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Occurrence of *Abudefduf* spp. (Pisces: Pomacentridae) in the Lebanese coastal waters (eastern Mediterranean) - morphological traits and visual evidence

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Abstract

New records of fish of the genus *Abudefduf* observed and photographed in the Lebanese coastal waters are reported in the paper. The individuals from photos were examined on the basis of visible external morphological characters and geographical location already known in the Mediterranean Sea, as well as compared with photos taken elsewhere in their natural environments from various online sources. In agreement with that reported by other authors, a careful analysis of these photos shows uncertainties in the validity of the visual characters previously used to distinguish between the two congeners *A. vaigiensis* and *A. saxatilis* already reported in the Mediterranean Sea, and even their possible confusion with *A. troschelii*. In some individuals, new morphological features are emphasized and may provide visual evidence for the presence of *Abudefduf* cf. *troschelii* (Gill, 1862). Sympatry and possible hybridization are discussed.

Keywords: Lebanese coast; eastern Mediterranean Sea; *Abudefduf* spp.; non-indigenous species; sympatry.

Introduction

In the Mediterranean Sea, the family of Pomacentridae Bonaparte, 1831 includes a single native species, *Chromis chromis* (Linnaeus, 1758), and seven exotic or cryptogenic species, namely *Abudefduf hoefleri* (Steindachner, 1881), *Abudefduf saxatilis* (Linnaeus, 1758), *Abudefduf sexfasciatus* (Lacepède, 1801), *Abudefduf vaigiensis* (Quoy & Gaimard, 1825), *Chrysiptera cyanea* (Quoy & Gaimard, 1825), *Chrysiptera hemicyanea* (Weber, 1913), and *Stegastes variabilis* (Castelnau, 1855) (Tardent, 1959; Goren & Galil, 1998; Vacchi & Chiantore 2000; Lipej *et al.*, 2014; 2019; Deidun & Castriota, 2014; Vella *et al.*, 2015; Vella *et al.*, 2016a, 2016b; Bilecenoglu, 2016; Giovos *et al.*, 2018; Deidun *et al.*, 2018; Osca *et al.*, 2020; Zenetos & Galanidi, 2020; Saad *et al.*, 2020). Along the Lebanese coast, the Atlanto-Mediterranean *C. chromis* is commonly observed forming schools in coastal habitats. However, the Indo-Pacific sergeant *A. vaigiensis*, already reported in the Levant Sea by Goren & Galil (1998), was recorded for the first time in the waters of Khaizaran, south of Lebanon in 2012 (Bitar, 2013; SPA/RAC-UN Environment/MAP, 2018). It was identified by examination of external morphological characters as seen in the photographs taken during fieldwork.

Tsadok *et al.* (2015) showed the existence of Atlantic species, the sergeant major *A. saxatilis*, in the south Levantine waters on the basis of molecular evidence. On the basis of this research, the same author also questioned

the presence of *A. vaigiensis* in the western Mediterranean which had been reported from the gulfs of Naples (Tardent, 1959) Genoa (Vacchi & Chiantore, 2000), and the Levant (Goren & Galil, 1998). According to Tsadok *et al.* (2015), *A. vaigiensis* could be misidentified as *A. saxatilis*. Subsequently, Bariche *et al.* (2015) identified a specimen of *A. vaigiensis* from Lebanon through genetic barcoding, and one year later, Vella *et al.* (2016a) found in their genetic study that *A. vaigiensis* and *A. saxatilis* have co-existed in Malta since 2013. Furthermore, similar co-existence has been recorded in Libya (Osca *et al.*, 2020) and indeed, the last record of *A. vaigiensis*, identified solely on the basis of external morphology, was reported from Syria (Saad *et al.*, 2020).

From a taxonomic point of view, the two species *A. saxatilis* and *A. vaigiensis* have a large degree of overlap in morphology (i.e., meristics). In the past, there has been a confusion related to the classification of different species belonging to the genus *Abudefduf*, particularly in the distinction between *A. saxatilis* and *A. vaigiensis*. In the work of Deidun & Castriota (2014) and references therein, several authors assigned examined specimens to *A. saxatilis* from the Pacific; it probably belonged to *A. vaigiensis* according to the known biogeographical range of the two species. These two species, together with *A. troschelii* (Gill, 1862) from the eastern Pacific and *A. abdominalis* (Quoy & Gaimard, 1825) from the central Pacific, are closely related because they are separated by a short genetic distance and therefore taxonomy validi-

ty and the phylogenetic relationships between all these species are not well understood (Quenouille *et al.*, 2011). Likewise, *A. saxatilis* and *A. troschelii* are extremely similar morphologically, and are considered to be geminate (sisters) species that have diverged since the uplift of the Isthmus of Panama between 2 and 5 million years ago (Gorman *et al.*, 1977; Foster, 1987). Indeed, the recent study of Dragičević *et al.* (2021) tested the validity of the main external morphological characters used the identification and distinction between *A. saxatilis* and *A. vaiigiensis* by visual inspection of underwater photos of these species taken in their regions of origin.

In this context, this article aims to examine and discuss the different morphological traits of individuals of *Abudefduf* species observed and photographed in five localities of the Lebanese coast, and comparing them with different photographs obtained from various online sources, and taken in both the Atlantic and Indo-Pacific oceans.

Materials and Methods

The data reported in this article forms part of many multidisciplinary (benthic and nectonic) investigations done continuously for more than 30 years along the Lebanese coast. These investigations aimed to survey the biodiversity and the native marine habitats, often associated with the detection of new marine introductions, as well as the impacts of pollution, climate change, and non-native species. Accordingly, fish communities were investigated by snorkeling and scuba diving through visual surveys and censuses. The direct visual observation was complemented by underwater photographs. Photographs and short video footage were taken *in situ* using underwater cameras (Nikonos IV, Canon PowerShot A650 IS, Sony CyberShot 16.1, and Tough TG-4 Olympus). It is worth noting that particular attention has been given to the east-

ern Mediterranean characteristic species, non-native, and new species. Concerning the *Abudefduf* species, they have been found in Beirut, Saadiyat, Khaizaran, Tyre, and Nakoura (Fig. 1).

Results

Based on various studies highlighting the presence of *Abudefduf* in several localities of the Mediterranean Sea, a total of 133 photos was taken during field surveys in the morning, from five localities of the Lebanese coast in 2012 (73 photos) and in 2017 (59 photos), and one photo in 2020 were investigated. However, some of these recorded photos may be based on the same individuals; in fact, from a conservative point of view, the records reported include at least twenty-one different individuals. Table 1 presents the names of the surveyed localities, their geographic coordinates, dates of the investigations, the conservative number of individuals, and the number of photos taken in each locality.

It is worth noting that all of these localities belonging to the southern half of the Lebanese coast from Beirut (Fig. 1). The individuals were all observed in the first three meters of depth except for the single individual of *Abudefduf* sp. from Beirut which was in a large deep pool of the vermetid reef and the one from Nakoura which had been caught by a Lebanese fisher by fishing in molinette and shared via social network (Facebook). *Abudefduf* spp. were found either solitary or in groups of two, three, or four individuals.

According to the work of Allen (1991), Azzurro *et al.* (2013), Deidun & Castriota (2014), Vella *et al.* (2016a), and Lipej *et al.* (2019), *A. saxatilis* is morphologically distinguished from *A. vaiigiensis* firstly by the continuous extension of the fifth dark vertical bar on the posterior margin of the dorsal fin (e.g., *A. vaiigiensis* has a space between the bar and the extension), secondly by the ori-

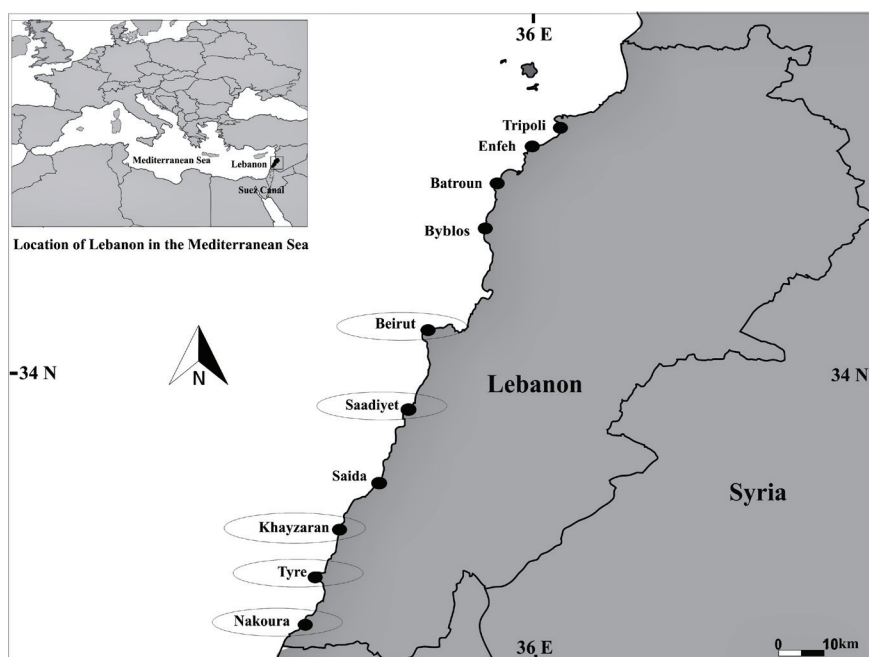


Fig. 1: Map of the Lebanese coast indicating the five localities surveyed, each circled by an oval.

Table 1. The localities surveyed (from the north to south of the Lebanese coast) with their geographical coordinates, date of investigations, conservative number of individuals, and number of photos taken in each locality. All photographs were taken by the author except one which was taken by a fisher at Nakoura.

Locality	Coordinates	Date	Conservative number of individuals	Number of shots
Beirut	33.902892° N 35.479625° E	September 25 th 2017	1	1
Saadiyat	33.698236° N 35.433711° E	June 29 th 2017	4	58
Khaizaran	33.446675° N 35.275592° E	August 9 th 2012	14	51
Tyre	33.265758° N 35.190892° E	September 15 th 2012	1	22
Nakoura	33.147156° N 35.153953° E	August 12 th 2020	1	1

gin of the 4th vertical bar which is located under the last dorsal spine, while in *A. vaigiensis* it is placed well behind the spine in the soft part of the dorsal fin, and thirdly by the presence of two black spots on the caudal peduncle. Azzurro *et al.*, (2013) also indicated a black spot at the upper base of the pectoral fins. Recently, Dragičević *et al.* (2021) highlighted the possibility that the main morphological characters previously used to distinguish *A. saxatilis* from *A. vaigiensis* are not consistent within the species and not sufficiently reliable for their definite identification. The same author pointed out the possible confusion of these above-mentioned species with another similar species, *A. troschelii*. Consequently, they re-assigned, as a cautionary measure, all the individuals visually identified as *A. saxatilis* or *A. vaigiensis* to the taxon *Abudefduf* cf. *saxatilis/vaigiensis/troschelii*.

Accordingly, in this study, and to distinguish between *Abudefduf* spp., we took into consideration the two distinctive criteria represented by the 5th bar on the body

of the species and the peduncle morphology. However, the 4th bar was not taken into consideration as a significant criterion because it generally requires the collection of specimens and moreover, it is considered not useful to distinguish between *A. saxatilis* and *A. vaigiensis* with accuracy (Allen, 1991; Deidun & Castriota, 2014; Dragičević *et al.*, 2021).

As a result, the majority of the *Abudefduf* individuals observed and photographed in the Lebanese waters (Fig. 2C), as well as the one caught in Nakoura, are characterized by a continuous 5th bar on the body, and by two spots on the caudal peduncle. It is worth noting that these distinctive morphological characters correspond to *A. saxatilis*, according to the Mediterranean literature until the end of 2020. Also, and based on our results, a few other individuals belonging to *A. vaigiensis* are characterized by a non-continuous 5th bar, separated from its extension, and the absence of spots on the peduncle. While the three individuals from Khaizaran and the one from Tyre are



Fig. 2: Principal forms of *Abudefduf* species observed (and photographed) in the Lebanese waters and provisionally identified on the basis of external morphological characters cited in the Mediterranean literature until 2020. (A): *A. saxatilis* found at the majority of the monitored sites; (B): *A. saxatilis* caught in Nakoura; both forms are characterized by a 5th bar without separation, and with two spots on the peduncle, marked by arrows; (C): *A. vaigiensis*, characterized by a 5th bar with separation and a peduncle without spots, marked by arrows; D, E): forms of *A. vaigiensis* with the corresponding 5th bar but with two spots in the peduncle, marked by arrows.

characterized by a 5th bar formed by two separate parts, but with two spots on the peduncle (Fig. 2D, E). This last form is not yet reported in the Mediterranean Sea. Based on the analysis of Dragičević *et al.* (2021), each of our three different forms of *Abudefduf* can correspond to either *A. saxatilis* or *A. vaigiensis* or even to *A. troschelii*. In this context, and since some Lebanese individuals exhibit other morphological features, we have examined various photos, originating from various online sources, from their native regions (Atlantic and Indo-Pacific), with permissions of the photographers. Also, additional photos have been sent to us for personal use by the photographers. For those photos for which we were unable to get a response to our request for use, we have simply provided their links (see Supplementary Material).

Photographs originating from online sources and corresponding to different forms of *A. saxatilis* and *A. vaigiensis* from Atlantic and Indo-Pacific origins are shown in Figure 3. From a comparative point of view, some of the forms are not in agreement with the specific morpholog-

ical characters mentioned in the Mediterranean literature which are used to distinguish between those two species. Such a remark has been already made for photographs in Malta (Deidun & Castriota, 2014). Confusion between these two species and *A. troschelii* (i.e., a species not yet reported in the Mediterranean) is also possible (see links 1-5 in Supplementary Material; Figures 3A and 3B correspond to links 1 and 2, respectively photograph by Peter Wirtz and Robert Patzner with permission in the legends).

In addition to those observations, individuals visible in the photos from online sources and attributed to *A. troschelii* show external morphological characters in line with those of both *A. saxatilis* and *A. vaigiensis* (see Figures 3E and 3F corresponding to links 6 and 8 in the Supplementary Material). Hence, they agree with the forms of *Abudefduf* spp. in the Lebanese waters. However, *A. troschelii*, a species distributed in the eastern Pacific, is particularly characterized by the presence of scales on the inner side of the base of the pectoral fin (Allen, 1991) which cannot be taken into consideration since it

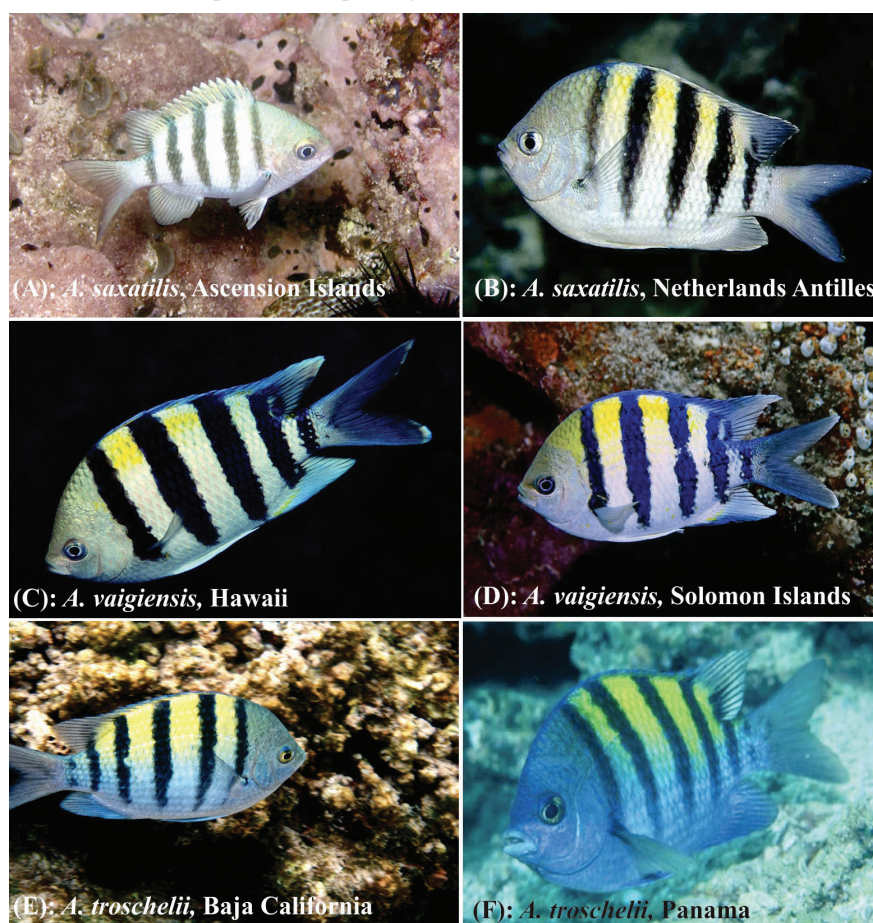


Fig. 3: Various photographs of *A. saxatilis*, *A. vaigiensis*, and *A. troschelii* taken from websites showing morphological characteristics different from the criteria of the two species cited in the Mediterranean literature: (A): *A. saxatilis* from Ascension Island, juvenile specimen characterized by a continuous 5th bar and a peduncle without spots (photograph by Peter Wirtz); (B): *A. saxatilis* from Bonaire, Netherlands Antilles, specimen characterized by a continuous 5th bar and a peduncle with two spots (photograph by Robert Patzner); (C): *A. vaigiensis* from Midway, Hawaii, characterized by a non-continuous 5th bar and a peduncle with two spots (photograph by Gerald R. Allen); (D): *A. vaigiensis* from Solomon Islands characterized by a non-continuous 5th bar and a peduncle without spots (photograph by Gerald R. Allen); (E): *A. troschelii* from Cabo Pulmo, Baja California, individual showing the same morphological characteristics, a continuous 5th bar and a peduncle with two spots, as two individuals of *A. saxatilis* photographed in the Lebanese waters (see Fig. 2A, B) (photograph by Roger Steeb); (F): *A. troschelii* from Panama, showing the same morphological characteristics, a non-continuous 5th bar and a peduncle with two spots, of the two individuals of *A. vaigiensis* photographed in the Lebanese waters (Fig. 2D, E) (photograph by Gerald R. Allen).

requires the collection of specimens.

One of our photos (Fig. 4) taken in Khaizaran shows the presence of both forms of *A. vaigiensis* (Fig. 4A) and *A. saxatilis* (Fig. 4B) reported in the Mediterranean literature. Based on the photos from online sources, this form is also attributable to *A. troschelii*. Therefore, the question is raised on how to distinguish between those forms and/or species with only photographs. It can be concluded that *A. vaigiensis* and *A. saxatilis* are probably sympatric in their new recipient region. At present it is not possible to presume the same for *A. troschelii*, although it cannot be rejected as well.

We also found individuals in the Lebanese waters characterized by various other morphological features at the level of the peduncles and the body shape, as follows:

The peduncles of both juveniles and adult individuals are either unspotted or have one spot or two (i.e., as the most common form mentioned above) or even three spots (i.e., Fig. 5). These different peduncles are already shown

in Figure 3 as well as in photos from online sources (links 9-15 in Supplementary Material).

In 1996, Randall in Azzurro *et al.* (2013) reported that the presence of two spots on the peduncle of *Abudefduf* is considered to be an incomplete sixth bar. In this context, we observed individuals of *Abudefduf* species in the Lebanese waters characterized by two other types of peduncles: either a peduncle with a stretched spot that clearly shows the beginning of a sixth bar (Fig. 6A) or another one with a full sixth bar (Fig. 6B). These two characteristics are also found in numerous photographs belonging to the three species recoded in the Atlantic and Indo-Pacific. As examples, the photos downloaded from online sources: (see links 16-22 in the list of Supplementary Material). The two figures (Fig. 6C of link 21 and Fig. 6D of link 22) each correspond to an *A. troschelii* originating respectively from Panama and Galapagos Islands: both have a 5th bar without separation and a 6th bar on the peduncle.

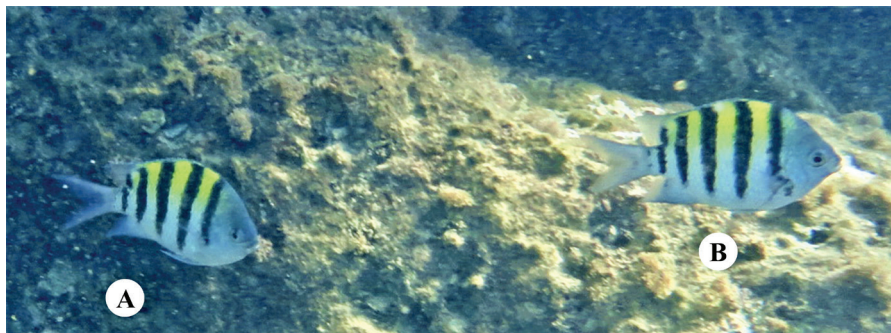


Fig. 4: Two individuals from Khaizaran (south Lebanon) showing the presence of two forms of *A. vaigiensis* (A), and *A. saxatilis* (B), morphologically distinguished according to previous Mediterranean literature.

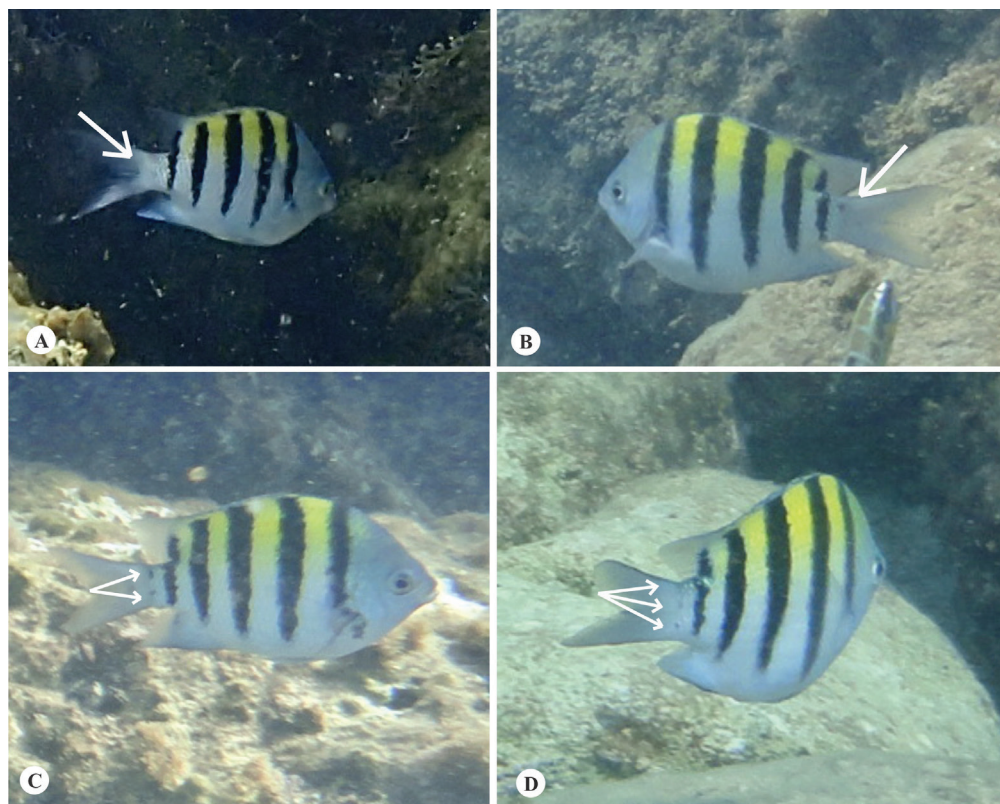


Fig. 5: Different peduncles observed in Lebanon. (A): Peduncle without spot; (B): Peduncle with one spot; (C): Peduncle with two spots, and (D): Peduncle with three spots. Arrows indicate the spots.

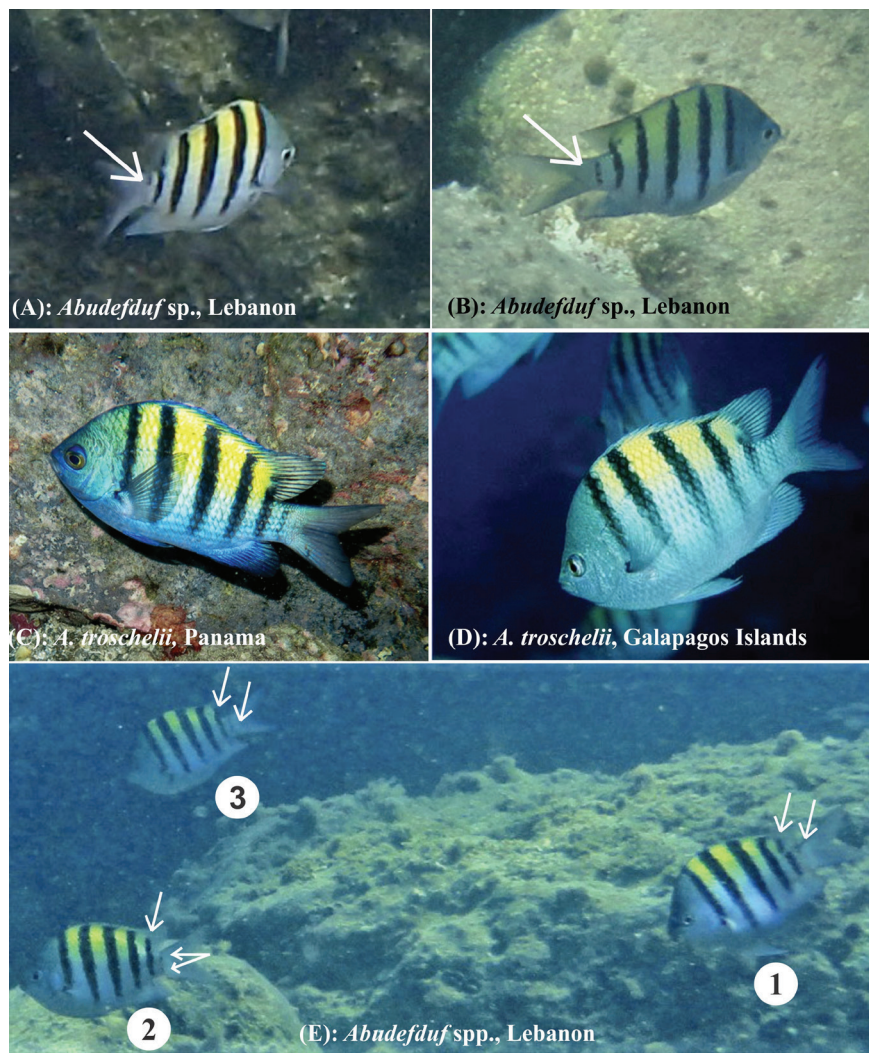


Fig. 6: Two individuals of *Abudedefduf* from Lebanon (A, B) similar to the photos of *A. troschelii* (C, D) from native regions. (A): with a stretched spot on the peduncle. (B): with a 6th bar on the peduncle. (C): *A. troschelii* from Panama (photograph by Ryan McMinds). (D): *A. troschelii* from Galapagos Islands (photograph by Gerald R. Allen). Both (A, B, C, D) have a 5th bar without separation and a 6th bar on the peduncle. (E): three individuals from Lebanon with different body shapes: the first (1) is characterized by its 5th continuous bar without separation and a peduncle with a single spot. The second (2) with a continuous 5th bar without separation, and a peduncle with two spots. The third (3) with a 5th continuous bar without separation, and a 6th bar on the peduncle.

A photo from the Lebanese collection (Fig. 6E) contains three individuals: the first (6E1) is characterized by a 5th continuous bar with visible, but not large separation, and a peduncle with a single spot; the second (6E2) has a 5th continuous bar without separation and two spots on the peduncle; and the third (6E3) with a 5th continuous bar without separation and a 6th bar on its peduncle. This is why, it is difficult to identify these *Abudedefduf* species with certainty and the possibility of presence of two or even three species cannot be rejected.

Regarding the shape of the body, we found that in addition to the oval shape of most of our individuals, two individuals had elongated bodies, one of which has a peduncle with a sixth bar and another without spots on its peduncle (Fig. 7). It should be noted that photos of *A. vaigiensis* and *A. troschelii* from some online sources featured individuals with elongated bodies (see links 23 to 25 in Supplementary Material).

Discussion and Conclusions

The appearance of the non-native fish *Abudedefduf vaigiensis* in Lebanon, identified on the basis of external morphological characters cited in the Mediterranean literature, dates from 2012 (Bitar, 2013). Subsequently, one specimen of the same species was genetically barcoded in 2015 (Bariche *et al.*, 2015). The morphological investigation of *Abudedefduf* spp. from five localities of the Lebanese coast shows different individuals with various morphological forms: the most abundant is the one characterized by an oval body, a 5th continuous bar without separation, and the presence of two spots on the peduncle. This form supposedly belongs to *A. saxatilis* according to external morphological traits reported in the Mediterranean literature up to 2020.

The presence of individuals with other external morphological traits observed in the photos of the individuals in the Lebanese waters and compared to the photos originating from various online sources of the three species



Fig. 7: Two photos showing individuals of *Abudefduf* spp. in the Lebanese waters characterized by the presence of individuals with both oval and elongated body shapes. (A): one of two *Abudefduf* with an elongated shape and a peduncle with a 6th bar (with the probability of the effect related to the position of the individual in photograph); (B): one of three *Abudefduf* with an elongated shape and with an unspotted peduncle, indicated by the arrow.

(*A. saxatilis*, *A. vaigiensis*, and *A. troschelii*) from their native regions (Atlantic and Indo-Pacific) deepen the confusion of the exact identification of these species.

The presence of two or three or even four individuals with different morphological characters in the same photos indicate either that we are working with the same species with varying morphology or two or even three different species. Therefore, the occurrence of sympatry between these species that could lead to hybridization cannot be excluded from our hypothesis. Furthermore, the presence of individuals characterized by oval and elongated body shapes should be noted. Based on the analyzed photos of the *Abudefduf* species from native ranges, it is important to note that individuals with the elongated bodies are characteristic of *A. troschelii* and *A. vaigiensis* (Fig. 7).

Indeed, the sympatry between two species can lead to the phenomenon of crossing and hybridization, as it has been reported in Hawaii between the endemic species *A. abdominalis* and the introduced one *A. vaigiensis* (Coleman, 2014). Likewise, the additional morphological features and the elongated body shape of some individuals suggest either the presence of *A. troschelii* or the presence of hybrid forms but such a hypothesis cannot be confirmed at present. Also, the presence of *A. troschelii* has not been ascertained in the Mediterranean but, and according to Coleman (pers. comm., 11 September

2020), the elongated form is found in the hybrid F1 *A. vaigiensis* x *A. abdominalis*. Coleman also noticed that F1 hybrids have a sixth black spot on the caudal peduncle (pers. comm., 11 September 2020).

It should also be noted that morphological variation was found in *A. saxatilis* studied in three localities along the Mexican Atlantic coast: Piñeros *et al.* (2015) found changes in body shape, head, and size which are all significantly associated with environmental factors such as chlorophyll a, temperature, and water flow velocity.

With regard to the arrival of *Abudefduf* spp. in the Mediterranean, in addition to the natural expansion of the range across the Strait of Gibraltar and the Suez Canal, the possible reasons for the emergence of *Abudefduf* spp. in the Lebanese waters are the seaway, marine debris (drifting garbage), oil-rig platforms (Pajuelo *et al.*, 2016), and the aquarium trade.

A careful analysis of the photos of *Abudefduf* spp. individuals in Lebanese waters agree with Dragičević *et al.* (2021) based on the distinction between *A. saxatilis* and *A. vaigiensis* in the Mediterranean Sea. The presence of other individuals in the Lebanese waters, distinguished by other morphological features not discussed in the work of Dragičević *et al.* (2021), allow us to mention the possible presence of *A. cf. troschelii*, at least in Lebanon. This species was not included in the image analysis of Dragičević *et al.* (2021) because it had not been reported

from the Mediterranean to date. Thus, it seems that these observations and analysis of photos are still insufficient for the accurate identification of *Abudefduf* in the Mediterranean region. Only *A. vaigiensis* has been barcoded in Lebanon and its presence is ascertained by Bariche *et al.* (2015). Subsequently, *A. saxatilis* is also present as it has been barcoded by molecular tools in the south Levantine waters (Tsadok *et al.*, 2015). Therefore, hybridization hypotheses are possible, while morphological ambiguity is probably related to variable morphology which allows overlaps given the wide distribution of the species.

The molecular approach with the morphological descriptions of *Abudefduf* spp. from the Lebanese coast, and indeed the whole Mediterranean, is necessary to obtain accurate identification, and consequently to study possible hybridization phenomena.

It is recommended to follow the status of these species, their evolution, and their impact on indigenous species, particularly on the native pomacentrid *C. chromis*. At the same time, monitoring dispersal of these non-natives throughout the Lebanese and Mediterranean coasts is needed. Volunteers (citizen science) along the Lebanese coast can play a significant role in this matter. This subject should be followed up in the EcAp-Med II project and the Integrated Monitoring and Assessment Program (IMAP) related to biodiversity (EO1) and non-native species (EO2).

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Supplementary data

The following supplementary information is available online for the article:

List of links consulted.