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Tracking the invasion of *Hemiramphus far* and *Saurida lessepsianus* along the southern Mediterranean coasts: A Local Ecological Knowledge study

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Abstract

Local Ecological Knowledge of 92 professional fishers from Tunisia and Libya was used to investigate the occurrence and establishment of the exotic *Hemiramphus far* and *Saurida lessepsianus* along the southern Mediterranean coasts. According to fisherman's knowledge, *H. far* and *S. lessepsianus* appeared in Libya in 1980 and 1989, respectively. In Tunisia these species were observed later on, in 2004 and 2007. Currently both *H. far* and *S. lessepsianus* are well distributed and established, along the entire surveyed area, from Tobruk (eastern Libya) to Tabarka (western Tunisia). A statistical analysis of the qualitative trends in abundance perceived by the respondents shows that both species have significantly increased in abundance in Tunisia. In Libya an increase in the abundance of *H. far* was also apparent during the first decade of the 21st century, but the current abundance of *S. lessepsianus* was found to be stable at the level of occasional captures. Given the lack of regular environmental monitoring programmes in the area, these findings provide information that could not have been obtained otherwise. Besides improving our understanding on the status and chronology of these invasions, this approach highlights the value of fisherman's knowledge to reconstruct ecological processes in the course of rapid historical modifications.

Keywords: Lessepsian migration, biological invasions, Hemiramphidae, Synodontidae, fish, fishermen.

Introduction

Exotic species represent a matter of growing concern for the Mediterranean Sea (Galil 2007; Zenetos *et al.,* 2010) deeply altering the structure of native communities (Fanelli et al., 2015), but data on their distribution and abundance are often difficult to gather (Azzurro 2010; Azzurro *et al.,* 2013). Indeed, due to the massive efforts needed to actively survey marine habitats, the real distribution of these species may be under-estimated, especially in poorly monitored areas of the Mediterranean Sea (e.g. Elbarassi *et al.,* 2014). Nevertheless, the so-called 'Local Ecological Knowledge' (LEK) (Johannes, 1998) is emerging as a new and alternative information source to overcome these limits. LEK can be defined as the information that a group of people have about local ecosystems and it aims to extract data and information from individuals' memory. This information is increasingly employed to understand ecosystem processes (e.g. Le Fur *et al.,* 2011), animal abundances (e.g. Anadón et al., 2009) and to investigate the ecological traits and historical trends of a diverse array of marine organisms (e.g. Rosa *et al.,* 2014; Silvano & Begossi, 2012). Recently LEK has been applied to the reconstruction of geographical and historical trends of some Mediterranean fishes (Azzurro *et al.,* 2011; Maynou *et al.,* 2011) and its use is considered to be particularly helpful in data-poor coastal ecosystems (Beaudreau & Levin, 2014), like the southern Mediterranean. Here we used LEK to investigate the distribution of two invasive fish species along the Mediterranean coasts of Libya and Tunisia: The black-barred halfbeak *Hemiramphus far* (Forsskål, 1775) (Hemiramphidae) and the lizardfish *Saurida lessepsianus* Russell, Golani & Tikochinski, 2015 (Synodontidae). Both species are absent from fishery statistics in both countries, being reported under general names together with other fishes. This information gap, together with the lack of regular environmental monitoring programmes in the area, makes it challenging to track the occurrence and possible range expansion of these exotic species with traditional methods.

The black-barred halfbeak *Hemiramphus far* is originally found in tropical and subtropical waters of the Indo-West Pacific, Red Sea and East Africa to Samoa, north to the Ryukyu Islands, south to northern Australia and New Caledonia (Collette, 1999). Halfbeaks are commercially exploited in many parts of the world (Fishstat, 2013) such as along the Arabian Sea Coast of Pakistan where the species is considered of great economic importance (Yousuf & Khurshid, 2008). *H. far* was one of the first Lessepsian fishes to have entered the Mediterranean Sea. It was recorded first from Palestine under the name of *H. marginatus* (Steinitz, 1927) and afterwards it spread along the coasts of Syria, Turkey, Greece, Croatia, Egypt, Libya (Golani *et al.,* 2013). The presence of *H. far* has also been documented from the coasts of Tunisia and Algeria, but only in the form of isolated records: in September 2003 a single specimen was captured by purse seine off El Haouaria, Cape Bon, at a depth of about 40 m (Ben Souissi *et al.,* 2005) and in December 2003 another single specimen was captured by Rafraf (North-East Tunisia) with a trammel net (Charfi-Cheikhrouha, 2004). More recently, isolated captures of *H. far* have been reported from Collo Bay in Algeria (Kara *et al.,* 2012) and Italy (Falautano *et al.,* 2014). To our best knowledge there is no published information about the possible establishment of *H. far* to the west of Libya (Bariche, 2012; Golani *et al.,* 2013). No available data existed on the occurrence of this species in Libya until 2006 (Shakman & Kinzelbach, 2006).

The lizardfish *S. lessepsianus* is a demersal fish, which inhabits soft bottom substrates. It is widely distributed in the Indo-Pacific from the Red Sea and East Africa to Australia and Japan (Fischer & Bianchi, 1984). So far, in the Red Sea-Mediterranean, this species has been commonly reported (and misidentified) as *Saurida undosquamis* (Richardson 1848) or *S. macrolepis* Tanaka 1917. Only very recently Russell et al. (2015) described *S. lessepsianus* as a new species. In the Mediterranean Sea, *S. lessepsianus* was first recorded in Israel (Ben-Tuvia, 1953). Almost immediately afterwards, this species established abundant populations along the eastern Mediterranean, attaining commercial importance (e.g. Ben-Yami & Glaser, 1974; Can & Demirci, 2004). It spread through the entire eastern Mediterranean (Golani *et al.,* 2013) up to the Adriatic Sea (Dulčić *et al.,* 2003), causing serious impacts on biodiversity. It has been listed among the 100 worst invasive species in the Mediterranean (Streftaris & Zenetos, 2006). The occurrence of this Lessepsian lizardfish in Libya has been reported only recently (Shakman & Kinzelbach, 2007) and in Tunisia, only the record of a single specimen was reported: in October 2004, by a benthic trawl, off Mahdia, in northern Gulf of Gabès, at a depth of 70 m on sandy muddy substrate (Ben Souissi *et al.,* 2005). To our best knowledge no other information is currently available on the establishment of *S. lessepsianus* along the north-African coasts.

Methods

Sampling area and interviews

Data were based on 92 interviews: 24 of which were collected in Libya and 68 in Tunisia. In Libya, interviews were carried out from February to December 2013, in Tobruk (eastern Libya) and Tripoli (western Libya). In Tunisia, fishermen were interviewed during the period October 2010 - December 2013, over seven main locations: Zarzis, Gabès, Mahdia, Kélibia, Gulf of Tunis, Bizerte and Tabarka (Fig. 1). The study was directed to every local professional fisherman with 10 or more years of experience in fishing. Fishermen were approached during their activities in harbours, according to the general guidelines given by Azzurro *et al.* (2011). Each interview was realized after informing fishermen on the objectives of this report. Due to the level of schooling of fishermen, terms were consented orally. In order to test the ability of questioned people to correctly identify the species, color photos of both *H. far* and *S. lessepsianus* were showed to them as well as

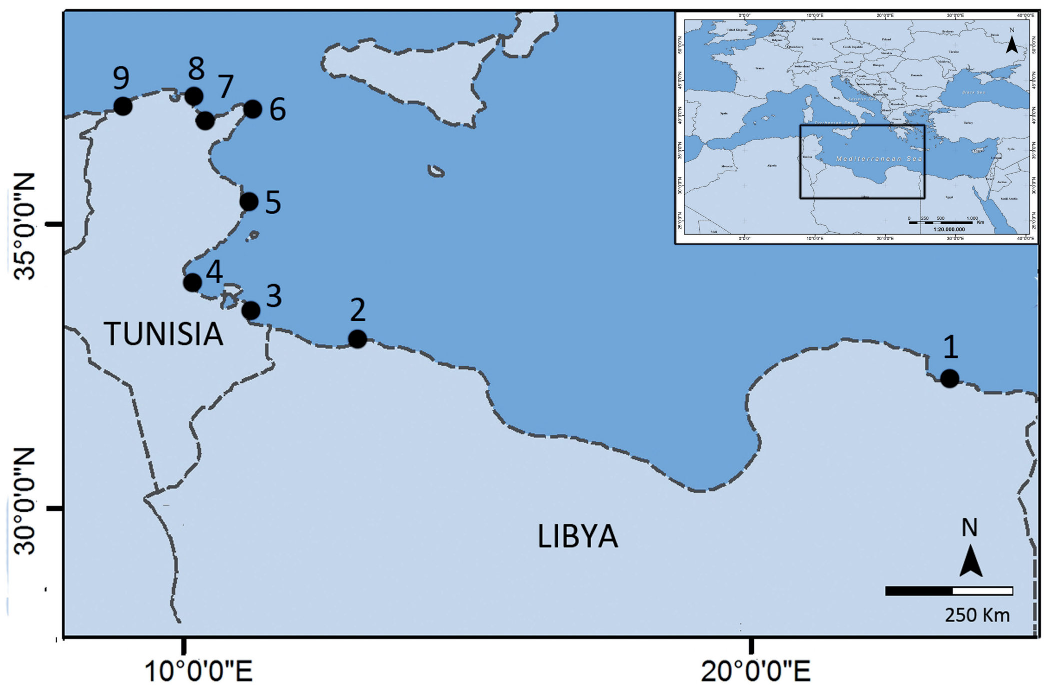

Fig. 1: Locations of the southern Mediterranean coasts where the interviews were performed. In Libya: 1) Tobrouk, 2) Tripoli. In Tunisia: 3) Zarzis, 4) Gabes, 5) Mahdia, 6) Kélibia, 7) Tunis (Goulette, Salambo, Sidi Bou Said, Sidi rais, Byrsa), 8) Bizerte, 9) Tabarka.

pictures of morphologically similar native fish (i.e. *Synodus saurus* and *Aulopus filamentosus* which resembles *S. lessepsianus* and *Belone belone* which resemble to *H. far*). Only those people who unambiguously identified *H. far* and/or *S. lessepsianus* were interviewed. Interviews were carried out in Arabic language on the basis of a semi-structured conversation (Appendix 1) between the researcher and a participant. The interview tackled questions related to the time and location of species occurrences and qualitative indices of species abundance along a temporal series. Specific questions included the 'time of first capture', 'fishing techniques used' and 'best day-catches'. Respondents were asked to provide a qualitative ranking of abundance through time on an annual basis according to the 6 different grades reported by Azzurro *et al.* (2011) and slightly modified: 0 =ABSENT; 1 =RARE (once in a year); 2=OCCASIONAL (sometimes in a fishing period); 3=COMMON (regularly in a fishing period); 4 =ABUNDANT (regularly in a fishing period and abundant); 5=DOMINANT (always in a fishing period and with great abundances). The duration of interviews ranged between 15 and 45 minutes.

Statistical analysis

The time series of semi-quantitative abundance data were subject to breakpoint structural analysis (Bai, 1994; Zeileis *et al.,* 2003) to assess the year(s) of statistically significant change in abundance, over the period 1970-2013, for each species and the two countries separately. Briefly, the breakpoint analysis consists in randomly splitting the data series in two or more subsets ("data windows") and the mean level compared by way of a modified F-test (known as structural change sc test, Zeileis *et al.,* 2003). The procedure was repeated iteratively until all significant breakpoints (if any) are identified (Bai, 1994). The number of significant breakpoints and their associated dates were assessed by the Bayesian Information Criterion (BIC) (Zeileis *et al.,* 2003). The breakpoint analysis was performed with the R library *strucchange*, developed by A. Zeileis at the University of Economics, Vienna (Wirtschaftsuniversität Wien, Austria).

Results

Interviewed fishermen were all men of age ranging between 32 and 75 years. Overall, 43 respondents provided information on only *H. far*, 20 fishermen on only *S. lessepsianus* and 29 on both species. All the respondents demonstrated the ability to recognize both *H. far* and/or *S. lessepsianus* and to be well aware of some conspicuous taxonomical characters of the species (e.g. the vertical dots on the caudal fin of *S. lessepsianus*). In Libya, local names are used for both *H. far* and *S. lessepsianus* in Arabic (Abomeshfa and Shkhrmo, respectively), whilst in Tunisia these species are still not designated with local names due to their recent occurrence.

In general, fishermen were highly collaborative and keen to share their knowledge with researchers. The distribution of fishing gears used by fishermen to capture both species in Libya and Tunisia is shown in Figure 2. A total of 58 fishermen remembered the exact location and approximate year where they first captured *H. far,* whilst 40 fishermen provided the same information for *S. lessepsianus* (Table 1).

According to the fishermen, *H. far* is captured along the eastern Libyan coasts (Tobruk) since the eighties' and it is being observed in western Libya (Tripoli) since 2007. In Tunisia, this species was firstly captured in 2004, from the area surrounding the fishing harbour of Gabès. The species is mainly captured by purse seine and it represents an occasional species of nets and trolling lines. In Tunisia and western Libya the best day-catches exceeded 50 kg with purse seine (mostly 'Lamparas', i.e. boats with powerful light to attract the fishes) but maximum values of less than one kg/day were reported for the other fishing techniques (Fig. 3). Captures of *H. far* were usually realized from the surface down to 40 m depth corresponding to soft bottoms and, in some occasions, above rocks, gravel and seagrass. According to interviewed fishermen, observations of *S. lessepsianus* in Libya were first reported in 1980 from the area of Tobruk and in 1990 from Tripoli. In Tunisia, *S. lessepsianus* was first reported in 2004 from the area of Mahdia. Fishermen reported to occasionally capture this species by nets, trawlers and longlines, mostly below 50 meters and over soft bottoms. Best-day catches did not generally exceed 1 kg/day over the entire sampling area (Fig. 3).

Average rank data for the last five years (2009-2013) are reported in Table 2. In most of the cases, both species were reported as "OCCASIONAL", but 33.3% of Libyan respondents reported *H. far* as "ABUNDANT" and 11.52% of Tunisian respondents as "COMMON" (regular in the fishing period). When questioned about

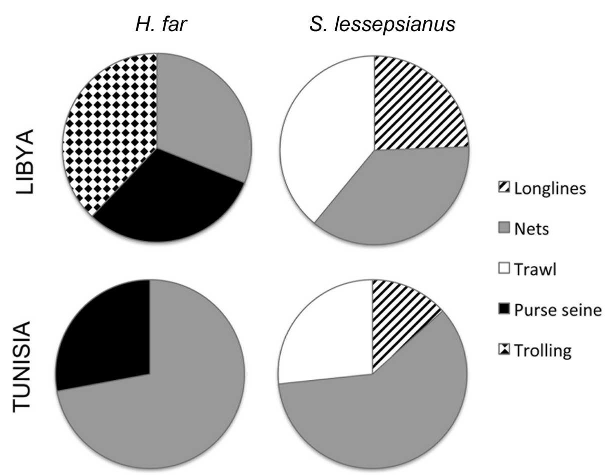

Fig. 2: Distribution of the fishing methods adopted by the interviewed fishermen in Libya and Tunisia: *H. far* respondents (tot: 67), *S. lessepsianus* respondents (tot: 69). Note that more than one fishing method could be adopted by a single respondent.

Table 1. First captures of *H. far* and *S. lessepsianus,* according to the fishermen's ecological knowledge. Year, locations and approximate coordinates are given. Only interviews (N=58) with fishermen who remembered the time and the site of first captures well, were reported.

LIBYA												TUNISIA											
H. far						*S. lessepsianus*						*H. far*						*S. lessepsianus*					
Respondent		First capture				Respondent		First capture				Respondent		First capture				Respondent		First capture			
Age	Fishing since	Location	lat.	long.	Year	Age	Fishing since	Location	lat.	long.	Year	Age	Fishing since	Location	lat.	long.	Year	Age	Fishing since	Location	lat.	long.	Year
60	1975	Tobruk gulf	32.077	24.038	1980	50	1980	Tobruk gulf	32.077	24.038	1988	35	1995	Gabès, near the harbour	33.950	10.214	2004	44	1994	Mahdia	35.529	11.136	2004
65	1965	Tobruk gulf	32.077	24.038	1980	65	1965	Tobruk gulf	32.077	24.038	1988	52	1980	Gabès, 2 miles from fishing port	34.028	10.373	2005	50	1990	Out off Salamboo	36.819	10.441	2006
55	1978	Tobruk gulf	32.077	24.038	1980	60	1975	Tobruk gulf	32.077	24.038	1989	34	1997	Gannouch (Gabès)	33.957	10.177	2005	44	1994	Kélibia 2 miles out off the harbour	36.814	11.149	2008
45	1981	Tobruk gulf	32.077	24.038	1984	42	1986	Tobruk gulf	32.077	24.038	1989	57	1975	Bizerte coasts	37.301	9.937	2006	48	1988	Kélibia	36.813	11.148	2011
50	1980	Tobruk gulf	32.077	24.038	1986	64	1964	East of Tripoli	32.915	13.455	1990	45	1987	Zaarat (Gabès)	33.863	10.196	2006	50	1990	Between Mahdia and Kerkennah	35.147	11.421	2008
42	1985	Tobruk gulf	32.077	24.038	1988	46	1982	East of Tripoli	32.915	13.455	1990	55	1978	Zarzis, near coast	33.525	11.165	2006	42	1991	Mahdia	35.529	11.136	2008
42	1986	Tobruk gulf	32.077	24.038	1989	55	1978	Tobruk gulf	32.077	24.038	1990	35	1998	El Biban Lake	33.235	11.317	2006	50	1993	Tabarka, out off	37.033	8.733	2011
52	1998	Tobruk gulf	32.077	24.038	2002	62	1990	East of Tripoli	32.915	13.455	1990	33	1998	Kélibia, 500m out off the harbour	36.827	11.115	2007	50	1983	Sidi Bou Said	36.935	10.421	2009
47	1995	West of Tripoli	32.858	12.872	2007	43	1980	East of Tripoli	32.915	13.455	1990	32	1999	Sidi Mechreg	37.185	9.115	2007	50	1980	Sidi Bou Said	36.935	10.421	2008
62	1990	East of Tripoli	32.915	13.455	2007	58	1972	East of Tripoli	32.915	13.455	1990	47	1998	Djerba	33.932	10.862	2007	43	1987	Sidi Bou Said	36.935	10.421	2009
64	1964	East of Tripoli	32.915	13.455	2008	41	1990	East of Tripoli	32.915	13.455	1990	40	1993	Bizerte, out off the harbour	37.325	9.932	2008	41	1999	Sidi Bou Said	36.935	10.421	2009
65	1965	East of Tripoli	32.915	13.455	2008	42	1985	Tobruk gulf	32.077	24.038	1991	38	1993	Gabès, a few miles from the harbour	34.003	10.389	2008	53	1986	Goulette	36.854	10.457	2009
57	1980	West of Tripoli	32.858	12.872	2008	37	1992	East of Tripoli	32.915	13.455	1992	43	1990	Kélibia	36.785	11.102	2008	50	1989	Sidi Bou Said	36.935	10.421	2010
41	1990	East of Tripoli	32.915	13.455	2008	45	1981	Tobruk gulf	32.077	24.038	1992	44	1991	Kélibia, 3 miles out off the coast	36.766	11.285	2008	64	1983	Sidi Bou Said	36.935	10.421	2008
42	1984	West of Tripoli	32.858	12.872	2009	65	1980	East of Tripoli	32.915	13.455	1992	38	1993	Sidi Mechreg	37.197	9.059	2008	48	1997	Goulette	36.854	10.457	2013
66	1967	East of Tripoli	32.915	13.455	2009	57	1980	West of Tripoli	32.858	12.872	1992	34	1998	Bizerte coasts	37.346	9.805	2009	40	2000	Goulette	36.854	10.457	2011
51	2000	West of Tripoli	32.858	12.872	2009	75	1950	West of Tripoli	32.858	12.872	1995	34	1999	Kélibia, near the harbour	36.805	11.148	2009						
53	1978	West of Tripoli	32.858	12.872	2009	66	1967	East of Tripoli	32.915	13.455	1996	54	1979	Kélibia, one mile out off the harbour	36.813	11.148	2009						
43	1980	East of Tripoli	32.915	13.455	2009	65	1965	East of Tripoli	32.915	13.455	1997	53	1978	Zarzis near the harbour	33.487	11.183	2009						
75	1950	West of Tripoli	32.858	12.872	2010	52	1998	Tobruk gulf	32.077	24.038	1998	44	1988	Fishing zone of Sidi Bou Said	36.935	10.421	2009						
37	1992	East of Tripoli	32.915	13.455	2011	47	1995	West of Tripoli	32.858	12.872	2002	40	1990	Fishing zone of Sidi Bou Said	36.935	10.421	2009						
46	1982	East of Tripoli	32.915	13.455	2012	51	2000	West of Tripoli	32.858	12.872	2003	60	1974	Fishing zone of Sidi Bou Said	36.935	10.421	2009						
65	1980	East of Tripoli	32.915	13.455	2012	53	1978	West of Tripoli	32.858	12.872	2005	43	1987	Fishing zone of Sidi Bou Said	36.935	10.421	2009						
58	1972	East of Tripoli	32.915	13.455	2012	42	1984	West of Tripoli	32.858	12.872	2006	45	1993	Zarzis near the cost	33.550	11.141	2010						
												35	1993	Between Zarzis and Lake of Biban	33.416	11.161	2010						
												43	1988	Tabarka	37.008	8.735	2011						
												64	1983	Sidi Bou Said	36.935	10.421	2012						

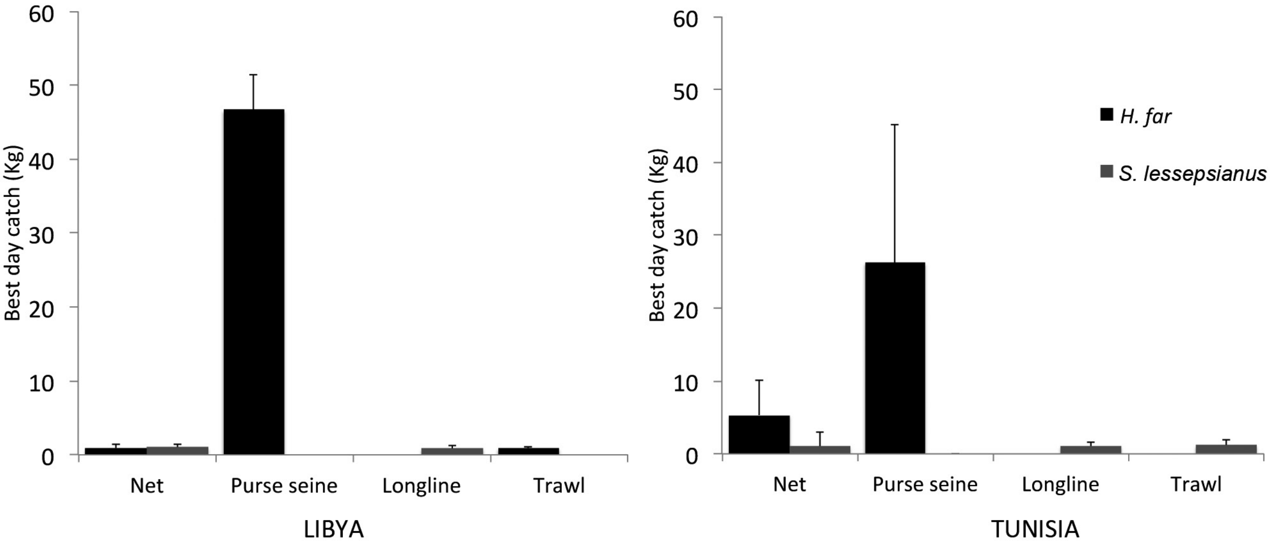

Fig. 3: Average best-day catches (and SD) for *H. far* and *S. lessepsianus* reported by Libyan and Tunisian fishermen.

Table 2. Percentage distribution of *H. far* and *S. lessepsianus* during the last five years (2009-2013). Data were computed on the basis of the respondents who recognized and captured the one and/or the other species.

	Perceived abundance	LIBYA		TUNISIA	
		H. far	*S. lessepsianus*	*H. far*	*S. lessepsianus*
0	ABSENT	10.0	0.00	12.44	11.22
1	RARE (once in a year)	0.00	42.5	36.40	32.14
2	OCCASIONAL (sometimes in the fishing period)	56.7	57.5	39.63	53.06
3	COMMON (regular in the fishing period)	0.00	0.00	11.52	2.55
4	ABUNDANT (regular and abundant in the fishing period)	33.3	0.00	0.00	0.00
5	DOMINANT (always with great abundances in the fishing period)	0.00	0.00	0.00	0.00

the fishing period, *H. far* respondents indicated Autumn: 11.1% of respondents; Autumn and Winter 38.9%; Winter 33.3%; Winter and Spring 16,7%. On the contrary, no specific season was indicated for *S. lessepsianus*.

The results of the breakpoint analysis are shown in Figure 4 and Table 3. A progressive increase in captures from the date of their first appearance onwards is apparent for both species in Tunisia but only for *H. far* in Libya. *H. far* in Libya made its first statistically significant appearance in 1980, and its abundance increased progressively in 1994 and 2007 to be perceived as “COMMON” in 2013. *S. lessepsianus* passed from “ABSENT” to “RARE” in 1989 and its abundance increased in 1995 and 2002 to be perceived as “RARE” to “OCCASIONAL” in 2013. In Tunisia *H. far* passed from “ABSENT” to “RARE” in 2004, although its trend is rapidly increasing and was considered “ABUNDANT” by a few fishers in recent years. *S. lessepsianus* in Tunisia passed from “ABSENT” to “OCCASIONAL” quickly after 2007, and its perceived abundance is also growing rapidly, with some fishers classing it as “COMMON” in recent years.

Discussion

According to fishermen’s ecological knowledge, both *H. far* and *S. lessepsianus* started to occur in Tunisian captures since 2004. This finding perfectly agrees with the chronology of first reports of these species made by professional scientists (Charfi-Cheikhrouha, 2004; Ben Souissi *et al.,* 2005). In eastern Libya, both *H. far* and *S. lessepsianus* have been observed since the 1980’s. As for *S. lessepsianus*, this finding matches the first Libyan record in 1982 (Zupanovic & El-Buni, 1982). In the case of *H. far* it was apparent that fishermen were well aware of this species before professional scientists were, in 2006 (Shakman & Kinzelbach, 2007). This latter observation highlights an important source of uncertainty in ecological observation that is related to major lags in detection of exotic species (*sensu* Crooks, 2011). Indeed, in many other occasions, Mediterranean fishermen were informed about the occurrence of exotic new taxa well before professional scientists. This has been the case of *Metapenaeus monoceros,* which was officially recorded in Tunisia in 1993 (Missaoui & Zaouali, 1995) but fishermen knew

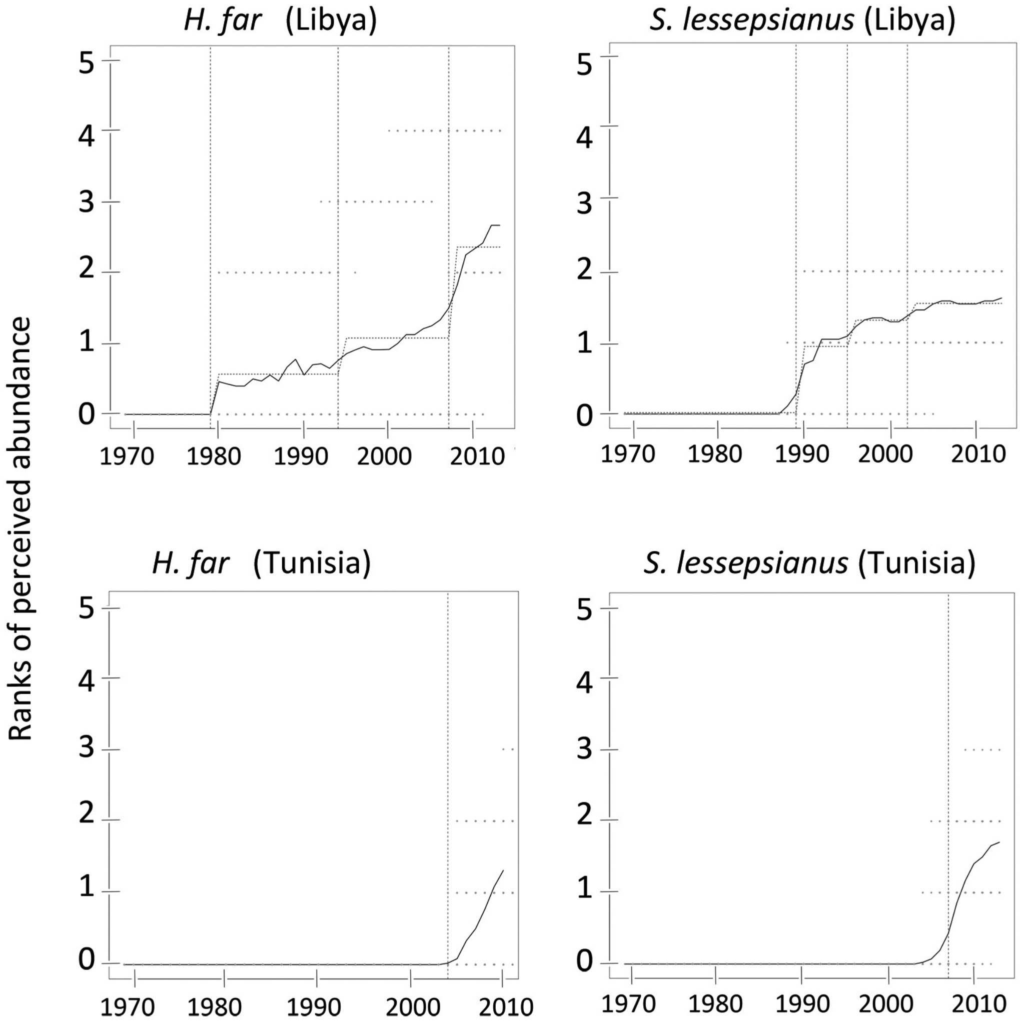

Fig. 4: Changes in the perceived abundance of *H. far* and *S. lessepsianus* in Libya and Tunisia during the period 1970-2013. Y-axis represents a semi-quantitative index of abundance: 0 "ABSENT", 1 "RARE", 2 "OCCASIONAL", 3 "COMMON", 4 "ABUNDANT" 5 "DOMINANT" (note that no fisherman classed any of the two species as dominant). Black line: mean of the annual observations across all fishers; dots: observations; horizontal dotted line: statistically significant mean line for the breakpoint periods; vertical dotted lines: years of breakpoint.

Table 3. Results of the breakpoint analysis for the selected models. All structural change tests based on the F-statistic were significant at p<0.0001.

	LIBYA		TUNISIA	
	breakpoint years	F-stat	breakpoint year	F-stat
H. far	1979, 1994, 2007	91.327	2004	88.071
S. lessepsianus	1989, 1995, 2002	491.990	2007	571.930

this species years before (Jamila Ben Soussi pers. obs.). In one other case, a single specimen of *Fistularia commersonii* was captured by fishermen 25 years before its official detection in 2000 (Bariche *et al.,* 2014). The present collective picture provided by fishermen's LEK showed that both *H. far* and *S. lessepsianus* are widely distributed and established along the entire Tunisian coasts with increasing trend of perceived abundances after 2004. Likewise, the data from Libyan interviews showed an apparent increase in the abundances of *H. far* in the last decade. On the contrary, any recent increase has been reported for *S. lessepsianus,* whose captures are still occasional. Interestingly, several fishermen operating with nets and purse seine, reported observations of very large numbers (hundreds up to thousands) of *H. far* during night. Fishermen repeatedly reported that *H. far* has the ability to jump over the nets and purse seines thus avoiding capture. These behavioural observations agree with a typical trait of *H. far,* which is prone to leap and skitter at the surface avoiding the fishing gear (Bariche, 2012).

Certainly, no quantitative data can be estimated from this survey, being that the best-day captures give just a rough idea of the fished quantities. Moreover the perceived changes in species abundance can be clearly influenced by fishing methods and equipment. Beside the above-mentioned limitations, information reported by fishermen can be evaluated for both reliability (sincerity) and accuracy, that is the degree to which the provided information is near to reality (Silvano & Begossi, 2012). In the present study, interviews can be considered as highly reliable since the extracted information was really based on their daily fishing practices and because of the spontaneous curiosity of many of the respondents. We also may consider that the fisherman's knowledge is accurate, because the historical appearance of a 'new' fish species in captures is a special event that is easily remembered by the fishermen (Azzurro *et al.,* 2011). Remarkably, the analysis of historical trends of abundance revealed coherent species responses for the different study locations and, as expected, invasion chronology followed the East-West gradient, from Tobruk in the eastern Libya to Tabarka in the western Tunisia. Surveying Local Ecological Knowledge about changes in exotic fish presence and abundance provided historical information that otherwise cannot be obtained. As a matter of fact, many southern Mediterranean countries lack the scientific efforts needed to properly track biodiversity changes. Under the urgency of tracking the advance of fish invasions in the Mediterranean Sea, we might broaden our confidence on Local Ecological Knowledge as monitoring tools for exotic species and consider fishermen as experts in these kinds of studies (Rosa *et al.,* 2014). This would overcome the lack of data collection on large spatial and temporal scales, and provide a complementary way to track and to properly manage these rapid and ongoing changes in the marine environment.

Acknowledgements

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