. brakenhielmi (Michaelsen, 1904). Moreover, two other species of the genus were described: S. rubra and Symplegma bahraini Monniot & Monniot 1997. Although these latter two species are very similar to S. brakenhielmi, they can be distinguished from S. brakenhielmi because
they never present male and female mature gonads at the same time. In addition, *S. rubra* showed a characteristic pigmented ring linking both siphons, while *S. bahraini* showed a lighter area encircling the siphons and two larval sense organs (Kott, 2004; Monniot, 2002; Monniot & Monniot, 1997).

Based on our morphological analyses, it is possible to assign both our red and yellow type colonies to *S. brakenhielmi*. Indeed, our colonies are characterized by prostrate zooids embedded in the common test, more than 8 stomach folds, a long curved caecum with two intestinal connectives from the pyloric caecum, one simple and one divided in two (Kott, 1964, 1985), gonads mature at the same time, the lack of a pigmented ring or lighter area linking both siphons, and only one larval sense organ.

This study also confirms that *S. brakenhielmi* is characterized by color variability with at least two color types: the yellow and the red type. This is the first record of *S. brakenhielmi* in the western and central Mediterranean Sea but also the first report of yellow-type colonies in the Mediterranean Sea, since only reddish colonies had previously been found along the coasts of Turkey, Israel and Lebanon (Bitar & Kouli-Bitar, 2001; Činar et al., 2006; Shenkar & Loya, 2009; Ulman, 2016; Ulman et al., 2017). So far, *S. brakenhielmi* yellow colonies have been found in south and central America (Lotufo, 2002; Goodbody, 2003), while red colonies have been recorded from the Indian Ocean, Melanesia and the eastern Mediterranean Sea (Tamilselvi et al., 2011; Tokioka, 1961; Činar et al., 2006; Shenkar & Loya, 2009).

The possible synonymy between *S. brakenhielmi* and *S. rubra*, highlighted by the ABGD species delimitation analyses, is not supported by the current morphological description of these two species. Therefore, it needs to be verified through the analysis of a larger number of COI sequences and other non-genetic characters, such as morphological and ecological traits, in both species. It is also crucial to carry out all these analyses on exactly the same specimens, in order to exclude sampling bias or specimen misidentification.

Our study highlights the importance of a synergistic approach between morphological and molecular studies. In particular, each published nucleotide sequence should be linked, in the relative paper or in the database entry, to the morphological description of the specimen and/or to the taxonomic key used for the species assignment. Only in this way will it be possible to reduce the degree of uncertainty due to a potential rough specific identification, and to unambiguously associate a nucleotide sequence to specific morphological characters. This approach is even more important for non-indigenous species, since it will allow management policies to be promptly implemented. Target 5 of the EU Biodiversity Strategy (COM EU, 2011) states that European countries are committed to identify Invasive Alien Species and their pathways by 2020, in order to develop management strategies able to control and prevent the introduction and establishment of new invasive species. Ascidians are one of the main bio-fouling taxa (Gewing et al., 2017) and important indicators of invasions. In fact, the short-lived non-feeding larvae do not usually disperse very far (Svane & Young, 1989) so a new finding in distant localities is usually symptomatic of human-mediated transport. The two localities where *S. brakenhielmi* has been found (Olbia and Taranto) are both strongly affected by anthropogenic activities, such as industrial activities, intense naval traffic and large mussel farms (Cardellinicchio et al., 1991; Bracchi et al., 2016; Marchini et al., 2016; Tursi et al., 2018). Indeed, the areas surrounding Olbia and Taranto are considered Italian hotspots of alien species introduction (Cecere et al., 2016; Marchini et al., 2013; Mastrototaro et al., 2008). In particular, *S. brakenhielmi* could be considered an established species on North-Eastern Sardinian coasts, having been recorded every year since 2003, with gonad maturation during the summer (Trainito, 2005). Recent studies carried out in these two areas also show that the alien species pool depends on the importation of mussels for breeding and that even the movement of vessels from these harbors can be an important invasion pathway for further spread of these aquaculture hitch-hikers (Cecere et al., 2016; Marchini et al., 2016). The proximity of the finding’s localities to commercial harbors and aquaculture activities suggests that mollusk importation together with naval traffic could be the most likely vector of introduction, as well as of the future spread, of the invasive ascidian *S. brakenhielmi*.

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The authors declare that they have no conflict of interest.

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