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Seven years and going strong: a comparative review of citizen Science, social media mining and field surveys in monitoring Libyan marine biodiversity

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Abstract

Libyan marine biodiversity is often described as under-studied and under-reported. However, in the past seven years, there has been a surge in the reporting of non-indigenous, and native species with the help of citizen science, social media mining-based research and field surveys. This review provides an updated checklist of non-indigenous fish species in Libyan waters. Between 2018 and July 2025, 14 non-indigenous species (NIS) and four range-expanding (RE) species were documented. Furthermore, between 2018 and July 2025, 27 species belonging to eight phyla (Porifera, Bryozoa, Tunicata, Cnidaria, Mollusca, Polychaeta, Decapoda, and Echinodermata) were recorded, including 23 NIS, one RE and three cryptogenic species. Additionally, this review paper draws a direct comparison between the scientific outcomes of citizen science, social media mining, and field surveys within the same time frame. The differences between the two main methods are discussed, with active and passive citizen science and social media mining produced the most non-indigenous fish species, while field surveys excelled in documenting native fish species, as well as small and minute species. Furthermore, this review addresses the implications of using citizen science and social media mining, pointing out the ethical concerns that have arisen from the methodologies observed in several scientific studies that employ these methods.

Keywords: Annotated checklist; Ethics; North Africa; Non-indigenous species.

Introduction

Following the natural catastrophe and subsequent floods caused by Storm Daniel on September 10, 2023, the destruction of large areas along the coast of Derna (Assessment Capacities Project, 2023; Altaeb & Sheira, 2024) highlighted the lack of baseline data in the city. This situation, with the exception of sporadic and irregular surveys (El Baraasi *et al*., 2019), personal research (Shakman, 2008), and a few reports from Marine Protected Areas (MPAs) (Bazairi *et al.*, 2013, Shakman *et al.*, 2024), is observed along the entire Libyan coastline (Regional Activity Centre for Specially Protected Areas, 2017). This issue was discussed at the Mediterranean Conference on Marine and Coastal Biodiversity in the Mediterranean Sea, held in Tripoli between April 12th – 14th, 2025 (Link: https://lsaff.org.ly/event/mediterranean-conference-on-marine-and-coastal-biodiversity-2025/#agend). Baseline data, which serve as a reference point for comparison to measure change (McQuatters-Gollop *et al*., 2022), when not available, hinder efforts to accurately assess the damage to marine biodiversity sustained following natural catastrophes when they are not available. Furthermore, assessing Libya's biodiversity to establish baseline data on its marine biodiversity is especially important now that Libya is progressing towards implementing a blue economy strategy, with a focus on marine biodiversity (Communication team, 2024), which is considered a key pillar of a sustainable blue economy (Kyriazi *et al*., 2023).

Establishing a baseline dataset (Appeltans *et al*., 2016) is crucial, especially in a water body like the Mediterranean Sea that is heavily impacted by various factors such as climate change, overfishing and continuous pressure from non-indigenous species (NIS) (Korpinen *et al.*, 2019). These data are essential for developing national strategies (Regional Activity Centre for Specially Protected Areas, 2017) and help to predict geographic patterns of occurrence (Elith *et al.*, 2006). Additionally, timely reporting of non-indigenous species, especially during their initial phase of colonisation (Mehta *et al.*, 2007) is crucial for early responses that could potentially prevent their establishment or mitigate their spread (Castro *et al*., 2021). However, this is often a difficult, time-consuming, and costly endeavour (Reaser *et al.*, 2019). The non-indigenous biota of Libya is still not

well-documented, with few annotated checklists available (Bazairi *et al.*, 2013; Shakman *et al*., 2019; Galanidi *et al*., 2023). This lack of information on Libyan biota, as well as the limited records of non-indigenous species, can be attributed to various factors. Libya's extensive, mostly remote coastline (Shakman *et al*., 2019) makes surveys aiming to assess marine biodiversity a mammoth task (Rizgalla, 2021). Coupled with 50 years of on-and-off political unrest (Mishra, 2025), social and economic constraints, and limited research funding (Rizgalla *et al*., 2019a; Rizgalla, 2021) have further hindered comprehensive studies in the area.

In response, almost parallel to the trend in other Mediterranean countries such as Lebanon (Bariche & Azzurro, 2016), Italy (Azzurro & Tiralongo, 2020), Greece (Giovos *et al*., 2019), Malta (Deidun *et al*., 2024) and Spain (Figuerola-Ferrando *et al*., 2024), social media mining and citizen science-based research began to develop in Libya (Rizgalla *et al*., 2017; Al Mabruk *et al.*, 2018). Over recent years, citizen science and social media mining have increasingly produced scientific output in various fields, including fish disease surveillance (Rizgalla *et al*., 2017), recording and monitoring of indigenous, and non-indigenous species (Al Mabruk *et al*., 2018; Al Mabruk & Rizgalla, 2019; Ragkousis *et al*., 2023), and macrofauna e.g., sea turtles (Rizgalla *et al*., 2020), contributing in recent years to increasing our knowledge of the country's underreported marine biodiversity.

Citizen science (CS) is a concept that has over 38 definitions (Haklay *et al.*, 2021). Bonney *et al.* (2016) define it as an activity that usually involves the voluntary participation of the general public in various stages of scientific research processes, particularly in data analysis. Encarnação *et al.* (2021) further define it as "any environmental and/or biological data collection and analysis, including data quality control, undertaken by members of the general public, as individuals or as organized groups of citizens, with the guidance and/or assistance of scientists towards solving environmental and/or community questions." This term is further divided depending on its nature into active citizen science (ACS) and passive citizen science (PCS).

Active citizen science is defined as the process whereby a person intentionally joins a specific research group as a volunteer, either with or without training, and is part of this research group for part or the entire research period (Bonney *et al.*, 2021).

Passive citizen science involves social media users who share their images on relevant social media platforms for purposes not originally intended for science. This method does not fall under specific campaigns or restrictions on species observations and timeframes; instead, data are extracted by scientists (Otero *et al.*, 2025). Defined as social media mining (SMM), which is the process of extracting data, including images, from user-generated content (defined as PCS) on social media platforms (Otero *et al.*, 2025). It is especially useful for identifying patterns or for epidemiological studies (Rizgalla *et al.*, 2017). All three methods are particularly helpful when collecting image-dependent information (Rizgalla *et al.*, 2017; Rizgalla, 2020).

These methods have proven to be a relatively low-cost new discipline (Skarzauskiene & Mačiulienė, 2021; Encarnação *et al.*, 2021), especially useful for overcoming geopolitical hurdles (Rizgalla, 2021). Citizen science (passive or active) and SMM are a direct result of the internet, social media platforms, and mobile phones equipped with a camera, which have developed into an alternative or supporting tool for field surveys and serve a complementary tool to classical research (Giovos *et al*., 2019).

With the global increase in the use of CS, there is a growing call for the regulation of this relatively new tool (Robinson *et al.*, 2018). Journals are becoming more concerned with the validity of data, fact-checking of records, (Lameira *et al.*, 2025) and maintaining scientific and ethical standards (Hunter & Hsu, 2015). These concerns, such as adequately acknowledging the role of CS in producing specific scientific work, are thoroughly addressed by several research groups (Hunter & Hsu, 2015; Monkman *et al*., 2018). Robinson *et al.* (2018) proposed a 10-point concept for regulating the use of CS and SMM. These guidelines outline what researchers can do or should adhere to when utilizing citizen science and social media mining for their research. Some researchers are taking this a step further by including citizen scientists as co-authors, depending on their role in the scientific work (Sandin *et al.*, 2025).

In Libya, the taxonomic group receiving the most attention from researchers is bony fish, including both native and NIS (El Baraasi *et al*., 2019; Shakman *et al*., 2019). The first report on Libyan bony fish was by Vinciguerra (1881), who documented 17 bony fish species off the coast of Tripoli. Irregular records continued into the 20th century, with the last update coming twenty years after the Contransimex' s study (1977). This update almost doubled the list to 201 bony fish species reported off the coast of Benghazi by Al-Hassan & El-Silini (1999), adding 42 first records for Libyan waters and nine NIS. Another twenty years passed before the most recent checklist by El Baraasi *et al*. (2019), which reported 104 new bony fish species as first records for Libya and 22 NIS, while Shakman *et al*. (2019) reported on 73 NIS belonging to different genera along the Libyan coastline, updating the list of bony fish NIS to 24 species. These numbers are significantly lower compared to the 342 NIS in the Aegean Sea (Zenetos *et al*., 2025) and the 173 non-indigenous fish species reported in the Mediterranean Sea (Zenetos *et al*., 2022), or the 303 species recorded from the central Mediterranean Sea (Galanidi *et al*., 2023). Even when excluding rare species that have only been seen once, the discrepancy in numbers is implausible (Shakman *et al*., 2019).

Mollusca is the second group of species that has drawn the attention of researchers. Various publications have been produced, including a few checklists, which have been recently compiled in Bek-Benghazi *et al.* (2020) incomplete list of native and NIS marine mollusks in Libyan waters. There is no mention of Heterobranchia, which were until recently overlooked and mostly never

reported in Libyan waters (Rizgalla *et al.*, 2025).

The latest study by Galanidi *et al*. (2023) updated the list of NIS in Libya to 77 species of different genera. The trend of fragmented reporting is particularly evident in marine taxa such as Cnidaria (e.g., Abushaala *et al*., 2022), while recently albeit incomplete updated checklists of Crustaceans Bek-Benghazi *et al.* (2025), and Echinodermata (Benzeglam *et al.*, 2025) have been published. Meanwhile, other groups such as Polychaeta and Tunicata lack in data (Bazairi *et al.*, 2013), and were only recently reported from a few specimens via field work (Rizgalla *et al.*, 2019a).

This review will summarise non-native species resulting from SMM, CS (ACS & PCS), comparing these findings to field surveys conducted during the same period. An updated checklist of non-indigenous bony fish, in addition to a list of NIS from eight different phyla, will be included. This review will address the time-lag between data collection and reporting, as discussed by Zenetos *et al*. (2019), and its potential impact on misinterpreting the fish invasive process or spread in Libya and the Mediterranean Basin. The mechanism of citizen science collaboration, its outcomes, demographic locations, and the type of records will be explored. Ethical standards related to the use of citizen science and social media mining will be discussed, along with areas for improvement.

Materials and Methods

The literature search encompassed Google Scholar, Google Search, Scopus, and ResearchGate. The baseline date for extracting the literature in this review was determined by the publication date of the first paper on marine biodiversity that utilized active citizen science (ACS) and/ or passive citizen science (PCS) (found via social media mining (SMM)) as sources for scientific output. The earliest relevant record was by Al Mabruk *et al*. (2018), who reported a non-indigenous fish species in the eastern Libya with the assistance of CS. The study period was set from 2018 to July 2025 (for both social media and fieldwork).

The published literature was categorised into fieldwork (F), PCS, ACS and hybrid records (combining field surveys with PCA, ACS and /or SMM). Each table specified the recording method (ACS, PCS, fieldwork, or a combination), the year of the post and if it was possible to obtain a specimen. In addition, the first Libyan record was noted. For ACS and PCS records, the collection methods for obtaining the records were noted, these included, spearfishing (harpooning), angling, blast fishing, netting, and manual collection.

The records were divided into two lists, including NIS, RE and cryptogenic species. The first was for bony fish (sorted by genus), and the second list containing all the other species recorded during the timeframe (sorted by phylum). In both lists, the initial detection year and region of the NIS—along with subsequent observations, where applicable—were documented. The regional division (East, West and Center) and biogeographic rationale are based on two primary factors. First, the regional approach accounts for known biogeographic boundaries and prevailing currents that influence NIS dispersal. By splitting the data, we can more effectively observe the "stepping-stone" progression of species moving from the Levantine Basin (East) toward the central Mediterranean (West) and vice versa. Second, this division allows us to better distinguish between natural range expansions and the influence of human-mediated vectors, such as shipping traffic.

Validation of records

To ensure data integrity, records gathered during the study period (2018– July 2025) underwent a stringent validation process. For data derived from Social Media Mining (SMM) and Citizen Science (CS), identifications were authenticated through a multi-tiered assessment: first, by evaluating the provided metadata and sampling context; and second, through the critical analysis of diagnostic morphological features captured in photographic evidence. Any records lacking high-resolution visual documentation or exhibiting taxonomic ambiguity were categorized as doubtful or refuted, as detailed in the Results section.

Time lag

The time lag between observation and publication year indicated the reporting delay of the species.

Social Media Records & Citizen Science Engagement

Citizen scientist collaboration frequency and geographical location were identified based on the number of times a citizen scientist was mentioned as a source of a record, in the materials and methods, photo credits, or the acknowledgment section.

Ethical considerations

Ethical standards were evaluated in active and passive citizen science-based publications following the guidelines set by Robinson *et al.* (2018). This evaluation involved examining the methodology and acknowledgments of the publications. Specifically, it was determined whether consent was clearly obtained from administrators of the different social media platforms to conduct the SMM, or if clear consent was obtained from the citizen scientists themselves to use their material. Furthermore, the adequacy of acknowledging citizen scientists was assessed in the acknowledgments, ensuring they were properly credited in the records.

Research groups

Based on a systematic review of published literature and scientific productivity a comprehensive inventory of academic institutions, government bodies, NGOs, and specific research projects specializing in marine biodiversity and citizen science was established. Furthermore, cross-border collaborations were quantified by analysing institutional partnerships and their subsequent co-authorship outputs. To highlight domestic capacity, and link it to scientific output location (East, Center or West of Libya), the specific geographical distribution of Libya-based researchers was also documented. This spatial mapping allows for a direct correlation between institutional headquarters (or researcher affiliation) and the specific regional focus of their marine biodiversity contributions.

Nomenclature was updated as needed following the World Register of Marine Species (WoRMS Editorial Board, 2025).

Results

Between 2018 and July 2025, including two significant records published in late 2025 and February 2026, a total of 45 publications were produced (Table 1). The majority of these publications reported on the first records of NIS, RE and Cryptogenic species (Figs 1 & 2 and Tables 2 & 3).

Species inventory

Bony fish were the most frequently recorded group. Between 2018 and July 2025, 14 new non-indigenous species (NIS) were recorded using active and passive citizen science, SMM, and field surveys (Table 2). Including two significant records published in late 2025 and February 2026 —*Heniochus intermedius* Steindachner, 1893 (Fitori & Rizgalla, 2025) and *Siganus javus* (Linnaeus, 1766) (Zenetos *et al.*, 2026)— the total checklist of non-indigenous fish species has increased to 38.

Most NIS were recorded for the first time in the east of Libya, while the majority of range-expanding species (RE) of Atlantic origin were found in the west of Libya (refer to Table 2; Figs 1 & 2).

It is worth mentioning, that native species with over 100 species were predominantly documented by field surveys, (e.g., El Baraasi *et al*., 2019). In contrast to only few native fish species documented by CS *Schedophilus ovalis* (Cuvier, 1833) (e.g., Fitori & Golani, 2025b).

A total of 27 non-native species from eight phyla, including Porifera, Bryozoa, Tunicata, Cnidaria, Mollusca, Polychaeta, Decapoda and Echinodermata were recorded between 2018 and July 2025. This total includes 23 NIS and one RE, as well as three cryptogenic species (refer to Tables 1&3; Fig. 1). Some species were observed twice, with one to two years between sightings (Table 2 and 3).

The record of the nudibranch *Algarvia alba* García-Gómez & Cervera, 1989 reported by Fitori *et al*. (2024b) was considered doubtful. This is because the photograph of the specimen is of such poor quality that diagnostic features of the genus Algarvia cannot be confirmed; furthermore, the absence of a preserved voucher specimen makes independent anatomical review impossible, rendering the record unverifiable.

Time Lag

The time lag from recording to publication for CS (active and passive), SMM, and field surveys conducted between 2018 and July 2025 ranged from 0 to 7 years. A lag of 0 indicates that publications were released in the same calendar year, or within one month of posting (refer to Tables 2 and 3).

Research groups

Records were obtained from six research groups across five cities: Tobruk, Derna, Al-Bayda and Benghazi in the east, and Tripoli and Tajoura in the west (Table 4).

Table 1. Number of research outputs of first records or spread of non-invasive species (**NIS**), cryptogenic (**Cry**), range expansion (**RE**), including bony fish (Chordata), and other taxa (Cnidaria, Decapoda, Echinodermata, Mollusca, Polychaeta, and Tunicata), produced by Libya-based research groups between 2018 and June 2025. **Note**: Two additional NIS fish records published in late 2025 and February 2026 were included to provide the most recent available data.

Type	Pub	sp.	F	ACS	SMM	Combi	Y	N
Fish sp.	22	20*	2	13	6	1	14	6
Other taxa	23	27**	13	6	3	1	10	
Total	**45**	**47**	**15**	**19**	**9**	**2**	**24**	**6**

Abbreviations: **ACS**: Record obtained by active citizen science; **Combi**: Record obtained by combining field surveys with PCA, ACS and /or SMM; **F**: Record obtained by field work; **N**: Indicates whether citizen science was not acknowledged; **Pub**: number of publications; **sp**.: Number of species; **SMM**: Record obtained by social media mining; **Y**: Indicates whether citizen science was acknowledged; *: includes (NIS: 16; RE: 4); **: includes (NIS: 23; RE: 1; Cry: 3)

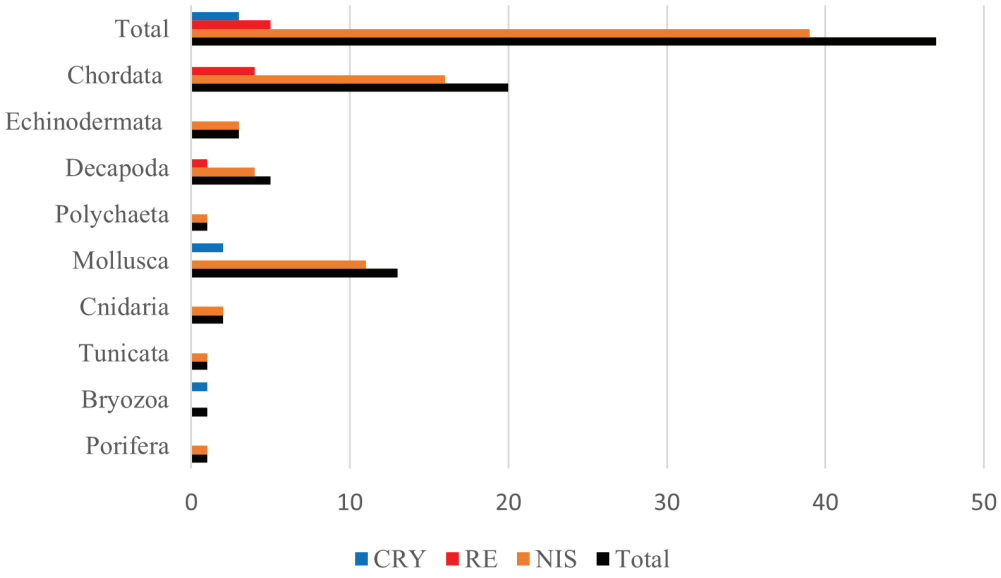

Fig. 1: Numbers and geographical location of the Phyla recorded from 2018- June 2025 in Libyan waters. **Abbreviations**: **C**: Center; **CRY**: Cryptogenic; **E**: East; **N**: Number of species; **NIS**: Non-indigenous species; **RE**: range expansion; **SMM**: Social media mining; **W**: West; **W&E**: West and East. **Note**: Two additional NIS fish records published in late 2025 and February 2026 were included.

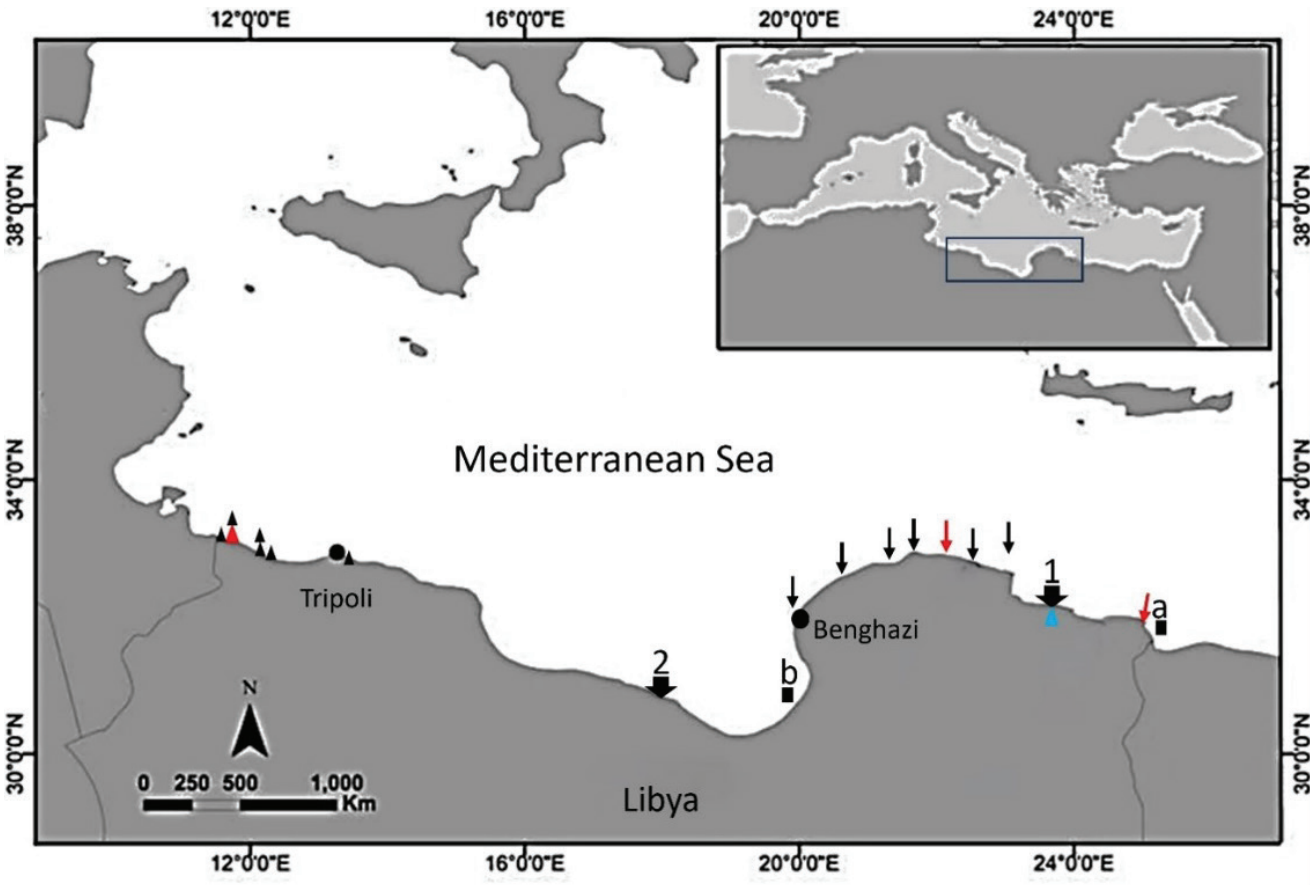

Fig. 2: Map highlighting the spread of a several NIS along the Libyan coastline including their first and second records, and range expansion (along the Libyan coastline). *Pterois miles* has expanded its rage 400 km from its first tow records in 2019 (shown with thin red arow). This expansion includes moving from the easternmost record at the border between Egypt and Libya (El Burdi) to the shores of Benghazi (Ragkousis *et al*., 2023). *Pteragogus trispilus* first record (thick arrow 1) (Fitori *et al*., 2021) and second record (thick arrow 2) (Nour *et al*., 2022). For *Diadema setosum*, the first record in the east (black square a) and second record in the centre, on the island of Gara (black square b). *Portunus segnis* first record (blue triangle) 2017 East of Libya by Shakman *et al*. (2017). Subsequently it was recorded in 2018 in in the Farwa lagoon (MPA) the west of Libya (red triangle) (Shakman *et al*., 2019), and along various points along the western Libyan coastline (black triangles) (Corsini-Foka *et al*., 2021).

Table 2. Non indigenous and range expansion fish species recorded in Libyan waters (47) including 38 NIS and 9 RE. **Note:** Two additional NIS fish records published in late 2025 and February 2026 were included to provide the most recent available data.

Species	GL	Org	1LD	R	Res	M	R	Lag
Order Angulliformes								
Muraenidae								
Enchelycore anatina (Lowe, 1838)	E	RE	2020	Ibrahim *et al*., 2022	E	CS		2
Order Clupeiformes								
Clupeidae								
Etrumeus golanii DiBattista, Randall & Bowen, 2012	W	NIS	2017	Shakman *et al*., 2017	W	ns	2	0
Herklotsichthys punctatus (Rüppell, 1837)	E	NIS	2005	Shakman & Kinzelbach, 2007	W	ns	2; 3	2
Synodontidae								
Saurida lessepsianus Russell, Golani, Tikochinski, 2015	Al	NIS	1982	Zupanovic & El-Buni, 1982	W	F	1;2;3	un
Order Atheriniformes								
Atherinidae								
Atherinomorus forskalii (Rüppell, 1838)	E	NIS	1929	Norman (1929) as *Prasenus pinguis* confirmed Shakman *et al*., 2017	W	ns	2; 3	un
Order Beloniformes								
Hemiramphidae								
Hemiramphus far Forsskal, 1775	E	NIS	2006	Shakman & Kinzelbach, 2006	W	F	2; 3	un
Exocoetidae								
Parexocoetus mento (Valenciennes, 1846)	E	NIS	1966	Ben-Tuvia, 1966	C	F	1; 2; 3	un
Order Holocentriformes								
Holocentridae								
Sargocentron rubrum Forsskål, 1775	W	NIS	1968	Štirn, 1970	W	F	1; 2; 3	2
Order Syngnathiformes								
Fistulariidae								
Fistularia commersonii Ruppell, 1838	E	NIS	2004	Ben Abdallah *et al*., 2005b	W	F	2; 3	1
Order Perciformes								
Scorpaenidae								
Pterois miles (Bennett, 1828)	E	NIS	2018	Al-Mabruk & Rizgalla, 2019	E&W	CS		1
Epinephelidae								
Cephalopholis taeniops (Valenciennes, 1828)	E	RE	2004	Ben Abdallah *et al*., 2007	E	ns	3	3
Order Apogoniformes								
Apogonidae								
Apogonichthyoides pharaonis (Bellotti, 1874)	E	NIS	2020	Al Mabruk *et al*., 2021	E	CS		1

Continued

Table 2 continued

Species	GL	Org	1LD	R	Res	M	R	Lag
Order Carangiformes								
Rachycentridae								
Rachycentron canadum (Linnaeus, 1766)	E	NIS	2019	Nour *et al*., 2021	E	CS		2
Carangidae								
Alepes djedaba Forsskal, 1775	E	NIS	1990	Ben Abdallah *et al*., 2005a	W	F	2; 3	15
Seriola fasciata (Bloch, 1793)	W	RE	2003	Shakman *et al*., 2017	W	ns	3	14
Seriola rivoliana (Valenciennes, 1833)	W	RE	2004	Shakman *et al*., 2017	E	ns	1,3	13
Eupercaria incertae sedis								
Haemulidae								
Pomadasys argenteus (Forsskål, 1775)	W	NIS	2022	Fitori *et al*., 2023a	E	CS		1
Labridae								
Pteragogus trispilus Randall 2014	E[#]&C*	NIS	2021	Fitori *et al*., 2021[#], Nour *et al*., 2022a* (CS)	E	F[#]; CS*		0
Sparidae								
Crenidens crenidens Forsskal, 1775	E	NIS	1999	AL-Hassan & EL-Silini, 1999	E	F	1;2; 3	un
Order Mulliformes								
Mullidae								
Upeneus moluccensis (Bleeker, 1855)	E	NIS	1968	Štirn, 1970	-	F	1; 3	2
Upeneus pori Ben-Tuvia & Golani, 1989	E	NIS	1994	Ben Abdallah *et al*., 2005a	W	F	2; 3	11
Parupeneus forsskali (Fourmanoir & Guézé, 1976)	E	NIS	2018	Bariche *et al*., 2020	W	CS		2
Order Acropomatiformes								
Pempheridae								
Pempheris rhomboidea Kossmann & Räuber, 1877	E	NIS	2004	Ben Abdallah *et al*., 2004	W	F	2; 3	un
Order Ovalentaria incertae sedis								
Pomacentridae								
Abudefduf cf. saxatilis (Linnaeus, 1758)	W	RE	2019	Osca *et al*., 2020	W	F		1
Abudefduf vaigiensis (Quoy & Gaimard 1825)	W	NIS	2018	Osca *et al*., 2020	W	F&SMM		2
Order Centrarchiformes								
Kyphosidae								
Kyphosus sectatrix (Linnaeus, 1758)	E*	RE	2013	El Baraasi *et al.*, 2013	E	ns	3	un
Kyphosus vaigiensis (Quoy & Gaimard, 1825)	E	RE	2021	Fitori *et al*., 2022a	E	CS		1
Terapontidae								
Terapon jarbua (Forsskål, 1775)	E	NIS	2020	Ibrahim *et al*., 2023	E	CS		3

Continued

Table 2 continued

Species	GL	Org	1LD	R	Res	M	R	Lag
Order Mugiliformes								
Mugilidae								
Planiliza carinata (Valenciennes, 1836)	E	NIS	2005	Shakman & Kinzelbach, 2007	W	F	2; 3	2
Order Acanthuriformes								
Chaetodontidae								
Heniochus intermedius Steindachner, 1893*	E	NIS	2025	Fitori & Rizgalla, 2025	E/W	SMM		0
Siganidae								
Siganus argenteus (Quoy & Gaimard,1825)	E	NIS	2015	Abdulghani *et al*., 2021	E	CS		6
Siganus luridus Rüppell, 1829	E	NIS	1950-60	Štirn, 1970	-	F	1; 2; 3	un
Siganus rivulatus Forsskål, 1775	E	NIS	1968	Štirn, 1970	-	F	1; 2; 3	2
Siganus javus (Linnaeus, 1766)	E	NIS	2025	Zenetos *et al*., 2026	E	CS		0
Acanthuridae								
Acanthurus xanthopterus Valenciennes, 1835	E	NIS	2024	Fitori *et al*., 2024a	E	SMM		0
Acanthurus monroviae Steindachner, 1876	W	RE	2019	Bariche *et al*., 2020	W	CS		1
Order Carangaria incertae sedis								
Sphyraenidae								
Sphyraena chrysotaenia Klunzinger, 1884	E	NIS	1950-60	Štirn, 1970	-	F	1; 2; 3	un
Sphyraena flavicauda Rüppell, 1838	E	NIS	1998	Ben Abdallah *et al*., 2003	W	F	2; 3	8
Order Scombriformes								
Scombridae								
Scomberomorus commerson Lacepède, 1800	E	NIS	1974	Ben Abdallah *et al*., 2003	W	F	2; 3	un
Order Tetraodontiformes								
Monacanthidae								
Stephanolepis diaspros Fraser-Brunner, 1940	E	NIS	1965	Chakroun, 1966	-	F	1; 2; 3	1
Diodontidae								
Diodon hystrix Linnaeus, 1758	E	NIS	2025	Fitori & Golani, 2025a	E	SMM		0
Tetraodontidae								
Lagocephalus guentheri Miranda Ribeiro, 1915	E	NIS	2019	Al Mabruk *et al*., 2020	E	CS		1
Lagocephalus sceleratus Gmelin, 1789	E	NIS	2006	Kacem-Snoussi *et al*., 2009	W	F	2; 3	3
Lagocephalus suezensis Clark & Gohar, 1953	E	NIS	2009	Kacem-Snoussi *et al*., 2009	W	F	2; 3	un
Torquigener flavimaculosus Hardy & Randall, 1983	E	NIS	2017	Al-Mabruk *et al*., 2018	E	CS		1

Continued

Table 2 continued

Species	GL	Org	1LD	R	Res	M	R	Lag
Torquigener hypselogeneion (Bleeker, 1852) ++								
Sphoeroides pachygaster (Müller & Troschel, 1848)	W	RE	1992	Ragonese *et al.*, 1992 as *Sphoeroides cutaneus* Günther, 1870	W/E	F	1;3	0
Order Callionymiformes								
Callionymidae								
Synchiropus sechellensis Regan, 1908	E	NIS	2025	Barich *et al*., 2025	E	F		0

Abbreviations: **C**: Centre; **C*:** Second record via social media; **CS**: Citizen science; **E**: East; **E#**: first record via field survey; **E*:** due to Nota *et al.*, 2024 recent findings ´´the majority of *Kyphosus* expanding in the Mediterranean are *K. vaigiensis*´´, it is suggested that the record by El Baraasi *et al.*, 2013 from Libyan waters remain pending molecular analysis, of recent findings; **F**: Field work; **GL**: geographic location of the record; **L**: Lessepsian; **Lag**: Lag: time lag between finding the record and reporting it in years, e.g. 0 = same year; **M**: survey method; **ns**; Not specified; **Org**: species status; **R**: Reference; **RE**: Range expansion i.e. of Atlantic origin; **Res**: research group location; **SMM**: Social media mining; **un**: un known; **W**: West; **x**: record obtained via social media and citizen science 2018- June 2025; *: Note: alternatively referred to as *H.* cf. *acuminatus* by Azzurro *et al.* (2026) **1**: AL-Hassan & EL-Silini ,1999; **2:** El Baraasi *et al.*, 2019; **3**: Shakman *et al.*, 2019; **1LD**: 1st Libyan detection year.

Table 3. Various non-native, cryptogenic, and range expansion species recorded between 2018 and 2026, resulting 27 species; 23 NIS, three cryptogenic, and one range expansion.

Species	GL	Org	M	Ref	1LD	Res	Lag
Porifera							
Paraleucilla magna Klautau, Monteiro & Borojevic, 2004	W	NIS	F	Katsanevakis *et al*., 2020	2019	W	1
Bryozoa							
Amathia verticillata (delle Chiaje, 1822)	W	CRY	F	Rizgalla *et al*., 2019a	2018	W	1
Tunicata							
Symplegma brakenhielmi (Michaelsen, 1904)	W	NIS	F	Rizgalla *et al*., 2019a	2018	W	1
Cnidaria							
Cassiopea andromeda (Forskål, 1775)	W	NIS	SMM	Crocetta *et al*., 2021	2021	E	0
Phyllorhiza punctata von Lendenfeld, 1884	W	NIS	SMM	Rizgalla & Crocetta, 2020b	2015	W	5
Mollusca							
Diodora funiculata (Reeve, 1850)	W	NIS	F	Rizgalla & Crocetta, 2020c	2018	W	2
Diodora ruppellii (G. B. Sowerby I, 1835)	W	NIS	F	Rizgalla *et al*., 2019b	2019	W	S
Crepidula fornicata (Linnaeus, 1758)	W	NIS	F	Dragičević *et al*., 2019	2018	W	1

Continued

Table 3 continued

Species	GL	Org	M	Ref	1LD	Res	Lag
Cerithium scabridum Philippi, 1848	W	NIS	F	Rizgalla *et al*., 2019a	2018	W	1
Fulvia fragilis (Forsskål in Neibuhr, 1775)	W	NIS	F	Rizgalla *et al*., 2019c	2018	W	1
Lamprohaminoea ovalis (Pease, 1868)	W	NIS	F	Rizgalla *et al*., 2018	2018	W	0
Aplysia dactylomela Rang, 1828	W	CRY	F&SMM	Rizgalla *et al*., 2019d	2016	W	3
Bermudella pellucida (Burn, 1967)	W	NIS	F	Rizgalla *et al*., 2023	2021	W	2
Bermudella polycerelloides Ortea& Bouchet, 1983	W	CRY	F	Rizgalla *et al*., 2019a	2018	W	1
Polycerella emertoni A. E. Verrill, 1880	W	NIS	F	Rizgalla *et al*., 2025	2018	W	7
Biuve fulvipunctata (Baba, 1938)	W	NIS	F	Rizgalla & Christa, 2025	2023	W	2
Bursatella leachii Blainville, 1817	W	NIS	F	Rizgalla & Crocetta, 2020a	2020	W	0
Godiva quadricolor (Barnard, 1927)	W	NIS	F	Rizgalla, 2025	2022	W	3
Polychaeta							
Branchiomma luctuosum (Grube, 1870)	W&E	NIS	F	Bariche *et al*., 2025	2019	W&E	6
Decapoda							
Callinectes sapidus Rathbun, 1896	W	NIS	CS	Corsini-Foka *et al*., 2021	2020	E	1
Carupa tenuipes Dana, 1852	C	NIS	CS	Nour *et al*., 2022a	2022	E	
Penaeus (Farfantepenaeus) aztecus Ives, 1891	E	NIS	CS	Abdulrraziq *et al*., 2021	2020	E	1
Synalpheus africanus Crosnier & Forest, 1965	W	RE	CS	Fitori *et al*., 2023b	2023	E	0
Thalamita poissonii (Audouin, 1826)	E	NIS	CS	Tiralongo *et al*., 2022	2021	E	1
Echinodermata							
Diadema setosum (Leske, 1778)	E &C	NIS	SMM	Nour *et al*., 2022b	2021	E	1
Tripneustes gratilla (Linneaus, 1758),	E	NIS	CS	Fitori *et al*., 2022b	2024	E	0
Lovenia cordiformis A. Agassiz, 1872	E	NIS	CS	Fitori *et al*., 2022b	2024	E	0

Abbreviations: **CS**: Citizen science; **CRY**; cryptogenic species; **E**: East; **F**: Field survey; **GL**: geographical location; **Lag**: Lag time in years, e.g., 0 = same year; **M**: record method; **Org**: origin; **RE**: Range expansion; **Res**: Research group location; **SMM**: Social media mining; **un**: Unknown; **W**: West; **1LD**: First Libyan detection year.

Table 4. Libyan based research groups, and their geographical location (Geo-location), and affiliated NGO´s. Abbreviation: G: research group; NGO: non-governmental organisation. Within the same institution there might be two different research groups affiliated to different groups, within the same university, or another university, or research center in Libya.

Groups	Publications 2018- June 2025	Geo-location	City	NGO
G1a	Department of Marine Resource, Faculty of Natural Resources, Tobruk University, Libya	E	Tobruk	
G1b	Department of Zoology, Faculty of Science, Derna University, Libya	E	Derna	
G1c	Department of Zoology, Faculty of Science, Tobruk University, Libya	E	Tobruk	
G1d	Marine Biology Research Centre, Tripoli, Libya (A)	W	Tripoli	
G1e	Marine Science Research Center, Benghazi, Benghazi, Libya	E	Benghazi	
G2a	College of Natural Resources and Environmental Sciences, Tobruk University, Libya	E	Tobruk	
G2b	Department of Biology, Faculty of Education, Tobruk University, Libya	E	Tobruk	
G2c	Department of General Nursing Technology, Higher institute of Science and Technology, Cyrene, Libya	E	Cyrene	Marine Biology in Libya Society (MBLs) https://iucn.org/es/node/41545
G2d	Department of Marine Resources, Omar Al-Mukhtar University, El Bayda, Libya	E	El Bayda	
G2e	Department of Marine Resources, Omar Al-Mukhtar University, El Bayda, Libya	E	El Bayda	
G2f	Higher institute of Science and Technology, Cyrene, Libya	E	Cyrene	
G2g	Zoology Department, Faculty of Science, Omar Al-Mokhtar University, El Bayda, Libya	E	El Bayda	
G3	Department of Aquaculture, Faculty of Agriculture, University of Tripoli, Tripoli, Libya	W	Tripoli	
G4	Department of Zoology, Faculty of Science, University of Benghazi, Benghazi, Libya	E	Benghazi	
G5	Marine Biology Research Centre, Tajoura, Libya (B)	W	Tajoura	
G6	Zoology Department, Tripoli University, Tripoli, Libya	W	Tripoli	Libyan society for artisanal fishery friends https://lsaff.org.ly/ar/

Most groups engaged in local and cross-border collaborations; notably, all external collaborators were from Mediterranean countries, with the exception of two institutions (Fig. 3). Data collection methods included field surveys, active and passive citizen science, or a combination of both approaches.

Citizen Science Engagement

Most published records were obtained through the engagement of 32 citizen scientists, with the majority of them (SCs) participating only once, three reporting twice. All citizen scientists were male fishermen, although it

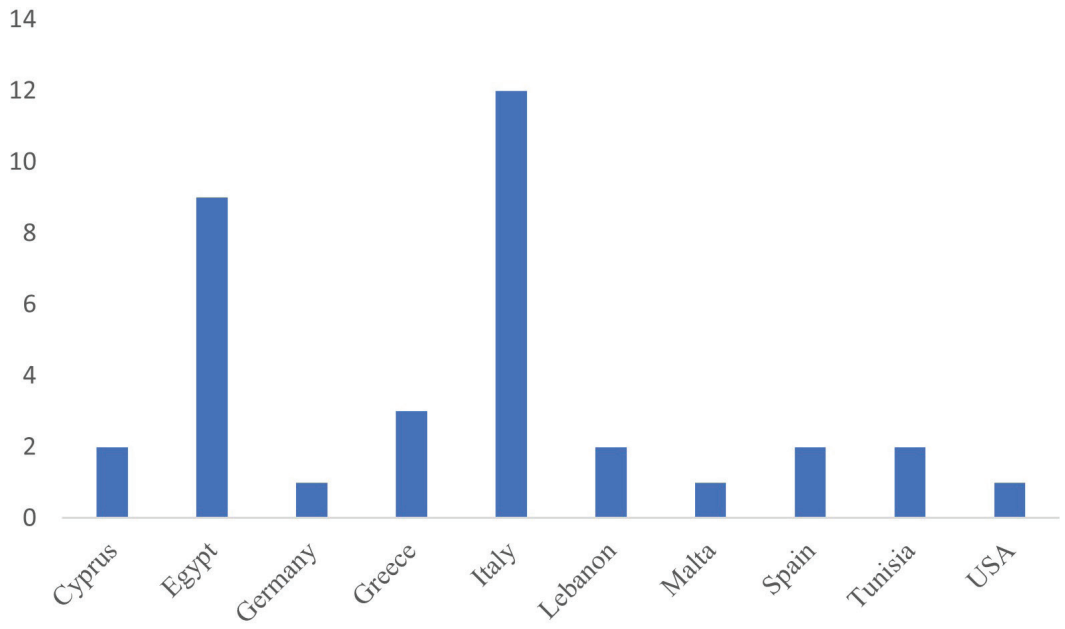

Fig. 3: Cross-border collaboration between research groups based in Libya and the counties of collaborating institutions. Number of institutes in scientific collaboration with Libyan based institutes, and geographical location of collaborating institutions (academia, research centres and NGO´s).

was not specified whether they were professional or recreational. Geographically the citizen scientists were located in the east (17), centre (2), and west (13) of Libya.

All records obtained via ACS and PCS were accidental findings, obtained through various fishing methods, including angling, gill net, long line, spearfishing and trammel net. Other species were either collected by hand or observed. The depth of the records ranged between 1.5 and 58 meters.

Ethical issues of ACS PCS and SMM

Out of 30 publications using ACS, PCS and SMM, or a combination of both, 24 publications acknowledge the citizen scientists (CSs). However, six publications did not acknowledge the CSs or the owners of images and records, using records without providing their name or evidence of obtaining permission to use the images (Table 1).

Discussion

According to the most recent list of exotic fish in the Mediterranean Sea, there are 173 non-indigenous fish species reported in the basin (Zenetos *et al*., 2022). The Occurrence Records of Mediterranean Exotic Fishes (ORMEF) listed 221 non-indigenous fish species in the Mediterranean Sea when it was last updated in 2023 (ORMEF GeoPortal, 2025). In Libya, the latest annotated checklist by El Baraasi *et al*. (2019) listed a total of 22 NIS out of 304 fish species, which includes 277 native species and 5 species of Atlantic Ocean origin (RE).

By utilizing interdisciplinary methods, such as field surveys, ACS, and PCS, an additional 16 NIS were added to the list. This brings the total number of recorded NIS in Libyan waters to 38 fish species as of February 2026. It comes as no surprise, as fish are among the taxonomic groups most frequently reported globally by CS (Lameira *et al.*, 2025), this was also reflected in the present review. Notably, the majority of NIS species recorded in this time frame were bony fish which could be attributed to their being targeted by fisheries activity. In contrast, records of native fish species, were compared to the 100 species documented via field surveys (e.g., El Baraasi *et al*., 2019), with records rarely generated through ACS or PCS (e.g., Fitori & Golani, 2025b).

This disparity highlights a significant reporting bias; as generally only specimens perceived as interesting, abnormal, novel or ‘’odd’’ tend to be shared on social media platforms (Tiralongo *et al*., 2020), leaving common native species underrepresented on such platforms.

Furthermore, Mediterranean fish catches posted by recreational fishers are rarely published in scientific literature unless tied to specific research questions (Rizgalla *et al*., 2017). Professional fishers may also omit NIS from social media if the species have become familiar over time, as fishermen who have encountered the fish for a long period may not recognize them as non-indigenous (pers. comm. Ben Abdalah). This underscores the necessity of assessing local ecological knowledge (Azzurro *et al*., 2019). Consequently, most Libyan literature published between 2018 and 2025 provides only single-occurrence records, including those using field work offering limited data on range expansion and ecological impacts (El Baraasi *et al*., 2019; Shakman *et al*., 2019, 2024).

Among the 20 fish species recorded, the most reported order was Acanthuriformes, followed by Tetraodontiformes with four species. This order includes species

of public health concerns such as the well-known *Lagocephalus sceleratus* Gmelin, 1789 (Ulman *et al*., 2024), and the recently reported diodontid *Diodon hystrix* Linnaeus, 1758, from a single sighting by PCS (Fitori & Golani, 2025a). This rare species has only been reported a few times in the Mediterranean Sea, and its spread in Libyan waters and the Mediterranean basin is still unknown (Fitori & Golani, 2025a). Some rarely reported species were also documented, such as the *cobia Rachycentron canadum* (Linnaeus, 1766). Although this record consists of only a single individual caught off the eastern coast of Libya in 2019 via citizen science (CS), it further supports the documented east-to-west expansion of the species (Nour *et al*., 2021). Despite some non-indigenous species, such as *Parupeneus forsskali* (Fourmanoir & Guézé, 1976), gaining commercial importance for artisanal fisheries in other Mediterranean countries (Evagelopoulos *et al*., 2020), NIS fish landings in Libya remain under-reported and documented with outdated data. For instance, although *Siganus luridus* (Rüppell, 1829) has been recorded in the region since the 1950s and 60s (Štirn, 1970) and was noted by Shakman *et al.* (2008) as part of local artisanal landings, there is a lack of recent data regarding its current commercial significance in Libya.

Molluscs were the second most frequently recorded phylum, identified largely from field surveys, with the exception of some conspicuous sea slugs such as *Aplysia dactylomela* Rang, 1828, a sea slug of Atlantic origin. This species has been recorded through field surveys and social media mining from the western and eastern Libyan coast (Rizgalla *et al.*, 2019d). Heterobranchia have been under-represented in CS and SMM. Overall, Heterobranchia had received little attention from researchers in Libya until recently with several records in both the east and west of Libya (Rizgalla *et al.*, 2025; Said *et al*., 2023).

It is worth noting that Nudibranchia, the order with the most NIS representatives in the Mediterranean Sea (Furfaro *et al.*, 2025), has, with the exception of *Felimare picta* (Philippi, 1836), a native species (Said *et al.*, 2023), never been reported from the central or eastern regions of Libya. The majority of non-indigenous sea slug species were recorded by field surveys from areas located within the vicinity of major commercial ports, with no further information on their spread or presence along the Libyan coastline (Rizgalla *et al.*, 2023; 2025). Notably a number of species were found in association with the cryptogenic bryozoan *Amathia verticillata* (delle Chiaje, 1822). For example, the Indo-Pacific nudibranch predator *Godiva quadricolor* (Barnard, 1927), which preys on Mediterranean species, poses a significant threat to local biodiversity (Rizgalla, 2025). Additionally, and *Bermudella pellucida* (Burn, 1967), a species only reported twice in the Mediterranean basin, in Libya and Malta (Rizgalla *et al*., 2023).

Amathia verticillata, despite its widespread distribution in the Mediterranean Sea, along with its high reproductive and dispersal potential, and role in offering habitat, a food source, and a nursery for NIS species (Furfaro *et al.*, 2025; was only recorded in one location in the west of Libya (Rizgalla *et al*., 2019a). These further highlights the lack of systematic surveys along the Libyan coastline.

While citizen scientists in Libya do not report on Heterobranchia, this does not mean that they are not reported via ACS, PCS or SMM. On the contrary, there is a thriving community of hobbyists in other parts of the world who share their findings on social media platforms, whether it be in the Mediterranean Sea or globally (Chow *et al*., 2022), resulting in spectacular records (Giovos *et al*., 2019). In Libya there is currently no Heterobranchia-oriented hobbyist community.

Decapoda and Echinodermata are often accidental findings from artisanal and recreational fishing methods such as trammel nets, gill nets, and longlines. These are shared by both ACS and PCS (Table 3), such as the omnipresent blue swimming crab *Portunus segnis* (Forskål, 1775), which has been frequently shared on social media in recent years. This crab, native to the Indian Ocean, Red Sea, and Persian Gulf (Naderloo, 2017), was first reported by Shakman *et al*. (2017) from a specimen found near the city of Tobruk in 2017 (in the east of Libya) and in 2019 from the west of Libya (Fig. 1). It is the most prominent among the decapods reported in Libyan waters, having taken the Libyan western coastline by storm as documented by Corsini-Foka *et al*. (2021) via ACS and PCS, in what seems like a west-to-east spread from the substantial Tunisian population (Castriota *et al*., 2022). Despite its swift invasive process across the Mediterranean basin, the possible lack of records from the Libyan eastern and central coastline might be due to a lack of surveys in the area, giving a false negative impression of its spread, which is probably underway. Given the mentioned constraints, in this instance, CS-based projects might come in handy to assess their expanded distribution, especially for this conspicuous species of economic importance for fisheries, which is increasingly sold at local fish markets in the west of Libya (pers. observ.).

The review of published literature has shown that there are two main clusters of non-indigenous fish species forming along the Libyan coastline. This is neatly illustrated on the distribution map provided by the ORMEF geoportal map (Azzurro *et al*., 2024), which can be viewed at www.ormef.ed/map. The clusters are clearly divided into an eastern and western cluster, with 86% (33 NIS) recorded from the east of Libya and 13% (5 NIS) recorded from the west. Notably, the eastern cluster is dominated by Lessepsian fishes moving east-to-west, while the western records often represent invertebrates introduced via different pathways. This suggests three possible invasive routes: a west-to-east approach, a north-to-south invasive process of NIS in the Mediterranean Basin, reliant on prevailing sea water currents, in addition to other influencing factors. An east to west approach evident from the eastern cluster, as seen in the lionfish expansion showing a westward movement (Mitchell & Dominguez Almela, 2025). The lionfish expansion has been gradually gaining ground since its initial sighting in Burdi and Karsa in 2018 (Al Mabruk & Rizgalla, 2019), covering approximately 350 km to the west and reaching Benghazi's shores (Ragkousis *et al*., 2023) (Fig. 2). The settlement

and expansion trend observed in the rest of the Mediterranean Sea (Mitchell & Dominguez Almela, 2025) has reached the southern Adriatic Sea (Fortič *et al*., 2023), as well as southern Italy (Azzurro *et al*., 2024).

The third route involves a combination of both invasive and spread processes happening simultaneously but potentially not related to one another as proposed for other NIS species. For example, the Lessepsian sideburn wrasse *Pteragogus trispilus* Randall, 2013, was initially reported from the east of Libya (Fitori *et al*., 2021). Within one year, it appeared to have expanded its range to reach the centre of Libya almost 400 km away (Nour *et al*., 2022a) (Fig. 2), raising several questions. If they are connected, who arrived first, or did they follow two different paths of invasion, from east to west and west to east? However, given the proximity of the second record to the so-called ´´oil crescent´´, where tankers and other commercial shipping arrive from around the world (e.g., Zueitina oil-port 2025), it is possible that such ships served as a local source for this particular record through primary introduction or secondary spread via ballast water discharge and exchange (Costello *et al*., 2022) from established nearby populations. Records of this species have been increasing in recent years, following a northward shift in the expansion range, including Malta and indications of established populations (Deidun *et al*., 2025).

Similar observations can be made for *Diadema setosum* (Leske, 1778), a non-indigenous long-spined sea urchin first reported from the east of Libya by Nour *et al*. (2022b), and found in the center of Libya, approximately 700 km from the first record (Shakman *et al*., 2024) (Fig. 2). These two records are potentially not connected, but rather a result of two separate introduction events, especially since both are in proximity to commercial harbours presenting a potential route for the introduction of NIS (Rizgalla *et al*., 2019b). While there is currently no available data on the spread of *D. setosum*, its invasive success in other Mediterranean regions certainly suggests a large population may yet be reported.

On the other hand, one-time records of species such as the silver grunt, *Pomadasys argenteus* (Forsskål, 1775), reported for the first time in the Mediterranean Sea from the port city of Misrata in the west of Libya (Fitori *et al*., 2023a), could be a result of shipping traffic. The record was within the proximity of a major commercial harbour with abundant international shipping traffic that could have contributed to the introduction of this fish. Such routes are well recognised with respect to a number of other invasive events within the Mediterranean basin (Costello *et al*., 2022).

This could also be true for other NIS recently recorded in Libyan waters, such as the nocturnal decapod *Carupa tenuipes* Dana, 1851 reported only once in the centre of Libya by citizen science (Nour *et al*., 2022a), as an accidental finding caught by a net. While *C. tenuipes* in Libya is also the furthest known western spread of this species within the basin, it stands out and reinforces shipping traffic as a mode of invasion and or secondary spread from the eastern Mediterranean. On the other hand, given the lack of consistent surveys of Libyan marine biodiversity it could have passed unnoticed, with populations in either the east or west of this record.

This also brings up two suggested factors previously proposed to explain the low numbers of recorded non-indigenous fish species in Libyan waters when compared to some other Mediterranean countries. The first proposed factor is sampling effort (Shakman *et al*., 2019). This proposal is supported by the notable increase in scientific output over the past seven years, which is in turn associated with an increase in sampling / observational effort, much of it reliant upon citizen science, social media mining and field surveys.

The second suggested factor relates to Libya's geographic location. Proposing that this naturally excludes it from invasion hotspots and protects it from natural dispersal of invasive species (Shakman *et al*., 2019). Such an explanation seems less likely and is contested by the increasing number of recent records.

Another influencing factor is the long time-lag between sampling and reporting non-native species. The longest recorded time-lag in the Mediterranean basin is 79 years (Zenetos *et al*., 2019). Furthermore, Zenetos *et al*. (2019) observed that lag periods are often related to specimens deposited in museum holdings, as they are "forgotten on shelves and in drawers slumbering for years" (Galanidi *et al*., 2025).

Shakman *et al*. (2017) reported three fish from museum holdings, *Sphoeroides pachygaster* (Müller and Troschel), S*eriola fasciata* (Bloch, 1793) and *Seriola rivoliana* Valenciennes, 1833. The most recent, *S. pachygaster*, was reported in 2017 off the coast of Misrata, following the first record in 1992 by Ragonese *et al.*, (1992) off the coast of Tripoli. Shakman *et al.* (2017) record involved a time lag of 24 years. This publication makes the spread of *S. pachygaster* to Benghazi's shores in 1995 (Fede ORMEF Lamboeuf *et al.*, 1995) more plausible, reinforcing the west-to-east expansion. Meanwhile, *S. fasciata* and *S. rivoliana* showed spread in Libyan waters with a time-lag of 14 and 13 years respectively (Shakman *et al*., 2017).

This delay in reporting can give the impression that certain non-indigenous fish species have failed to colonise the entire Libyan coast, despite being reported from neighbouring countries for a considerable period (see ORMEF GeoPortal, 2025). This result in a knowledge gap, which may lead to misleading conclusions locally and within the basin regarding the dynamics by which both Atlantic and NIS spread. This was also observed in earlier Libyan records. However, this is becoming an isolated incident, with lag periods visibly shortening in Libya— especially for bony fish, which are often reported within months if not days from their discovery (Fitori & Golani, 2025; Shakman *et al*., 2017). The average span between record and publication in recent studies has decreased to between the same year and 7 years. This could be attributed to research groups specializing in assessing marine biodiversity in Libyan waters, resorting to CS as the main tool, often reporting their findings as short communications. While social media platforms serve as re-

positories for passive citizen science posts that are shared and stored, they can still contribute to creating "back to the future" records. For example, *Pontonia pinnophylax* (Otto, 1821) (a Mediterranean species) was posted in 2014 and subsequently reported within a year of its record (Tsagarakis *et al*., 2021). The downside of this largely social media-oriented methodology has resulted in neglecting Mediterranean species, as previously addressed, a field in which field surveys excelled, especially in reporting small, minute, or inconspicuous species such as Heterobranchia. This neglect is likely due to the specific sampling protocols and targeted searches that were employed in field surveys (Rizgalla *et al*., 2025).

There has been a rapid shift from reliance on photographic images to the use of physical sample identification in terms of new species and distribution records obtained via CS. Initially, obtaining samples was impossible as the records were often from the past, sometimes years ago (Rizgalla *et al*., 2017; Rizgalla *et al*., 2019d; Rizgalla & Crocetta, 2020b), or the sample had been consumed or discarded (Zenetos *et al*., 2026; Fitori & Golani, 2025a). However, likely due to the proximity of two research groups located in the east of Libya and with the most recent records of invasive species originating in the east, these groups were able to establish a network that enabled them to obtain some of the samples (Fitori *et al*., 2024a; Nour *et al*. 2022a). Inter-institutional collaboration has also helped in obtaining samples from mixed research groups with members based in eastern, and western Libya (Fitori *et al*., 2022b). This is the direction that citizen-science-based projects should aim for *i.e.* the timely employment of real-time interactive collaboration with citizen scientists in inclusive projects. Prompt reporting of new non-indigenous species observations would help determine the timing of their first introduction (Fitori & Golani, 2025a), which is often difficult to ascertain. Despite this positive trend toward physical specimen collection, the practical reality remains that many records still lack tangible voucher specimens (Osca *et al*., 2020; Fitori *et al*., 2024b). Consequently, while citizen science and social media records provide a vital resource for documenting and tracing non-indigenous species in Libya, the frequent lack of physical samples and voucher specimens makes detailed taxonomic reassessment heavily dependent on photographic material (Rizgalla & Crocetta, 2020b; Osca *et al*., 2020). In the absence of high-resolution imagery, this dependency can lead, in rare cases, to misidentification (Azzurro *et al*., 2026), rendering certain records doubtful and pending future validation. To ensure these observations remain scientifically useful, a cautious taxonomic assignment—utilizing open nomenclature (e.g., *cf*., *aff*.) is the most robust approach (Sigovini *et al*., 2016).

Considering the large pool of members using relevant Libyan-based social media platforms (Rizgalla *et al*., 2017; Rizgalla, 2021), it is surprising that only 32 citizen scientists have contributed to producing records. The majority of these only reported once, while three citizen scientists reported twice. The question of how to foster the transition of citizen scientist collaboration from the initial first stage to more sustained participation in citizen science projects is widely recognised for citizen-scientist-based projects as a whole (Veeckman *et al*., 2019). However, this trend is expected to gradually decrease over time due to competing research groups systematically using social media and citizen-science-based approaches to monitor marine biodiversity. Thus, encouraging PCS to transition to active participation as ACS in marine biodiversity campaigns could involve utilizing existing relevant platforms in more structured campaigns. These campaigns could be disseminated through platforms already used by researchers, offering the opportunity to recruit platform users in activities linked to CS-based projects such as monitoring the invasive process of NIS (Encarnação *et al*., 2021).

An important outcome of the dynamic between citizen scientists and research groups on social media is the contribution toward enhancing scientific literacy (Skarzauskiene & Mačiulienė, 2021). Such improved literacy is clear, for instance from the reactions of fishermen to the invading lionfish and their engagement in reporting on its spread (Ragkousis *et al*., 2023). Greater opportunities for increasing scientific literacy are also evident in recent efforts to encourage fishermen to participate in a three-day fishing contest for the silver cheeked toadfish *L. sceleratus* for a prize in 2021. This contest was organized as a collaboration between the University of Tobruk (Tobruk) and the local municipality (Alwasat, 2021).

While the motivation for PCS to transition into ACS could be influenced by education level and personal interest (Lucrezi *et al.*, 2018), reducing CS to only a tool may ultimately become unsustainable. Alongside scientific literacy, there may be an interest in a more inclusive role. Therefore, offering co-authorship, based on significant CS contribution (Sandin *et al*., 2025), might be an incentive.

This new and relatively low-cost complementary tool to classical research disciplines (Skarzauskiene & Mačiulienė, 2021; Giovos *et al*., 2019) has been especially useful in overcoming geopolitical hurdles in Libya (Rizgalla, 2021). However, it has also raised several ethical issues that should be addressed both at the start of a project and throughout the course of scientific investigation.

In recent years, numerous authors have emphasised the importance of meticulously describing and acknowledging the role that citizen scientists play in a specific project, providing formal recognition of their contributions (Veeckman *et al*., 2019; Hunter & Hsu, 2015). This, in turn, helps to maintain trust and encourages continued engagement in such research (Ozolinčiūtė *et al*., 2022). Several authors have proposed codes of conduct, providing ethical guidelines for the use of citizen science (Monkman *et al*., 2018). Robinson *et al*. (2018) suggested ten principles to follow when collaborating with citizen scientists.

However, in the current review, six papers failed to mention citizen scientists or clearly describe their contributions, raising concerns about whether the owners of the data agreed to its use. It remains unclear if this was the choice of the citizen scientist, who may prefer anonymity

(Robinson *et al*., 2018). If this is the case, then it needs to be specifically documented in the acknowledgments section or elsewhere.

Acknowledging the contribution of a citizen scientist is crucial, and failure to do so should not be considered a trivial oversight. After all, without their contribution, such records would be lost to science. Regardless of whether an omission is deliberately or accidental, it is the responsibility of the lead researchers to provide an accurate account and acknowledge when necessary (Robinson *et al*., 2018). From a different perspective, the meticulous and often painstaking detailing of the records, while sometimes seeming unnecessary, lends credibility and helps explain the dynamics of the record. This can further aid in understanding the motivation compelling a citizen scientist to collaborate with a researcher, an issue that has long puzzled scientists (Wright *et al*., 2015).

Scientific research has become increasingly collaborative on a global scale (Wang *et al*., 2024). This trend was evident in the papers reviewed; nearly all scientific work on marine biodiversity by Libyan scientists was conducted in collaboration with research groups from other countries (transboundary). These efforts form occasional or recurring liaisons with one or more research groups from various countries (e.g., Al Mabruk *et al*., 2018; Osca *et al*., 2020). Such collaborations may be driven by a lack of local facilities for molecular analysis (Osca *et al*., 2020; Rizgalla & Christa, 2025) or a shortage of trained taxonomists (Shakman *et al*., 2019). This expertise gap is a leading cause for the long lag periods in reporting non-indigenous species (NIS) observed in other Mediterranean countries as well (Galanidi *et al*., 2025).

However, research groups based in Libya have started contributing to large-scale publications by sharing data-based manuscripts (Ragkousis *et al*., 2023), which can be utilised to evaluate the invasive success of specific species (Chandler *et al*., 2017). Additionally, they are participating in observation-based papers where scientists gather data from various Mediterranean countries through citizen science and mining social media posts related to their scientific inquiries (Ulman *et al*., 2024), effectively ending the era of the so-called ´´parachute science´´ in Libya (Odeny & Bosurgi, 2022).

These international collaborations, rooted in social media and citizen science (Chandler *et al*., 2017), are shifting the approach from one that compartmentalizes the Mediterranean coastline into East, Central, West and Adriatic Sea. Instead, stakeholders are increasingly working as a unified entity toward a common goal. While large-scale collaborations remain somewhat fragmented at the national, European, and basin levels, there is a clear need for wider Mediterranean cooperation regardless of geographical location. This approach enhances scientific output that benefits all countries bordering the Mediterranean Sea, as non-indigenous species know no boundaries and recognise no borders (Zenetos *et al*., 2025).

One of the significant challenges facing Libyan scientists is choosing the appropriate outlet for their research. Many choose to publish in local peer-reviewed journals, which are only available in Arabic or in paper format, in addition to grey literature publications such as governmental reports and survey-based reports that are only available in paper form. This severely hinders the dissemination of scientific output both within and outside of Libya (pers. observ., Rizgalla *et al*., 2019c). These publications contain important initial findings that, even when referenced multiple times, are often unattainable (Rizgalla *et al*., 2019c), contrasting with institutional journals like Acta Adriatica, Scientia Marina or Mediterranean Marine Science that have achieved international reach.

This highlights Libya's urgent need of a free, online national or institutional repository to preserve scientific work and prevent duplicate records.

In addition to encouraging the Libyan scientific community to choose mainstream journals as outlets for their research, which is already a practice in some institutions (pers. comm.), financial government support for local journals is crucial. This support will enable these journals to gain international recognition, providing an accessible outlet for the Libyan scientific community and allowing for the timely publication of their results.

Seven years, integrating citizen science and field surveys has increased engagement among scientific groups across Libya in recording marine biodiversity. However, challenges persist in securing sustainable funding, long-term management, and increasing public awareness and participation.

Despite the high prevalence of non-indigenous, cryptogenic, and questionable taxa in the Mediterranean (Galanidi *et al.*, 2023), relatively few NIS species are documented in Libyan waters, highlighting a critical knowledge gap. Establishing a baseline dataset is essential for a sustainable blue economy (Pauli, 2010) for a country aiming to foster robust economic growth while safeguarding biodiversity for future generations.

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