IUCN, International Union for Conservation of Nature

United Nations Environment Program Mediterranean Action Plan

REPORT OF THE MARINE SURVEY IN TYRE

Part of THE SUSTAINABLE FISHERIES MANAGEMENT FOR IMPROVED LIVELIHOODS OF THE COASTAL FISHING COMMUNITY IN TYRE, SOUTH LEBANON. FUNDED BY DROSOS FOUNDATION AND IMPLEMENTED IN PARTNERSHIP WITH ADR.

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Foreword

The present document has been prepared thanks to the consultancy contract (IUCN/06/HR/035/017) signed by the SPA/RAC (Specially Protected Areas/Regional Activity Center) and IUCN Rowa within the framework of the Sustainable Fisheries Project led by the IUCN Rowa in Tyre, Lebanon.

A full marine biodiversity assessment was previously conducted in 2013 in Tyre, with the support of IUCN as part of the MedMPAnet Project, whose general objective is to enhance the effective conservation of regionally important coastal and marine biodiversity features, through the creation of an ecologically coherent MPA network in the Mediterranean region, as required by Barcelona Convention's Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD Protocol). Marine and coastal surveys were successfully implemented in Lebanon.

Throughout the project, SPA/RAC assisted Lebanon to implement the prioritized elements of the Strategic Action Programme for the Conservation of Biological Diversity (SAP/BIO) in the Mediterranean Region, through the provision of a series of enabling activities at national, sub-regional and regional levels.

SPA/RAC and IUCN ROWA have joined their effort to assess the situation of the marine environment in Tyre, following the initial biodiversity assessment back in 2013 by UNEP SPA/RAC and partners, as there was a lot of local and national actions towards improved marine management and sustainable fisheries. To overcome challenging issues and to help a smooth implementation of this activity, a

multilateral collaboration has been set up between the representatives of the Ministry of Environment of Lebanon, SPA/RAC, the University of Alicante, Spain, the American University of Beirut, Lebanon and University Côte d'Azur, France.

1. Introduction

Marine Protected Areas (MPAs) are currently considered the only management strategy for the conservation of marine habitats and their biodiversity. A widely accepted definition of MPAs stipulates that they could permit the sustainable use of resources, while maintaining biological diversity over a range of spatial and temporal scales (IUCN, 1994). MPAs also include fully protected zones (also called *no-take zones* or *marine reserves*) that are considered important tools for achieving conservation and management purposes (PISCO and UNS, 2016). MPAs are known to be particularly effective for protecting key habitats and fish assemblages (Guidetti et al. 2014; Mellin et al. 2016). They can also provide much needed support for fisheries as they can export eggs and larvae as well as allow the relocation of adults and subadults to nearby areas due to density-dependent effects (Gell and Roberts, 2003; Abesamis et al., 2005; Alcala et al., 2005). In fact, many species are of economic importance and targeted by fisheries, and their populations have low mortality within MPAs. The protection benefits are more evident in fully protected zones than in partially protected ones (PISCO and UNS, 2016).

All over the world, scientists monitor MPA effectiveness by assessing fish assemblages using underwater visual census (UVC) methods after MPA establishment, often comparing data from fish transects carried out under protected and fished conditions (e.g. Sala et al., 2012; Edgar et al. 2014; Aburto-Oropeza et al. 2015; Caldwell et al. 2016).

The coastal areas in Lebanon have been subjected to high human pressure, resulting in a severe degradation of the marine environment, resources and biodiversity. The Lebanese fishery has remained artisanal over the years due to several reasons, however illegal or unregulated fishing practices, together with a lack of an overall sustainable fishery management plan, resulted in the overexploitation of these resources and the degradations of essential habitats. The reduced catches and impoverished livelihoods of the fishermen mean that they can hold themselves an important role to improve their situation.

The Tyre Coast Nature Reserve (TCNR) is situated in the south of the city of Tyre (Sour in Arabic), a World Heritage Site designated by the UNESCO in 1984. It was established in 1998 (Act no. 708, issued November 5, 1998) and is constituted by a number of private lands of about 380ha coupled with a long sandy beach. A five-year Management Plan was developed for the TCNR by the MedWetCoast Project, an initiative under the Ramsar Convention, and funded by the "Fonds Francais pour l'Environnement Mondial" (FFEM) with national contributions. It was executed by the Ministry of Environment (MoE) and managed by the United Nations Development Programme (UNDP) from 2002 to 2006. A management plan was developed to protect the biodiversity at global and regional levels, with little focus on the conservation of marine biota and habitats. The plan was endorsed by the MoE and by the Council of Ministries (Decree 8044, dated 25/4/2012). TCNR is also recognized as a wetland of international importance by Ramsar Convention on Wetlands and as an Important Bird Area (IBA). The Lebanese Ministry of Culture

(MoC), through the Directorate General of Antiquities (DGA), is mandated over all archaeological and historical sites in the region, and this includes that of Ras el Ain (part of the TCNR), which was designated as national heritage through a governmental decree.

The "Sustainable Fisheries Management for Improved Livelihoods of the Coastal Fishing Community in Tyre, South Lebanon" project was implemented by IUCN and ADR (Association for the Development of Rural capacities) and funded by DROSOS. The project aims at improving livelihoods security and empowerment, as well as sustainable marine ecosystem management. A result of the empowerment of stakeholders on marine management planning has been the creation of the "Tyre Caza Platform for Fisheries Legislation Application". This platform is constituted by concerned ministries, security forces, municipalities, union of municipalities, fishermen cooperatives and syndicates, NGOs and the TCNR. Its vision is to promote sustainable marine ecosystems while fostering economic prosperity across fisheries and the maritime sector. Its main goal is to reduce the use of destructive fishing techniques and landing of protected species, through collaborations and coordination, in order to achieve long-term sustainable fisheries management.

The coastal fishermen operating in South Lebanon, and particularly in Tyre, are among the most deprived people in the country. The South Governorate, to which Tyre District belongs, is the second poorest Governorate in Lebanon, with a 42% prevalence of overall poverty. Within this context, the fishing community forms an economically, socially and culturally distinct, highly specialized but also highly

impoverished subgroup, which is steady across generations. This community is organized in the Tyre Fishermen's Syndicate, which operates along the entire coast of the District. The members of the Tyre Fishing Syndicate are largely aware of these problems, and are willing to address the root causes of the breakdown in their coastal fisheries as well as the socio-economic situation of the fishers and other stakeholders.

Reference made to the above considerations, the present project aims at (i) assisting the members of the Tyre Fishing Syndicate and their families to jointly improve their livelihoods through sustainable fisheries management, better processing/marketing and providing supplementary income for future generations, and (ii) empowering the Tyre Coast Nature Reserve (TCNR) to improve the conservation efforts and establish a Locally Managed MPA.

To reach the aforementioned objectives, the activity was built on existing information, especially that gathered and compiled within the framework of the "Regional Project for the Development of a Mediterranean Marine and Coastal Protected Areas" (MPAs) Network through the boosting of Mediterranean MPAs creation and management (MedMPAnet Project).

To overcome challenging issues and to help a smooth implementation of the activities, especially the field ones, a multilateral collaboration has been set up between the representatives of the Ministry of Environment of Lebanon, SPA/RAC, IUCN-ROWA, the University of Alicante, the University of Nice Sophia Antipolis, the

Lebanese University and the National Council for Scientific Research (CNRS). They have joined their efforts and formed a multidisciplinary team that took part to the field survey at Tyre Coast Nature Reserve and its surrounding area.

The study was done in April 2017 with two main aims:

- To characterize key habitats in the TCNR (between 0 and 50 meters down),
- To actualize and compare fish assemblage in different managed and control locations, with reference to the 2013 inventory established in the same localities.

The present report brings together and compare data about managed and control areas of TCNR, including key habitat, fish assemblage metrics evolution, and fishing market description in Tyre city. This report also includes recommendations for the possible management and development of the sites being studied, as future protected locations.

2. Report of the mission

2.1 Chronogram

The team visited Lebanon for 10 days and the survey and assessment lasted from 15 to 22 April 2017 (Table 1). Work was 9 to 10 hours per day, starting from around 6 a.m. until about 5 p.m.

Table 1. Distribution of activities/day during the mission

Activities/day	15	16	17	18	19	20	21	22
Work meeting	X						X	X
Field work		X	X	X	X	X		

Day 1: Friday 14 April 2017

- Arrival to Beirut of SPA/RAC experts

- Transfer to Tyre

Day 2: Saturday 15 April 2017

- Coordination meeting with the IUCN team and representative of Tyre Coast Nature Reserve to plan the mission and prepare the logistic aspects

- Visit to the fish market of Tyre

Day 3: Sunday 16 April 2017

- Fish visual census and habitats characterization:

1. Four dives, divided in three sites in *Bayada*
2. Four dives, divided in three sites in *Jamal*
3. Four dives in three sites in *Bakbouk*
4. Four dives in three sites in *Zire*

- Work progress meeting.

Day 4: Monday 17 April 2017

- Fish visual census and habitats characterization:

1. Four dives in three sites in *East Zire*
2. Four dives in three sites in *Jamal deep*

- Work progress meeting.

Day 5: Tuesday 18 April 2017

- Fish visual census and habitats characterization:

1. Four dives in three sites in *Qasmieh* freshwater springs
2. Four dives in three sites in *Turtle Reef*

- Work progress meeting.

Day 6: Wednesday 19 April 2017

- Fish visual census and habitats characterization:

1. Four dives in three sites in *Bayada*
2. Four dives in three sites in *Jamal*
3. Four dives in three sites in *Zire*
4. Four dives in three sites in *Bakbouk*

- Work progress meeting.

Day 7: Tuesday 20 April 2017

- Fish visual census and habitats characterization:

1. Four dives in three station in *Qasmieh* hot springs

- Work progress meeting.

Day 8: Friday 21 April 2017

- Data processing
- Departure to Beirut

Day 9: Saturday 22 April 2017

- Data processing
- Wrap-up meeting

Day 10: Sunday 23 April 2017

- Departure of SPA/RAC experts

2.2 Staff

Table 2 shows the participants of the mission from UNEP/MAP - SPA/RAC, IUCN-ROWA, Nice Sophia Antipolis University (France) and the University of Alicante (Spain). Five research divers took part in the assignment.

Table 2. Participants to the mission with affiliation and corresponding tasks

Name	Affiliation	Tasks
Yassine Ramzi SGHAIER	UNEP/MAP - SPA/RAC	Marine Habitats
Aitor FORCADA	University of Alicante	Ichthyofauna, GIS
Carlos VALLE	University of Alicante	Ichthyofauna, GIS
Emna BEN LAMINE	INAT/UCA	Ichthyofauna, GIS
Ziad SAMAHA	IUCN-ROWA	Logistics activities and diving supply
Majed BAWAB	Owner of "Abou Mahmoud" boat	Skipper
Hussein GHANEM	Tyre municipality	Skipper
Elias MBAYED	Tyre municipality	Skipper
Clara LEAC	Freelance	Communication

3. Material and methods

3.1 Study area

Overall, habitat and fish assemblages were surveyed in a total of eight localities around the coast of Tyre, in the southern part of Lebanon (Figure 1). Geographically, they extended from *Bayada* (South Tyre) to *Qasmieh* springs (North Tyre) and their depth ranged from 1.5 to 47 m. The team aimed at sampling a maximum of localities in order to provide high quality data, useful in future management decisions. Two localities, namely *Zire* and *Jamal*, were regularly patrolled to prevent fishing activities, which became illegal according to the Lebanese law since 2015. They were both considered in the study as managed areas. On the other hand, patrol enforcement was not present in two other localities *Bayada* and *Bakbouk*, where fishing activities occurred regularly. They were considered as control sites. Finally, in addition to the survey, the three localities *Bayada*, *Qasmieh* springs and *East Zire* were sampled to allow temporal comparisons with samples obtained in a previous survey in 2013 (RAC/SPA and UNEP/MAP, 2013).

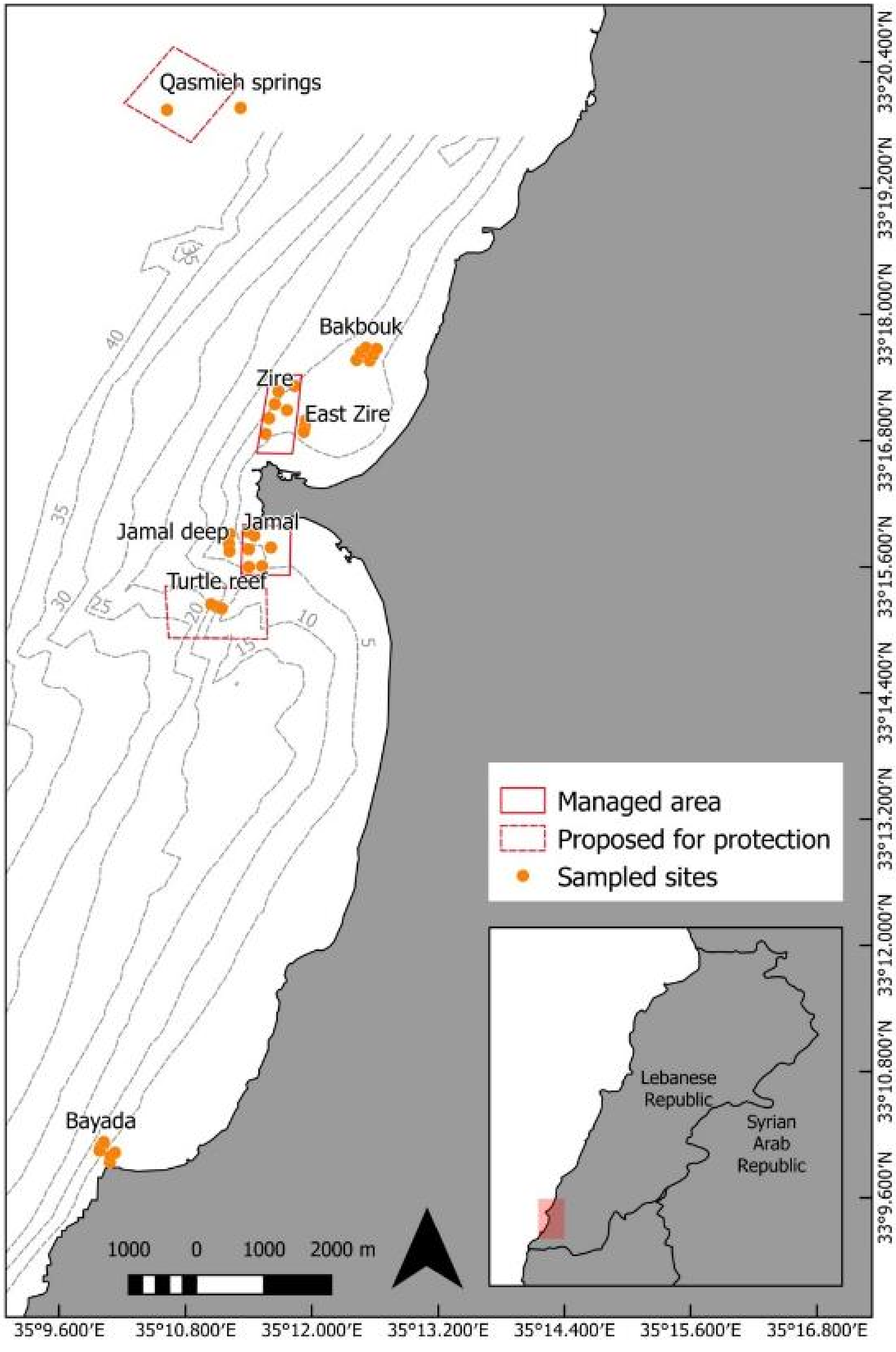


Figure 1. Study area with the location of the managed areas, localities prospected and sampling sites


(a)


(b)

Figure 2. "Abou Mahmoud" boat (a) and RHIB (b) used for the transfer to localities and diving
(©C. LEAC)

Four to six sampling sites were chosen randomly in each of the eight localities (see Table 3 and Figure 1 for details). In total, 39 sites were prospected by scuba diving. A total of 52 dives were performed resulting in a total of 35 hours of underwater

work. Each researcher used his/her own diving equipment, GPS and underwater cameras, while scuba tanks (15 and 18 litres) and diving weights were provided by the IUCN-ROWA. The University of Alicante provided measuring tapes for the visual census of fishes.

Table 3. Surveyed sites GPS coordinates, depth, number of divers and substrates type

Locality	Site	Longitude (WGS84)	Latitude (WGS84)	Depth (m)	Divers	Substrates
Bakbouk	S1	W35°12'30.94"	N33°17'41.08"	10.2-12.7	4	Rocks
	S2	W35°12'28.11"	N33°17'38.55"	12.0-14.5	4	Rocks
	S3	W35°12'25.61"	N33°17'34.13"	11.5-14.0	4	Rocks
	S4	W35°12'33.09"	N33°17'33.70"	9.0-10.2	4	Rocks
	S5	W35°12'35.09"	N33°17'37.03"	9.5-12.0	4	Rocks
	S6	W35°12'37.09"	N33°17'40.53"	10.5-11.0	4	Rocks
Bayada	S1	W35°9'59.78"	N33°10'5.242"	9.8-12.9	4	Rocks
	S2	W35°10'1.513"	N33°10'7.806"	12.0-15.0	4	Rocks
	S3	W35°9'59.10"	N33°10'2.924"	10.4-11.7	4	Rocks
	S4	W35°10'4.996"	N33°9'56.25"	2.5-5.7	4	Rocks
	S5	W35°10'5.311"	N33°9'59.72"	6.5-10.0	4	Rocks
	S6	W35°10'7.946"	N33°10'1.761"	9.0-11.5	4	Rocks
East Zire	S1	W35°11'56.00"	N33°16'56.31"	5.9-6.9	4	Cobbles and rhodoliths
	S2	W35°11'56.61"	N33°16'59.75"	6.0-7.5	4	Cobbles and rhodoliths
	S3	W35°11'55.53"	N33°16'53.16"	6.0-7.5	4	Cobbles and rhodoliths
Jamal	S1	W35°11'36.71"	N33°15'47.14"	1.5-4.9	4	Rocks
	S2	W35°11'27.22"	N33°15'53.97"	1.5-4.5	4	Rocks
	S3	W35°11'23.18"	N33°15'56.25"	4.0-8.0	4	Rock
	S4	W35°11'31.62"	N33°15'36.50"	2.0-5.5	4	Rocks
	S5	W35°11'24.13"	N33°15'36.09"	4.0-9.0	4	Rocks
	S6	W35°11'24.04"	N33°15'46.08"	5.0-7.0	4	Rocks
Jamal deep	S1	W35°11'13.24"	N33°15'54.91"	11.2-13.9	4	Rocks
	S2	W35°11'13.05"	N33°15'45.01"	10.0-13.0	4	Rocks
	S3	W35°11'12.72"	N33°15'49.20"	9.5-12.0	4	Rocks
Qasmieh	S1	W35°11'19.39"	N33°19'57.89"	32.2-40.9	5	Rocks

springs						
	S2	W35°10'37.41"	N33°19'57.89"	37.0-44.0	5	Rocks
	S3	W35°11'8.609"	N33°19'57.89"	37.0-44.0	5	Rocks
	S4	W35°11'5.866"	N33°19'56.74"	38.9-39.0	5	Rocks
	S5	W35°11'2.599"	N33°19'56.74"	34.0-39.0	5	Rocks
	S6	W35°11'35.68"	N33°19'56.74"	37.0-47.0	5	Rocks
Turtle reef	S1	W35°11'40.91"	N33°15'12.36"	6.5-9.0	4	Rocks
	S2	W35°11'38.94"	N33°15'13.27"	9.0-13.5	4	Rocks
	S3	W35°11'45.87"	N33°15'14.79"	11.0-16.5	4	Rocks
Zire	S1	W35°11'50.20"	N33°17'0.848"	7.1-9.7	4	Rocks
	S2	W35°11'33.76"	N33°17'16.23"	5.0-9.0	4	Rocks
	S3	N35°11'38.94"	N33°17'8.952"	7.0-8.0	4	Rocks
	S4	N35°11'45.87"	N33°17'5.467"	4.6-5.3	4	Rocks
	S5	N35°11'50.20"	N33°17'19.29"	6.0-8.0	4	Rocks
	S6	N35°11'33.76"	N33°16'51.98"	5.0-6.5	4	Rocks


(a)

(b)

Figure 3. Example of survey sites with very low (a) and medium (b) algal covering (© E. Ben Lamine)

3.2 Observations and characterization of habitats

Scuba diving gear and underwater photographs were used to acquire data regarding depth, type of seabed, and the fauna and flora present. Detailed notes were taken underwater on plastic plates with polyester paper. In addition, some species were sampled for taxonomic determination (Figure 3). Each dive was located using GPS. Habitat characterization was then made (UNEP/MAP, 1998; Bellan-Santini et al., 2007).

At each site, percentage algal coverage was estimated using 50×50 cm metal quadrats, divided into 10 cm^2 squares (Figure 4). A total of 10 cover measures were obtained at each studied site along a 50 m transect (one measure every 5 m).

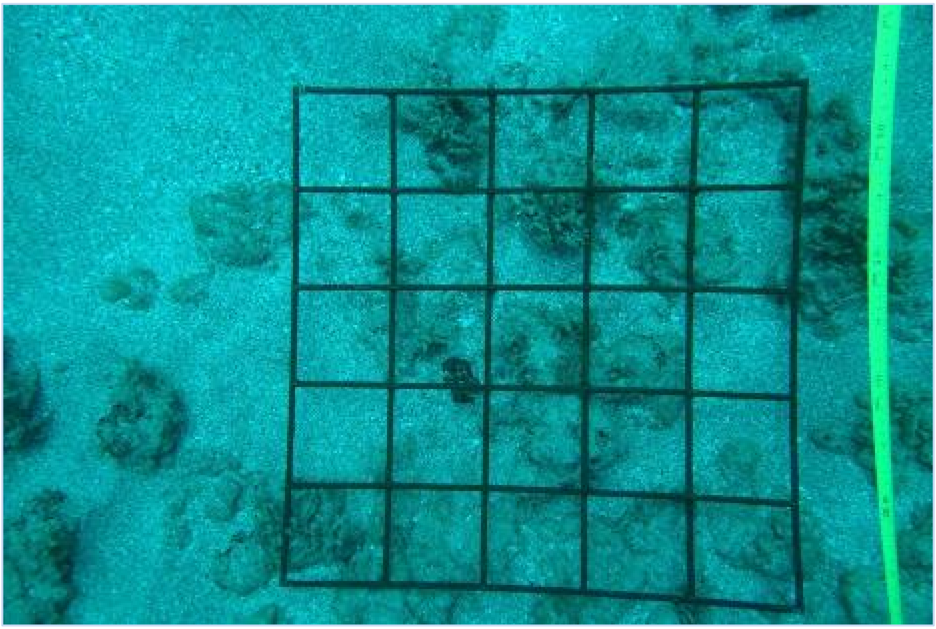


Figure 4. Quadrat used for percentage cover of algae species estimation (©Y.R. Sghaeir).

3.3 Visual fish census

Fish assemblage was characterized using underwater visual censuses along strip transects of 25x5 m. At each site, four replicates were made, for a total of 144 replicates. Censuses were performed on rocky substrates, since other substrate types (like sand or seagrass meadows) represented less than 10% in cover.

Along each transect, the diver swam at an approximate constant speed of 4 meters/min. The name, number and size of each fish encountered were estimated and recorded while the measuring tape was unrolled. Fish sizes (total length: TL) were estimated within 2 cm size classes for all species.

Figure 5. Fish, habitat and rocky blocks counts (©Y.R. Sghaeir)

3.4 Processing the samples and data treatment

Fish assemblage structure was specified for each transect: (1) species richness, total density, total biomass and economic value for the whole fish assemblage, (2) density, biomass and size-class distributions per relevant species (i.e. species with high relative frequency of occurrence (>10%) and/or those of commercial interest for fishing). Fish wet mass was estimated from size data by means of length-weight relationships from the available literature: $W=a*L^b$, where W is the biomass (in grams), L is the total length estimated underwater (in cm), a is the intercept and b is the slope of the log-transformed relation between length and weight (Le Cren, 1951; Froese, 2006), while a and b are available on Fishbase database (Pauly et Froese, 2017). ECOCEN software (Bayle-Sempere et al., 2002) was used for compiling the data collected on fish assemblages.

Total density and total biomass were estimated by excluding from the calculations all pelagic species (Atherinidae, Centracanthidae, Pomacentridae, the Sparidae Boops

boops and Oblada melanura). These species are often abundant and gregarious, forming schools, and their high variability in spatial distribution may mask the effect of protection (Harmelin, 1987; Garcia-Charton et al., 2004). Species belonging to Gobiidae and Scorpaenidae are particularly cryptic or hidden and they require a surveying procedure specifically adapted to their characteristics (Willis, 2001). For this reason, these species were not analysed and were also removed from total density and biomass estimations.

3.5 Data analyses

Statistical tests were performed to compare fish assemblages between the two managed (*Zire* and *Jamal*) and control sites (*Bakbouk* and *Bayada*). Fish assemblages were also compared between 2013 and 2017 in three locations (*Bayada*, *Qasmieh* springs and *East Zire*). Fish assemblage data of 2013 were available from the same three locations surveyed previously (RAC/SPA and UNEP/MAP, 2013).

The experimental design was different for each comparison:

(1) For the comparison between managed and control areas, three factors were considered: “Management” (fixed with two levels: managed and control), “Locality” (random and nested in factor “Management”, four levels) and “Site” (random and nested in factor “Location”, with six levels). Thus, four underwater visual censuses resulted in 96 observations.

(2) To compare fish assemblages between 2013 and 2017, the experimental design comprised two factors: "Year" (fixed with two levels: 2013 and 2017) and "Locality" (fixed and orthogonal, with three levels: *Bayada*, *Qasmieh* springs and *East Zire*). Thus, with n ranging between 5 and 24, there were a total of 69 observations.

Univariate (ANOVA) and Multivariate (PERMANOVA) statistical tests were performed for both comparisons. Analysis of variance (ANOVA) (Underwood, 1997) was used to test for significant differences in species richness, total density, total biomass and economical value, and density and biomass by species (analyses were performed only on those non-pelagic taxa sufficiently frequent throughout the study, i.e. with a frequency ≥10%) considering the previous experimental designs. If the ANOVA F-test were significant, post-hoc analyses were conducted using Dunnett-Tukey-Kramer multiple comparison (Dunnett, 1980). Before analysis, Bartlett test (Bartlett, 1937) was used to test for homogeneity of variance. Where significant heterogeneity was found, the data were transformed by $\sqrt{(x+1)}$ or $\ln(x+1)$. When transformations did not remove heterogeneity, analyses were performed on the untransformed data but with the F-test α value set at 0.01, since ANOVA is robust to departures from this assumption, especially when the design is balanced and contains a large number of samples or treatments (Underwood, 1997). All ANOVA were conducted by R statistical computing software (R Core Team, 2014) and the R's packages GAD (Sandrini-Neto and Camargo, 2014) and DTK (Matthew, 2013).

Multivariate analyses were performed using Permutational Analysis of Variance (PERMANOVA) (Anderson, 2001) considering the previous experimental designs and

Metric Multi-Dimensional Scaling (MDS). Two matrices were composed by n=96 samples and 47 species (one for abundance and the other for biomass) for the comparisons between managed and control areas. Two other matrices were composed of n=69 samples and 47 species (abundance and biomass also), and were used for comparisons between years. All data were standardized using square roots transformation. Resemblance using Bray-Curtis dissimilarity was used before performing PERMANOVAs. Pairwise tests were used whenever necessary (significant interactions). Primer 7.0 software and PERMANOVA+ packages were used for performing PERMANOVA. We used Monte Carlo test whenever the number of permutations was <200. Post-hoc tests were also used whenever interactions between factors were significant.

4. Results

4.1. Habitats

4.1.1. List of habitats

All the prospected localities were characterized by a rocky bottom or coarse sand substrates and different typologies were observed (Photo credit: Y.R. Sghaeir):

Fine and coarse sand

This type of substratum was observed in the *East Zire*. In some places the cobbles are abundant with some rhodoliths.

Low and smooth flat rocks

The rocky seabed is more or less continuous without crevices or canals; only some small boulders, cobbles or pebbles are present. Normally, this type of rocky substratum is covered with shell gravel and coarse sand. It is widespread in the locations of *Jamal* and *Bayada*.

Low and irregular flat rock with channels

The rock is 0.5-1 m high, with irregular shell gravel coarse sand channels. This is a dominant seabed in *Bakbouk*, *Jamal deep* and *Zire*.

High irregular rocks

The rocks form a great massif. This is a dominant seabed in *Zire*, *Turtle reef* and *Qasmieh* springs.

4.1.1.1. Sheltered photophilic macroalgae

Facies with Chama pacifica and Spondylus spinosus

Widespread and presumably native to the Indo-West Pacific, Chama pacifica invaded the Mediterranean Sea at least at the beginning of the last century (Tillier and Bavay, 1905; Mienis et al., 1993), becoming first established and then invasive among the fouling communities from the intertidal to the infralittoral zone of the deep eastern Mediterranean Sea (Zenetos et al., 2010). Spondylus spinosus was first recorded in 1988 in the Mediterranean Sea (Mienis et al., 2013). It is usually found attached to rocky sea beds at depths ranging between 2 and 40 m. Together with Chama pacifica, they form dense populations; their shells provide strongholds for a diverse community of algae and invertebrates (Fishelson, 2000).

In 2013, although these non-indigenous bivalves can be present from 1 to 30 m depth, they were observed between 5 to 25 m depths in Tyre area and were sometimes dominant, forming unique facies. Such facies were observed during this mission in both *Zire* and *Bayada*.

Figure 6. Chama pacifica shell covered by diverse communities of algae in *Zire* locality (©Y.R. Sghaeir)

Association with Galaxaura rugosa and Laurencia sp.

First described from Jamaica and the Bahamas respectively, they are widespread in warm seas. Galaxaura rugosa is a non-indigenous species, first recorded in the Mediterranean Sea from Syria as G. lapidescens (Mayhoub, 1990). In Lebanon, G. rugosa was first found in 1995 and spread in 2007 (RAC/SPA - UNEP/MAP, 2014). Subsequently, it was observed down to a depth of 35 m (RAC/SPA - UNEP/MAP, 2014). Described from the Caribbean Sea, L. chondrioides was first recorded in the Mediterranean Sea from the Balearic Islands, the Aeolian Islands and from Lachea Island (Boisset et al., 1998). In Lebanon, we found large quantities of this Laurencia in October 2009 at *El Bayada* and between Tyre and Nakoura. We confirmed the spread in Saida and the Tyre – Nakoura region, where the species was abundant

from the sea-surface down to 23 m depth (RAC/SPA - UNEP/MAP, 2014). The association between Galaxaura rugosa and Laurencia chondrioides is widespread in the prospected areas (*Bayada*, *Jamal*, *Zire*, *Deep Zire*, *Bakbouk* and *Turtle Reef*).

Figure 7. Galaxaura rugosa observed in *Bayada* (©Y.R. Sghaeir)

Figure 8. Laurencia chondrioides observed in *Deep Zire* (©Y.R. Sghaeir)

Association with Cystoseira spp.

In the Mediterranean, the genus Cystoseira is constituted by perennial species that dominate several benthic assemblages from the littoral fringe down to circalittoral depths. They generate high primary production and are known to constitute a suitable habitat to many species, such as shelter, food, and nursery areas. The Cystoseira genus is listed among the group of endangered species [Annex II of the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean of the Barcelona Convention (UNEP/MAP - RAC/SPA, 2009)]. The Cystoseira spp. encountered in Lebanon could be C. foeniculacea (C. discors) cited by Bitar and Kouli-Bitar (2001). Cystoseira spp. associations were observed in *East Zire* between 7 and 9 m depth.

Figure 9. Cystoseira spp. observed in *East Zire* (©Y.R. Sghaeir)

Association with Lophocladia lallemandii

First described from the Red Sea, Lophocladia lallemandii first record from Lebanon dates back to 1973 (Basson et al., 1976). Subsequently, it was observed at Batroun and Barbara, in 1996-1997 (Lakkis & Novel-Lakkis, 2000, 2001). The species is qualified as 'dominant upper infralittoral species' (Lakkis & Novel-Lakkis, 2007; Lakkis, 2013). We found it in the port of Barbara (1993), on the Vermetid reefs of Amchit (2000), and in the infralittoral zone at Ras Chekaa and Hannouch, from the sea-surface down to 25 m depth (Bitar, 2010; RAC/SPA - UNEP/MAP, 2014). Lophocladia lallemandii is well established in Lebanon. This association with

Lophocladia lallemandii is very abundant in *Qasmieh* freshwater spring at 38 m depth.

Figure 10. Lophocladia lallemandii covering the rocky substrate of *Qasmieh* fresh spring at 38m depth (©Y.R. Sghaeir)

4.1.1.2 Maerl beds

Association with rhodolithes

Although this community is enclosed in the biocoenosis of coarse sands and gravels under the influence of bottom currents, its originality and rare habitat in the Mediterranean deserves to be considered separately. Rhodolithes were observed in *Bayada*, Zire, *Deep Zire*, *Bakbouk* and *Qasmieh* springs.

Figure 11. Rhodolithes were observed in *Bayada* (©Y.R. Sghaeir)

4.1.1.3 Submarine cold and hot freshwater springs

The submarine cold and hot freshwater springs are very interesting due to their rarity and organisms adaptations around them. We have had the opportunity to dive in these underwater features in *Qasmieh* springs.

Cold freshwater springs

The abundance of shallow water species, such as the hydrozoan Pennaria disticha and the ascidian Phallusia nigra, around the springs in this deep site (38 - 42 m) is noteworthy. Other common species were Crambe crambe, Eudendrium spp., Chama

pacifica and Spondylus spinosus. Lophocladia lallemandii covered the rocky substrate of *Qasmieh* freshwater spring at 38 m depth.

Figure 12. Axinella polypoides and Synaptula reciprocans in the cold freshwater springs' area (©Y.R. Sghaeir)

Hot-water springs

Located in the north of Tyre, between 38-50 m depth. The colonies of the bacteria Beggiatoa are characteristic and they grow quite near to the hot spring hole. The biodiversity around the hot springs is poorer than that of the cold-water ones, dominating the encrusting rhodophytes.

Figure 13. Hot water spring with Beggiatoa bacterial colonies (white) and some branched rhodoliths of Lithothamnion corallioides (©Y.R. Sghaeir)

4.1.2. Characterization of habitats

Galaxaura rugosa and Laurencia chondrioides were the most dominant seaweeds in the prospected rocky sites, except for *Qasmieh* springs where Lophocladia lallemandii covered 80% of the surface. In *East Zire*, the density of the Mediterranean Cystoseira foeniculacea was 4±1.8 m^{-2} (Table 4).

Table 4. Percentage cover of seaweed species estimation

	G. rugosa	L. chondrioides	C. mediterranea	C. foeniculacea	L. lallemandii
Jamal		29%			
Bayada		14%			
Bakbouk	32%		4%		
Zire	50%	10%	20%		
East Zire				13%	
Turtle reef	40%		10%		
Qasmieh springs					80%

4.1.3. Marine habitats: 2013 vs 2017

No differences were observed between 2013 and 2017 regarding marine habitats. However, two new Non-Indigenous Species (NIS)(Lophocladia lallemandii and Ganonema farinosum) were observed for the first time in Tyre area. Lophocladia lallemandii was recorded with very high cover in *Qasmieh* springs fresh water.

G. farinosum was first found in April 1993 at El Heri (Bitar et al., 2000, as L. farinosa; Bitar, 2010). Subsequently, it was observed as a G. farinosum facies along the whole coast, growing mainly in shallow habitats (2-3 m depth) (Lakkis and Novel, Lakkis, 2000, 2001, 2007, as Liagora farinosa). Ganonema farinosum was established in Lebanon. During this mission, G. farinosum was observed in *Turtle Reef*.

Figure 14. Ganonema farinosum observed in *Turtle reef* (©Y.R. Sghaeir)

4.2. Fish assemblages

4.2.1. Fish assemblages per locality

4.2.1.1. Species richness, total abundance, total biomass and economical value

In total, 19,176 individuals were observed. They represented 41 fish species from 16 different families (Table 5). The highest mean species richness and highest mean biomass were found in *Jamal deep* location (Table 6 and Figures 15 and 17), while the highest mean abundance was encountered in *Turtle reef* and *Zire* locations (Table 6 and Figure 16). Meanwhile, the highest mean economical value was censused in *Qasmieh* Springs (Table 6 and Figure 18).

Table 5. Families and fish species censused during the survey

Status (N: Native Mediterranean species, NIS: Non-Indigenous Species); spatial category (SC: 1- highly mobile gregarious, pelagic erratic species, 2- planktophagous and relatively sedentary species, living throughout the water column, 3- demersal mesophagic species, with medium-amplitude vertical movements and relatively broad horizontal movements, 4- demersal species, with slight vertical and high lateral movements, 5- sedentary demersal mesophagic species, 6- highly sedentary cryptic benthic species); trophic category (TC: HBV: herbivores, MIC: microphagic carnivores, MEC: mesophagic carnivores, MAC: macrophagic carnivores); commercial value ($/Kg, NC: No commercial value) and total abundance.

Family	Species	Status	SC	TC	Commercial value		Total abundance
					Juvenile	Adult	
Haemulidae	Pomadasys incisus (Bowdich, 1825)	NIS	4	MEC	NC	NC	2
Dasyatidae	Dasyatis centroura (Mitchill, 1815)	N	6	MAC	NC	NC	1
	Dasyatis marmorata (Steindachner, 1892)	N	6	MAC	NC	NC	1
	Dasyatis pastinaca (Linnaeus, 1758)	N	6	MAC	NC	NC	3
Gobiidae	Gobius bucchichi Steindachner, 1870	N	6	MEC	NC	NC	7
Holocentridae	Sargocentron rubrum (Forsskål, 1775)	NIS	6	MEC	NC	NC	146
Labridae	Coris julis (Linnaeus, 1758)	N	5	MEC	NC	NC	548
	Labrus viridis (Linnaeus, 1758)	N	5	MEC	NC	NC	1
	Pteragogus pelycus Randall, 1981	N	5	MEC	NC	NC	1
	Symphodus doderleini (Jordan, 1981)	N	5	MEC	NC	NC	5
	Symphodus mediterraneus (Linnaeus, 1758)	N	5	MEC	NC	NC	1
	Symphodus roissali (Risso, 1810)	N	5	MEC	NC	NC	2
	Symphodus tinca (Linnaeus, 1758)	N	5	MEC	NC	NC	22
	Thalassoma pavo (Linnaeus, 1758)	N	5	MEC	NC	NC	1764
	Xyrichtys novacula (Linnaeus, 1758)	N	5	MEC	9.9	13.2	1
Monacanthida	Stephanolepis diaspros Fraser-Brunner, 1940	NIS	5	MEC	NC	NC	20
Mullidae	Upeneus pori Ben-Tuvia & Golani, 1989	NIS	4	MEC	23.1	39.6	1
Muraenidae	Muraena helena Linnaeus, 1758	N	6	MAC	NC	NC	6
Pempheridae	Pempheris rhomboidea Kossmann & Rauber,1877	NIS	6	MEC	NC	NC	106
Pomacentridae	Chromis chromis (Linnaeus, 1758)	N	2	MIC	NC	NC	6782
Scaridae	Sparisoma cretense (Linnaeus, 1758)	N	5	MEC	4.62	9.9	77
Scorpaenidae	Pterois miles (Bennett, 1828)	NIS	6	MAC	NC	NC	1
	Scorpaena maderensis Valenciennes, 1833	N	6	MAC	9.9	16.5	1
	Scorpaena porcus Linnaeus, 1758	N	6	MAC	9.9	16.5	2
Serranidae	Epinephelus costae Valenciennes, 1828	N	5	MAC	17.82	23.1	9

	Mycteroperca rubra (Bloch, 1793)	N	5	MAC	17.82	23.1	50
	Serranus cabrilla (Linnaeus, 1758)	N	5	MAC	NC	NC	50
	Serranus scriba Linnaeus, 1758	N	5	MAC	NC	NC	14
Siganidae	Siganus luridus (Rüppell, 1829)	NIS	3	HBV	3.3	6.6	75
	Siganus rivulatus Forsskål & Niebuhr, 1775	NIS	3	HBV	3.3	6.6	6335
Sparidae	Boops boops (Linnaeus, 1758)	N	1	MIC	5.28	9.9	800
	Diplodus annularis Rafinesque, 1810	N	3	MEC	4.62	9.9	1
	Diplodus cervinus Lowe, 1841	N	3	MEC	4.62	9.9	2
	Diplodus puntazzo Cetti, 1789	N	3	MEC	4.62	9.9	1
	Diplodus sargus (Linnaeus, 1758)	N	3	MEC	4.62	9.9	79
	Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	N	3	MEC	4.62	9.9	5
	Oblada melanura (Linnaeus, 1758)	N	1	MIC	3.96	7.92	69
	Spicara smaris (Linnaeus, 1758)	N	3	MIC	NC	NC	18
	Spondyliosoma cantharus (Linnaeus, 1758)	N	3	MIC	NC	NC	1
Tetraodontidae	Lagocephalus sceleratus (Gmelin, 1789)	NIS	2	MAC	NC	NC	4
	Torquigener flavimaculosus Hardy & Randall, 1983	NIS	4	MIC	NC	NC	21

Table 6. Mean species richness (species/125 m^2), mean total abundance (individuals/125 m^2), mean total biomass (kg/125 m^2) and mean economical value ($/125 m^2) (±s.e.) of the fish assemblage observed in the eight sampled localities.

	Managed areas			Non-managed areas				
	Jamal	Zire	Jamal deep	Bayada	Bakbouk	East Zire	Qasmieh	Turtle reef
Species richness	4.3 ± 0.4	5.5 ± 0.5	7.7 ± 0.7	4.6 ± 0.3	5.3 ± 0.3	2.9 ± 0.5	2.8 ± 0.3	6.1 ± 0.6
Total abundance	65.6 ± 17.7	106.7 ± 22.4	71.5 ± 26.6	87.8 ± 24.3	21.3 ± 3.3	27.5 ± 16.4	11.7 ± 2.2	106.3 ± 34.4
Total biomass	1.3 ± 0.5	1.4 ± 0.2	3.6 ± 2.4	2.9 ± 2.0	1.6 ± 1.2	0.4 ± 0.2	2.2 ± 1.4	0.9 ± 0.2
Economical value	6.5 ± 2.7	6.0 ± 1.0	6.3 ± 1.7	12.9 ± 10.0	1.9 ± 0.4	4.7 ± 2.6	24.4 ± 23.8	9.0 ± 2.6

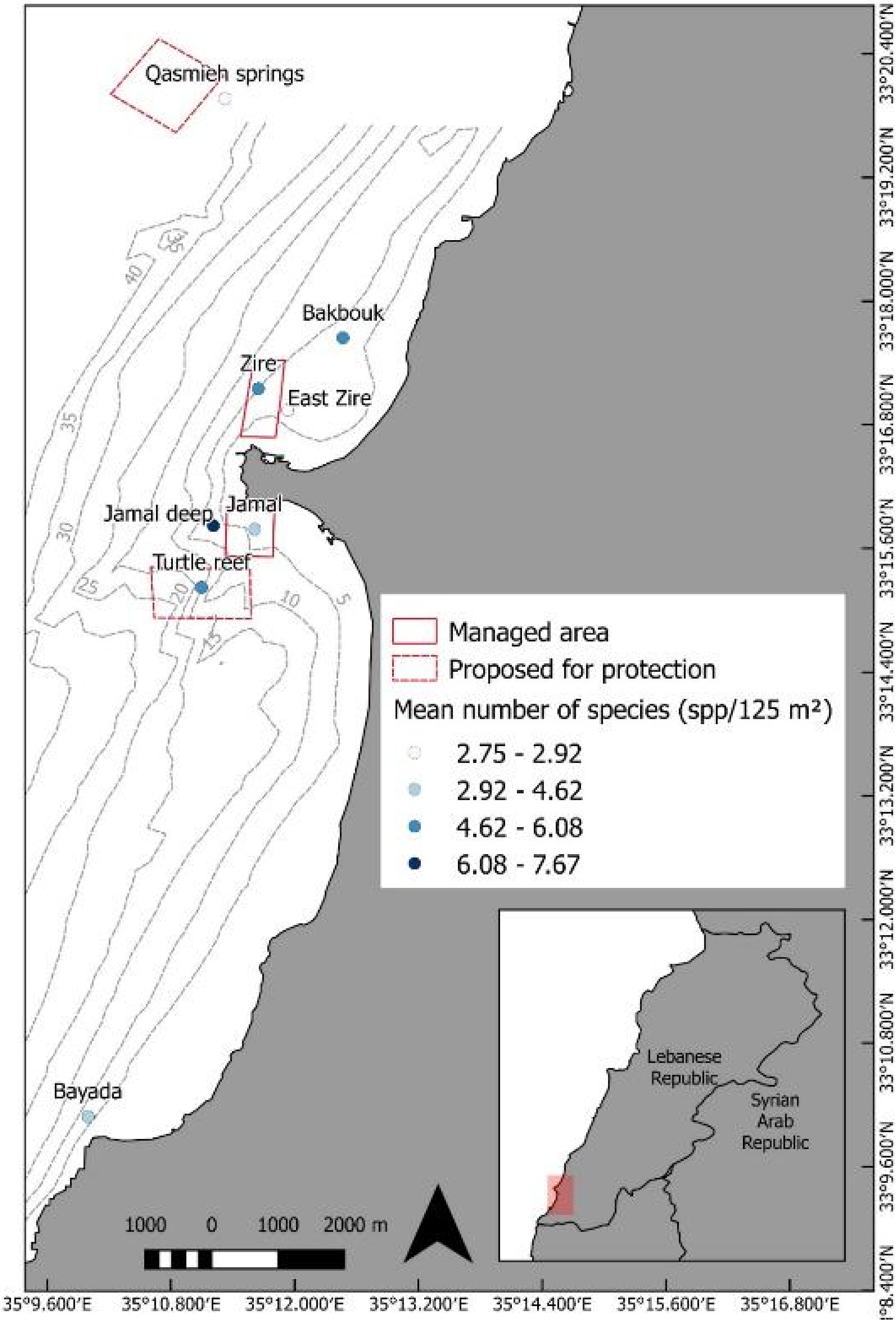


Figure 15. Mean species richness distribution per location

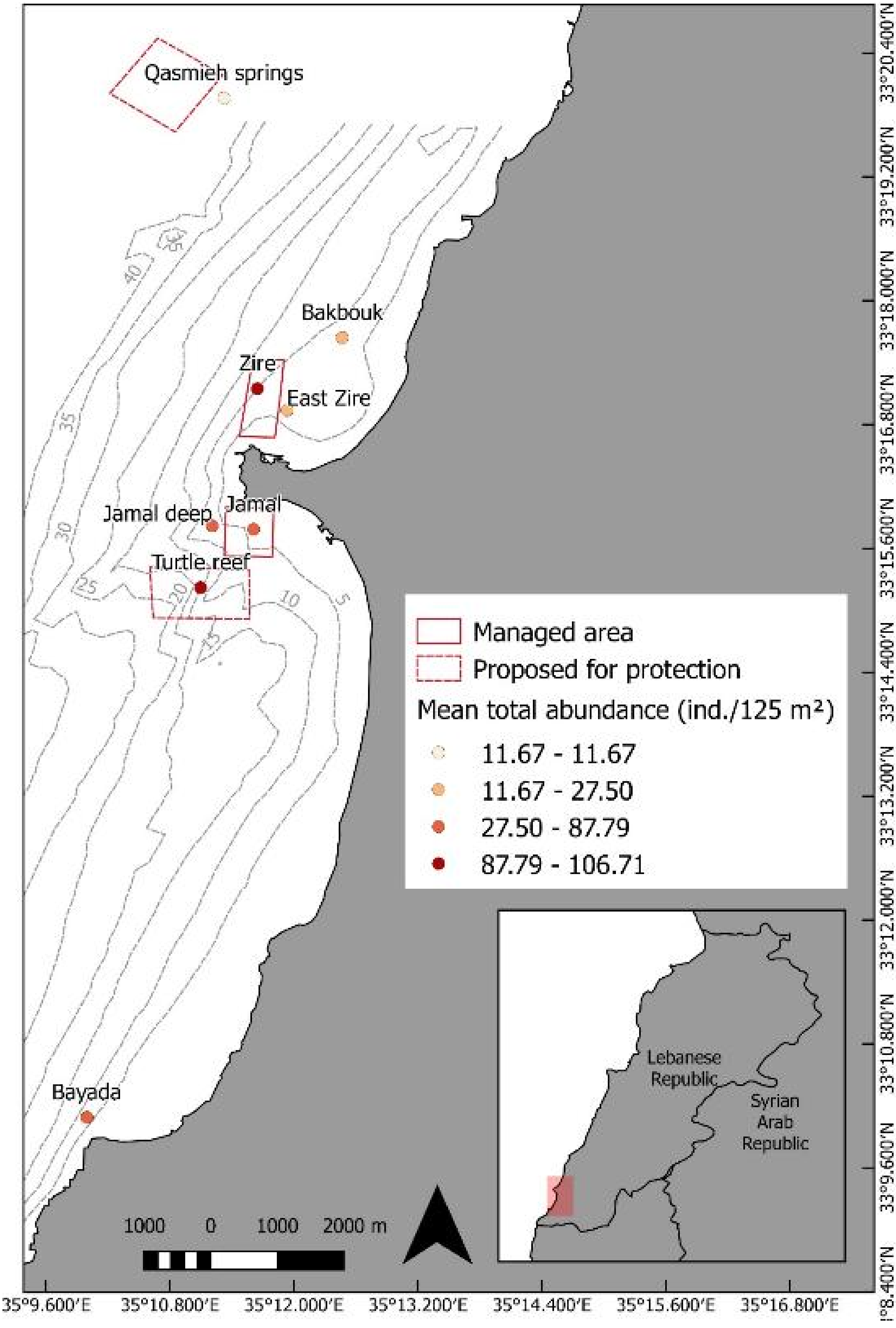


Figure 16. Mean abundance distribution per location

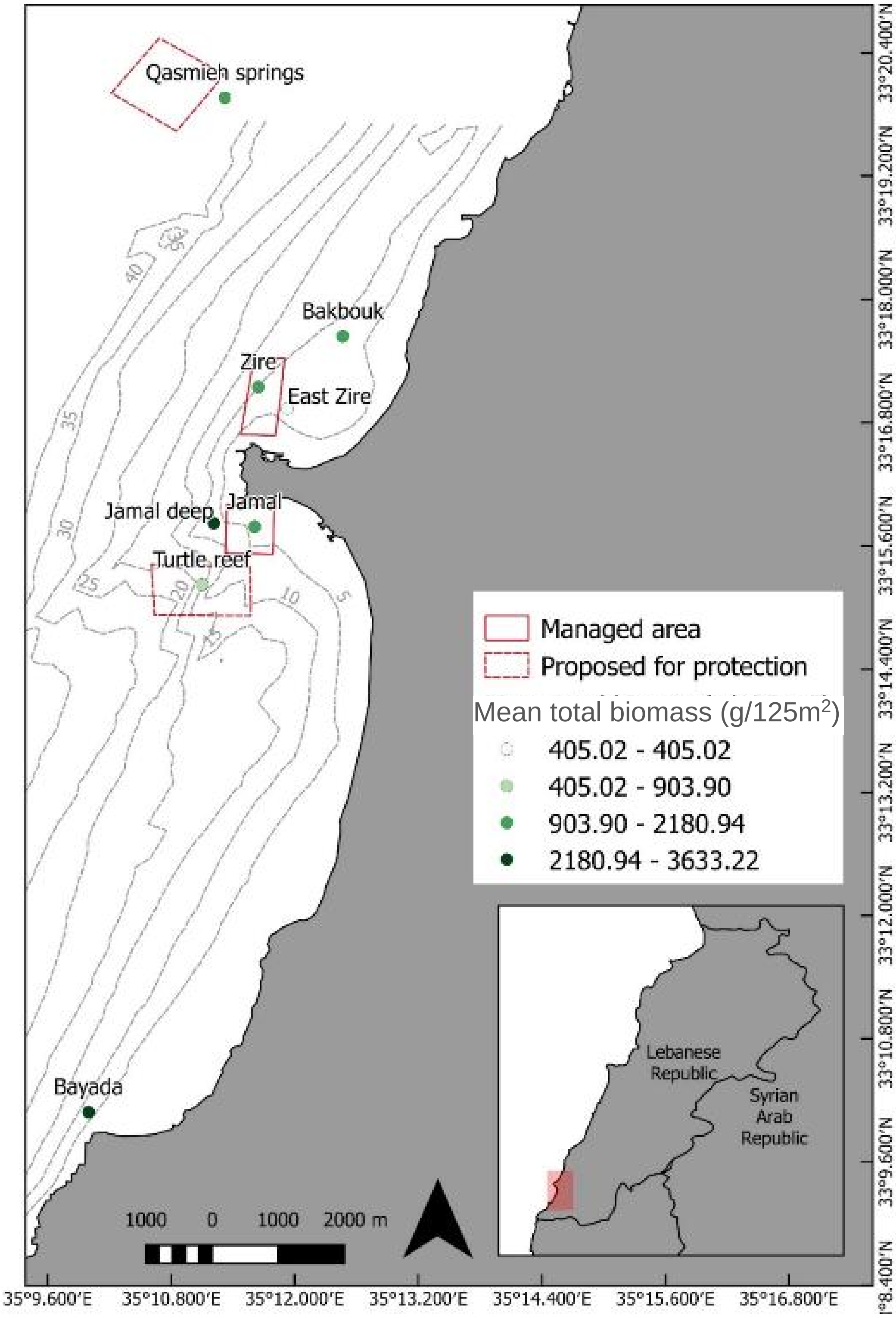


Figure 17. Mean biomass distribution per location

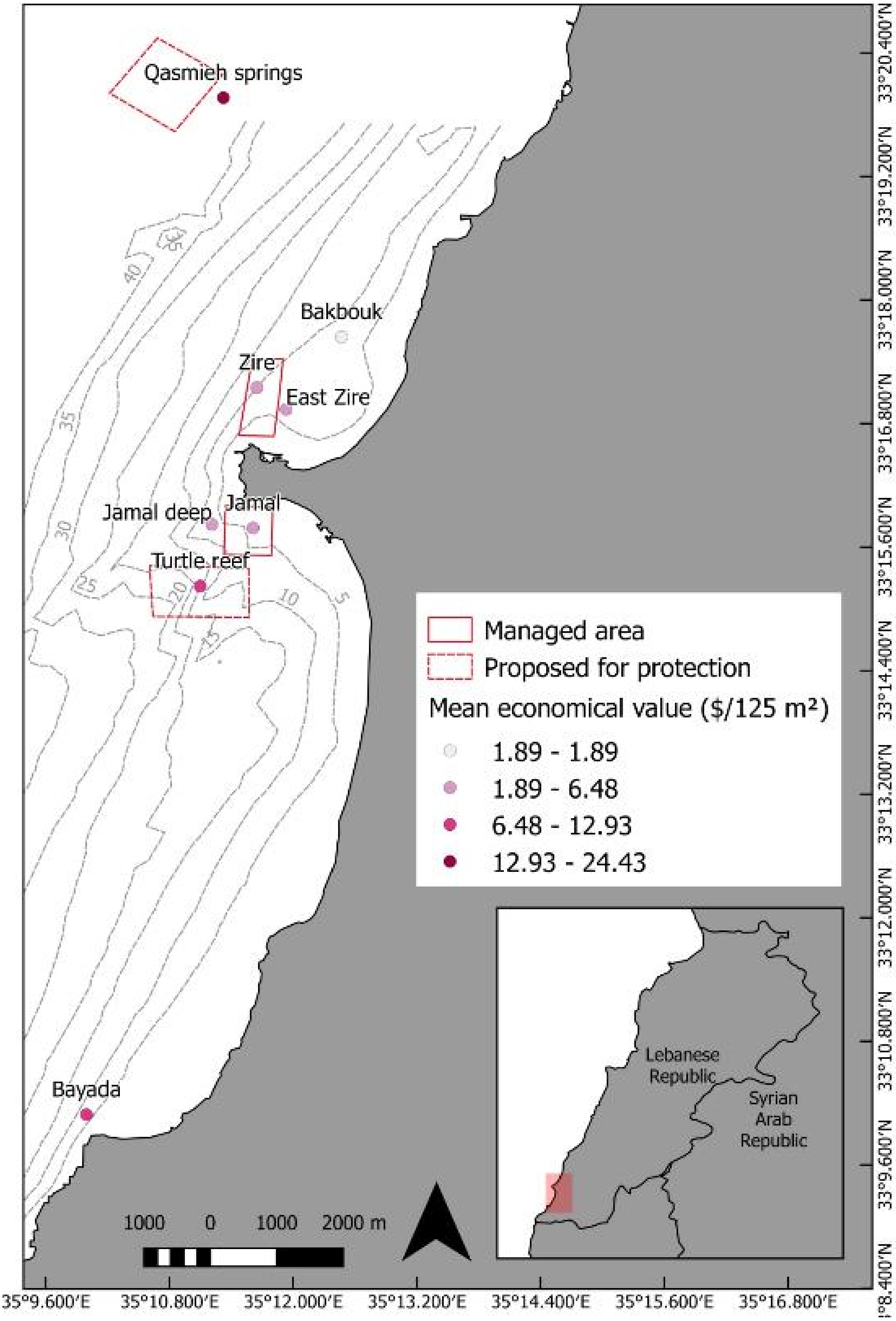


Figure 18. Mean economic value distribution per location

4.2.1.2. Abundance and biomass per species

Among the 41-fish species (16 families) censused, Sparidae and Labridae were the most represented in species richness index, while Pomacentridae (Chromis chromis), Siganidae (mainly Siganus rivulatus) and Pempheridae (Pempheris vanicolensis) were the most abundant. Only four species have high commercial value (Table 5). We noticed a high presence of invasive species (10 out of 41), which represented 35% of the observed individuals (Table 5).


(a)


(b)


(c)

Figure 19. Pempheris rhomboides and Diplodus cervinus (a), Chromis chromis (b) and Siganus rivulatus (c) (©E. Ben Lamine)

The most abundant species per locality (Table 7) were C. chromis in *Turtle reef* and *Bayada* and S. rivulatus in *Zire* and *Bayada*. From an economic point of view, the highest abundance of M. rubra was in *Jamal deep* and *East Zire*. The individuals of M. rubra were mainly juveniles, with small biomass, except in *Qasmieh* springs where the largest individuals were recorded (Table 8).

Table 7. Mean abundance per species (individuals/125 m^2 ± s.e.) in the eight sampled localities.

	Managed areas			Non-managed areas				
	Jamal	Zire	Jamal deep	Bayada	Bakbouk	East Zire	Qasmieh	Turtle reef
B. boops	0	0	0	0	0	26.4 ± 26.4	0	40.3 ± 27.7
C. chromis	14.3 ± 5.3	34.4 ± 16.0	80.7 ± 35.6	115.0 ± 41.7	10.3 ± 3.4	0	3.0 ± 2.0	133.3 ± 49.9
C. julis	2.8 ± 1.2	0.6 ± 0.2	6.8 ± 2.5	4.2 ± 1.0	3.0 ± 0.5	14.3 ± 8.2	2.5 ± 1.0	0.9 ± 0.3
D. annularis	0	0	0	0	0	0	0	0
D. centroura	0	0	0.1 ± 0.1	0	0	0	0	0
D. cervinus	0	0	0.1 ± 0.1	0	0	0	0	0
D. marmorata	0	0	0	0	0	0	0	0
D. pastinaca	0	0	0	0	0	0	0.1 ± 0.1	0
D. puntazzo	0	0	0	0	0	0	0	0
D. sargus	0.4 ± 0.1	1.3 ± 0.6	1.0 ± 0.3	0.3 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.3	0.8 ± 0.6
D. vulgaris	0	0	0.3 ± 0.2	0	0	0	0	0.1 ± 0.1
E. costae	0	0	0.2 ± 0.1	0	0.1 ± 0.1	0	0	0.3 ± 0.3
G. bucchichi	0	0	0	0.1 ± 0.1	0	0	0.1 ± 0.1	0.1 ± 0.1
L. scleratus	0.1 ± 0.1	0	0	0	0	0	0	0
Labrus spp.	0	0	0	0	0	0	0	0
M. helena	0	0.1 ± 0.1	0.1 ± 0.1	0	0	0	0.1 ± 0.1	0
M. rubra	0.3 ± 0.1	0.3 ± 0.1	0.9 ± 0.3	0	0.6 ± 0.2	0.8 ± 0.5	0.3 ± 0.3	0
O. melanura	2.3 ± 2.0	0.1 ± 0.1	0	0.4 ± 0.3	0	0	0	0
P. incisus	0	0	0	0	0	0	0	0
P. pelycus	0	0	0	0	0	0.1 ± 0.1	0	0
P. rhomboides	1.1 ± 1.1	3.2 ± 1.8	0	0.1 ± 0.1	0	0	0	0
P. miles	0	0	0	0	0	0	0.1 ± 0.1	0
S. cabrilla	0	0.2 ± 0.1	0.9 ± 0.3	0.7 ± 0.2	0.6 ± 0.2	0	0.2 ± 0.2	0.1 ± 0.1
S. cantharus	0	0	0	0	0	0	0	0
S. cretense	0.1 ± 0.1	0	0.3 ± 0.3	0.3 ± 0.2	0	0	4.5 ± 2.5	0.7 ± 0.3
S. diaspros	0.2 ± 0.1	0.3 ± 0.2	0.4 ± 0.3	0	0	0.1 ± 0.1	0	0
S. doderleini	0	0	0.3 ± 0.2	0	0	0	0	0
S. luridus	0.9 ± 0.4	0.2 ± 0.1	0.8 ± 0.4	0.7 ± 0.4	0.2 ± 0.1	0.1 ± 0.1	0	1.4 ± 0.7
S. maderensis	0	0	0	0	0	0	0	0
S. mediterraneus	0	0	0.1 ± 0.1	0	0	0	0	0
S. porcus	0	0.1 ± 0.1	0	0	0	0	0	0
S. rivulatus	43.6 ± 16.3	77.8 ± 20.5	50.2 ± 22.4	71.9 ± 23.6	8.4 ± 2.8	9.3 ± 8.0	0	65.1 ± 25.3
S. roissali	0	0	0	0	0	0	0	0.1 ± 0.1

S. rubrum	0.3 ± 0.2	1.8 ± 0.6	1.9 ± 0.8	1.8 ± 0.8	0.5 ± 0.3	0	0	1.5 ± 0.4
S. scriba	0.1 ± 0.1	0.2 ± 0.1	0.3 ± 0.2	0	0.1 ± 0.1	0	0	0.2 ± 0.1
S. smaris	0	0	0	0	0	0	0	1.5 ± 1.5
S. tinca	0	0.3 ± 0.1	0.6 ± 0.4	0	0.3 ± 0.1	0	0	0.1 ± 0.1
T. flavimaculosus	0	0	0	0.5 ± 0.3	0	0.7 ± 0.4	0.2 ± 0.1	0
T. pavo	15.5 ± 2.6	20.3 ± 4.3	6.4 ± 2.4	7.3 ± 1.5	6.9 ± 0.9	2.0 ± 0.7	3.6 ± 1.1	35.1 ± 13.7
U. pori	0	0	0	0	0	0	0	0
X. novacula	0	0	0	0	0	0.1 ± 0.1	0	0

Table 8. Mean biomass per species (grams/125 m^2 ± s.e.) in the eight sampled localities

	Managed areas			Non-managed areas				
	Jamal	Zire	Jamal deep	Bayada	Bakbouk	East Zire	Qasmieh	Turtle reef
B. boops	0	0	0	0	0	65.6 ± 65.6	0	372.5 ± 205.1
C. chromis	150.9 ± 59.2	337.6 ± 125.0	569.3 ± 243.0	882.0 ± 318.7	97.5 ± 33.0	0	17.5 ± 12.8	1149.9 ±
C. julis	19.2 ± 6.7	10.5 ± 4.9	47.3 ± 15.2	32.8 ± 6.9	28.8 ± 4.7	84.3 ± 44.6	8.7 ± 2.8	11.8 ± 5.1
D. annularis	0	0	0	1.8 ± 1.8	0	0	0	0
D. centroura	0	0	2439.6 ±	0	0	0	0	0
D. cervinus	35.0 ± 35.0	0	9.0 ± 9.0	0	0	0	0	0
D. marmorata	0	0	0	0	19.9 ± 19.9	0	0	0
D. pastinaca	0	0	0	122.4 ± 122.4	1219.8 ±	0	663.0 ± 663.0	0
D. puntazzo	0	0	0	2.1 ± 2.1	0	0	0	0
D. sargus	28.8 ± 11.3	89.4 ± 32.9	56.9 ± 20.2	9.0 ± 5.2	16.4 ± 9.0	8.3 ± 5.6	6.7 ± 6.7	40.2 ± 27.1
D. vulgaris	0	1.1 ± 1.1	6.6 ± 4.7	0	0	0	0	3.5 ± 3.5
E. costae	3.8 ± 3.8	0	42.3 ± 40.3	5.4 ± 26.6	6.4 ± 4.5	0	0	121.2 ± 121.2
G. bucchichi	0	0	0	0.2 ± 0.2	0	0	0.3 ± 0.3	0.1 ± 0.1
L. scleratus	62.8 ± 62.8	13.4 ± 13.4	0	0	0	0	0	0
Labrus spp.	0	2.1 ± 2.1	0	0	0	0	0	0
M. helena	0	24.3 ± 17.7	54.6 ± 54.6	27.3 ± 27.3	3.8 ± 3.8	0	191.0 ± 191.0	0
M. rubra	49.3 ± 26.3	21.9 ± 9.9	90.1 ± 43.8	0	50.1 ± 16.7	173.3 ± 122.0	1166.3 ± 1166.3	0
O. melanura	87.2 ± 81.5	15.5 ± 15.5	0	7.1 ± 5.3	0	0	0	0
P. incisus	0	3.7 ± 3.7	0	0	2.6 ± 2.6	0	0	0
P. pelycus	0	0	0	0	0	0.2 ± 0.2	0	0
P. rhomboides	20.7 ± 20.7	90.4 ± 59.2	0	9.4 ± 9.4	0	0	0	0
P. miles	0	0	0	0	0	0	12.1 ± 12.1	0
S. cabrilla	0.8 ± 0.8	2.6 ± 1.7	12.2 ± 4.1	17.1 ± 6.6	17.1 ± 7.5	0	5.2 ± 5.2	0.9 ± 0.9
S. cantharus	0	0	0	0	0.1 ± 0.1	0	0	0
S. cretense	4.4 ± 4.4	1.5 ± 1.5	11.9 ± 10.1	7.4 ± 5.0	0.5 ± 0.5	0	104.4 ± 53.3	13.0 ± 5.9
S. diaspros	21.0 ± 9.0	32.0 ± 15.6	32.4 ± 19.4	4.3 ± 4.3	0	3.9 ± 3.9	0	0
S. doderleini	0	1.0 ± 1.0	6.3 ± 4.6	2.5 ± 2.5	0	0	0	0
S. luridus	39.9 ± 19.3	13.9 ± 9.3	19.4 ± 9.3	25.1 ± 13.2	9.7 ± 6.0	4.1 ± 4.1	0	44.7 ± 19.6
S. maderensis	0	0	0	0	1.3 ± 1.3	0	0	0
S. mediterraneus	0	0	3.5 ± 3.5	0	0	0	0	0
S. porcus	0	3.4 ± 3.4	0	0	0	0	0	0
S. rivulatus	846.5 ± 505.0	934.0 ± 208.1	593.4 ± 246.4	2529.1 ± 2030.2	109.7 ± 40.9	112.9 ± 69.1	0	499.7 ± 149.2
S. roissali	0	1.1 ± 1.1	0	0	0	0	0	0.4 ± 0.4

S. rubrum	8.9 ± 5.7	76.2 ± 26.8	106.6 ± 51.5	84.2 ± 42.1	26.5 ± 14.7	0	0	52.8 ± 14.3
S. scriba	2.4 ± 2.2	5.8 ± 4.5	19.6 ± 16.7	0	3.3 ± 1.9	0	0	7.2 ± 5.0
S. smaris	0	0	0	0	0	0	0	77.0 ± 77.0
S. tinca	2.1 ± 2.1	13.2 ± 5.0	47.0 ± 32.4	0	9.4 ± 3.6	0	0	2.8 ± 2.8
T. flavimaculosus	0	0	0	4.9 ± 4.0	0	7.7 ± 4.6	1.6 ± 1.2	0
T. pavo	120.4 ± 20.4	109.7 ± 19.7	34.5 ± 9.5	39.6 ± 3.7	47.9 ± 7.2	9.6 ± 3.8	21.9 ± 5.5	105.6 ± 26.7
U. pori	0	1.1 ± 1.1	0	0	0	0	0	0
X. novacula	0	0	0	0	0	0.7 ± 0.7	0	0

4.2.1.3. Abundance and biomass of species with high economic value per location

In all localities, 12 economically valuable species were censused during our survey. Three of them were present only in control localities, namely D. annularis, D. puntazzo and S. maderensis. Four other species (D. cervinus, S. porcus, D. vulgaris and U. pori) were only encountered in managed localities (Tables 7 and 8). The abundance and biomass of O. melanura was higher in managed localities (Tables 7 and 8). Three other species were found in both managed and control localities with different patterns: (1) E. costae was censused in two control localities with higher abundance and biomass than one managed locality (Figure 22 and 23), (2) M. rubra had higher abundance and biomass in control sites (Figure 20 and 21) and (3) Diplodus sargus displayed higher abundance and biomass in managed than in control sites (Figure 24 and 25).

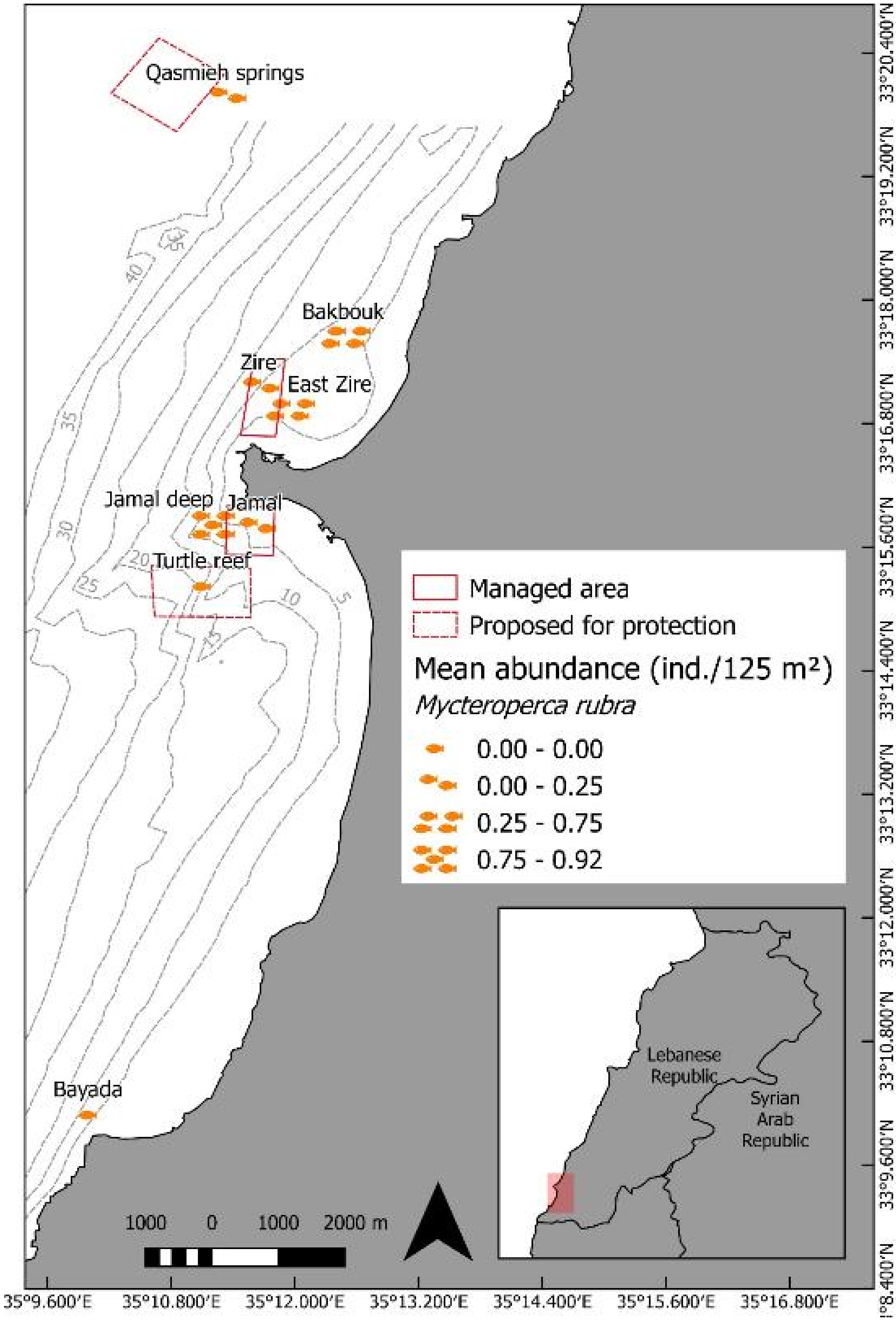


Figure 20. Abundance of M. rubra per location

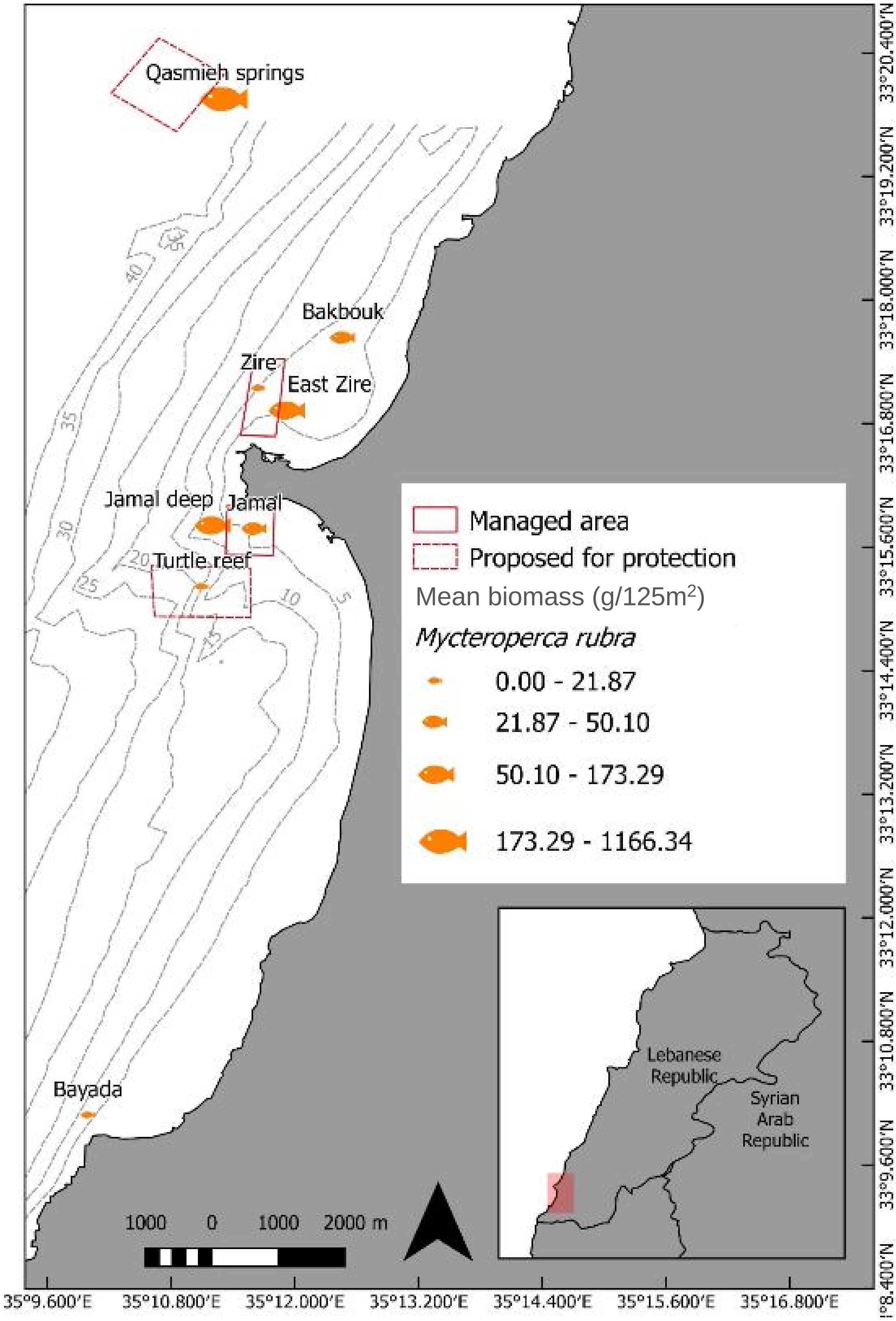


Figure 21. Biomass of M. rubra per location

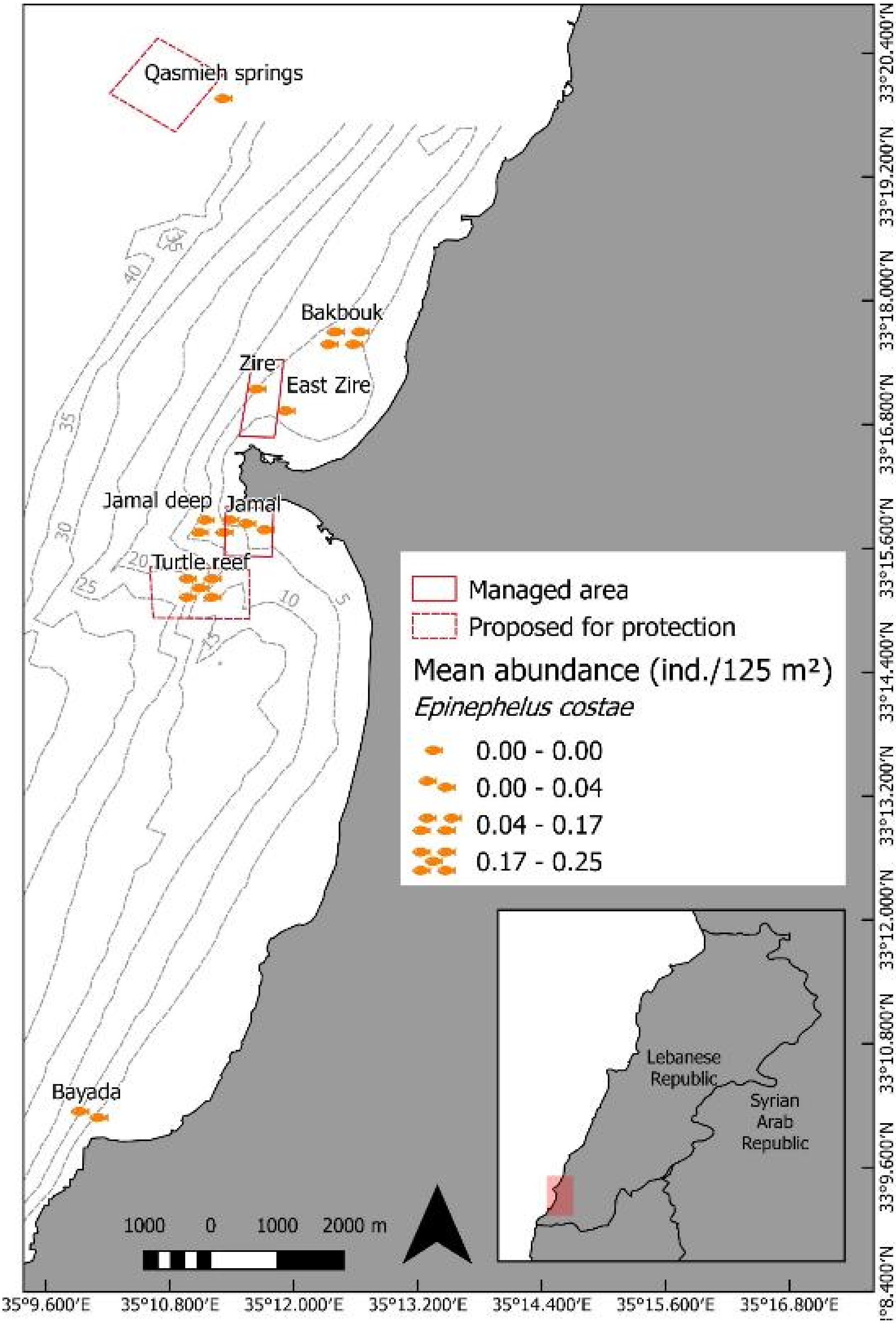


Figure 22. Abundance of E. costae per location

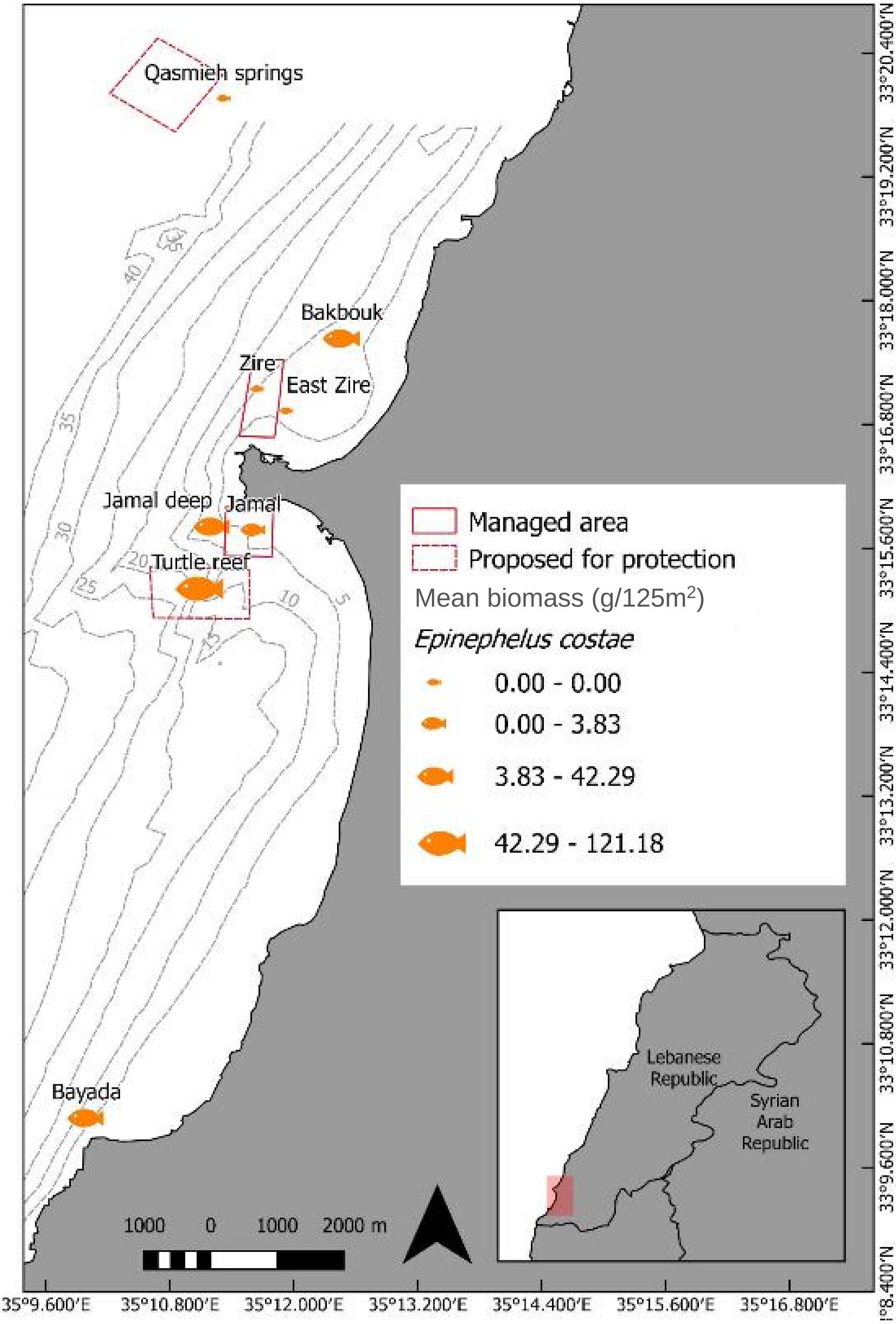


Figure 23. Biomass of E. costae per location

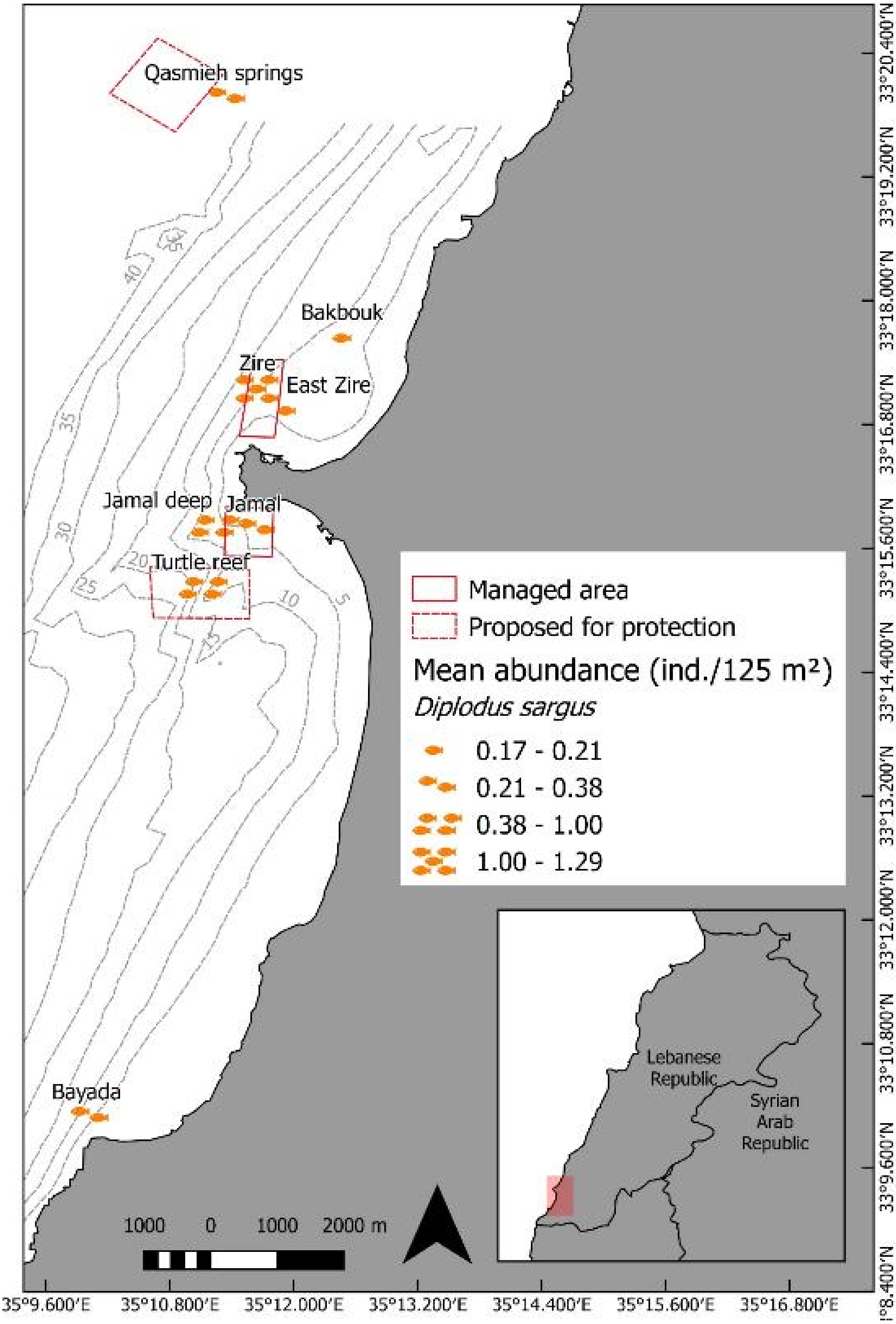


Figure 24. Abundance of D. sargus per location

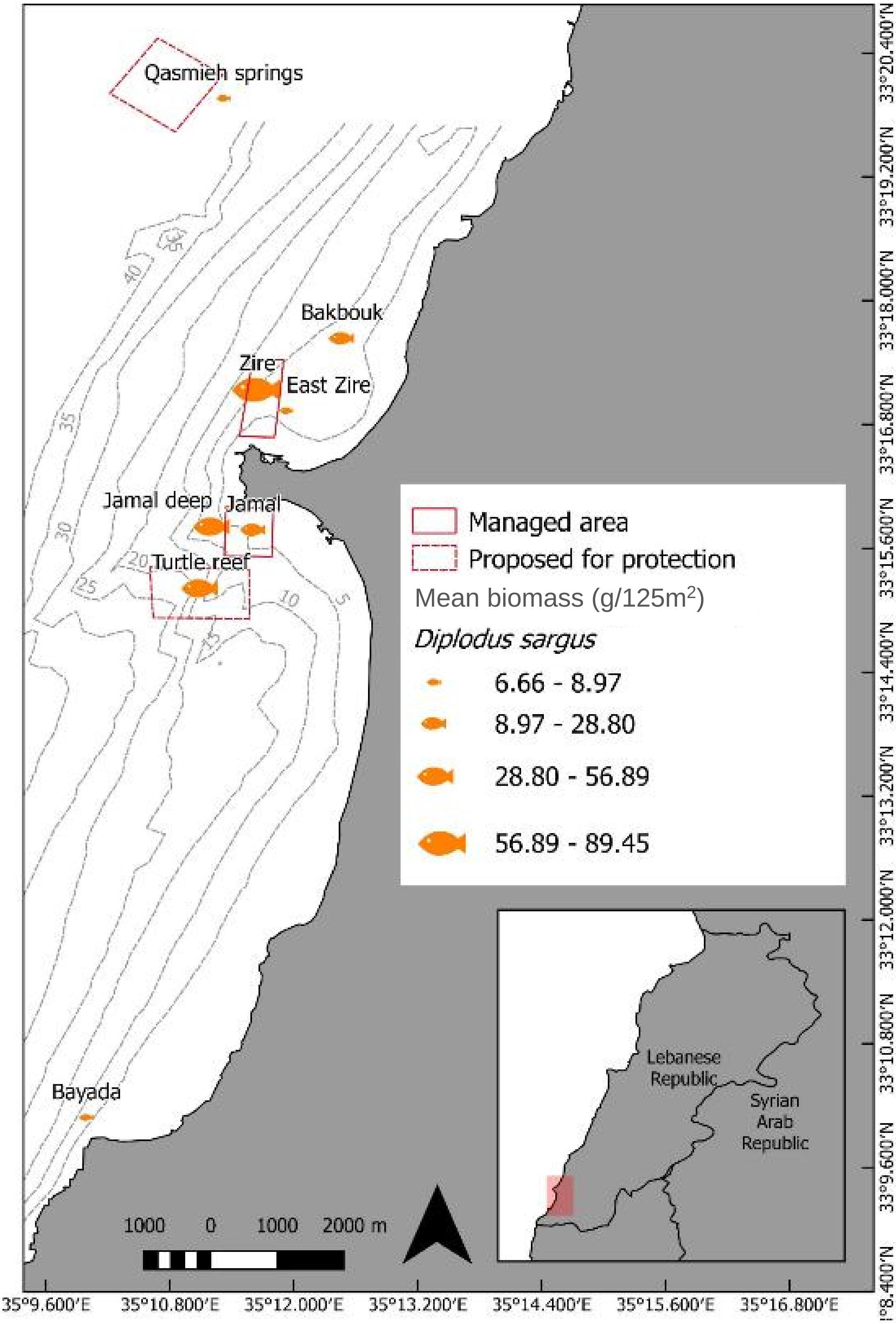


Figure 25. Biomass of D. sargus per location

4.2.2. Fish assemblage per management level

4.2.2.1. Number of species, total abundance, total biomass and economical value

The number of species, total biomass and economical value showed similar values in both managed and control areas (Figure 26 a, c, d). Total abundance showed higher values in the managed areas (Figure 26 b), however this difference was not statistically significant (Table 9). All fish assemblage parameters exhibited very high spatial heterogeneity among sites (Figure 26). ANOVA showed significant differences among sites for total abundance and total biomass (Table 9).

Table 9. Results from the analysis of variance (ANOVA) with three factors (M: Management, L: locality, S: site), for the number of species, total abundance, total biomass and economical value; df: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P < 0.05; ** = P < 0.01; *** = P < 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P < 0.01; ** = P < 0.001.

Sources of variation		Number of species			Abundance			Biomass			F versus
	df	M.S.	F	P	M.S.	F	P	M.S.	F	P	
M	1	0.094	0.007	0.939	24035.010	0.655	0.503	5.674	0.748	0.478	L(M)
L(M)	2	12.677	2.503	0.107	36693.802	1.762	0.197	7.584	1.805	0.190	S(L(M))
S(L(M))	20	5.065	1.644	0.065	20822.190	4.114	0.000**	4.203	3.342	0.000***	Residual
Residual	72	3.080			5061.406			1.258			
Transformation		-			-ϖ			ln(x+1)			

Sources of variation	Economical value				F versus
	df	M.S.	F	P	
M	1	33.387	0.046	0.851	L(M)
L(M)	2	732.895	1.134	0.342	S(L(M))
S(L(M))	20	646.207	0.986	0.489	Residual
Residual	72	655.563			

Transformation -ϖ

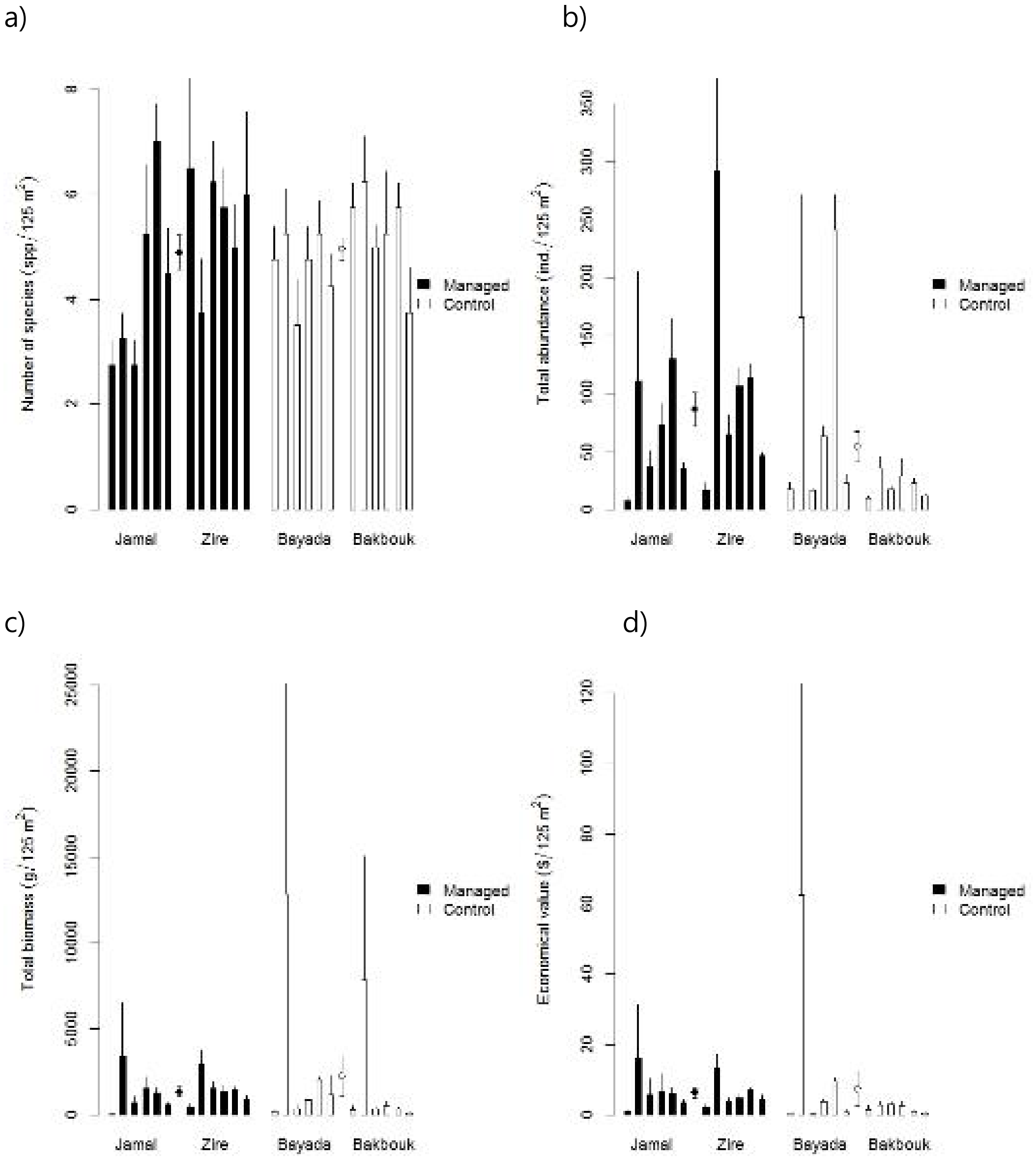


Figure 26. a) Number of species (species/125 m^2), b) total abundance (individuals/125 m^2), c) total biomass (g/125 m^2) and d) economical value ($/125 m^2) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

4.2.2.2. Abundance of the most representative species

To estimate fish assemblage composition, we considered the most representative species, i.e. those with a frequency of occurrence equal to or higher than 10%. Siganus rivulatus, Mycteroperca rubra and Diplodus sargus were present in high

relative abundance and are, at the same time, economically valuable species (Tables 5 and 7). Diplodus sargus, D. cervinus, D. vulgaris, O. melanura, S. porcus, U. pori, P. rhomboides, S. rivulatus, S. diaspros and T. pavo were more abundant in managed sites, while E. costae, D. annularis, D. puntazzo, S. cretense, S. maderensis, C. chromis, C. julis, M. rubra and S. cabrilla were mostly abundant in control sites (Figure 27). On the other hand, S. luridus, S. rubrum, S. tinca showed similar abundances in managed and control localities. ANOVA showed these significant trends only for S. cabrilla and T. pavo (Table 10). Additionally, abundances of C. chromis, S. cabrilla, S. luridus, S. rivulatus and T. pavo showed significant spatial variability among sites, while M. rubra and S. tinca varied among localities (Table 10).

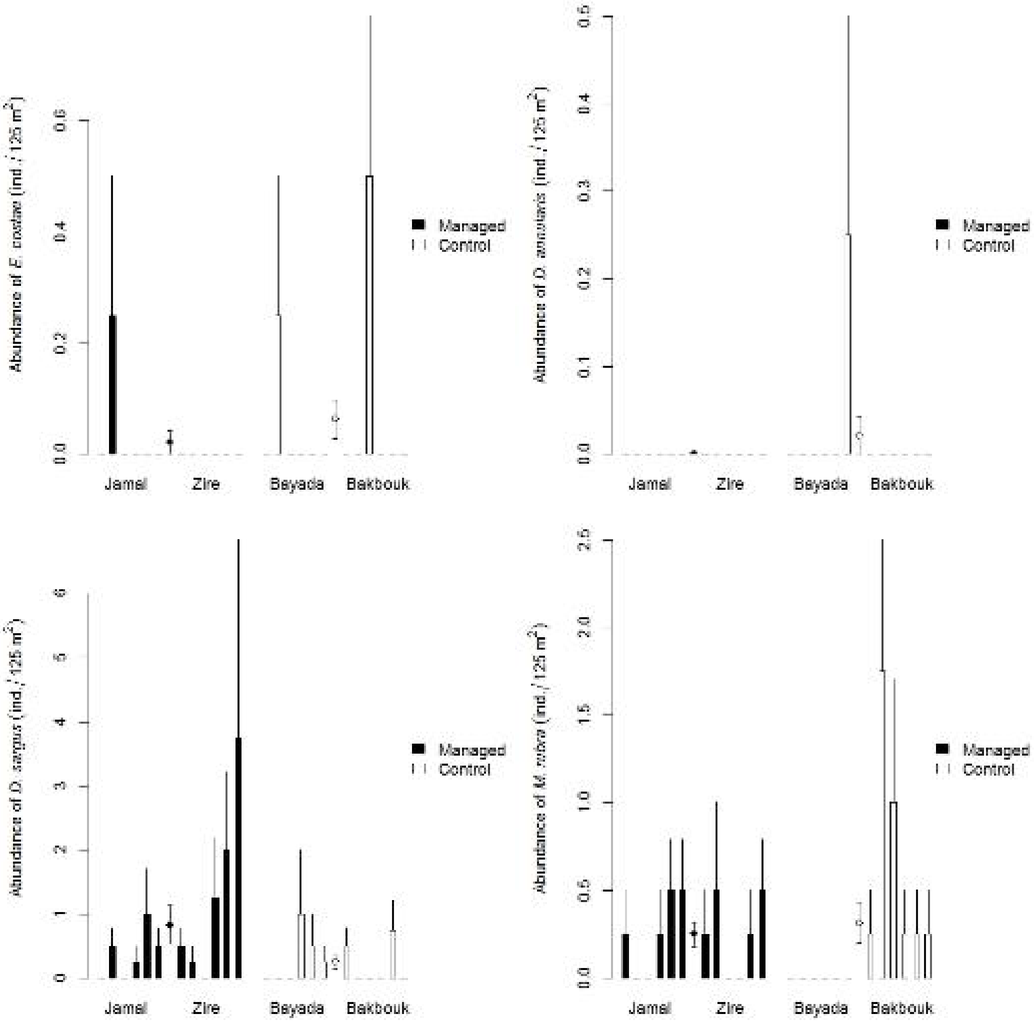


Figure 27. Mean abundance (individuals/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

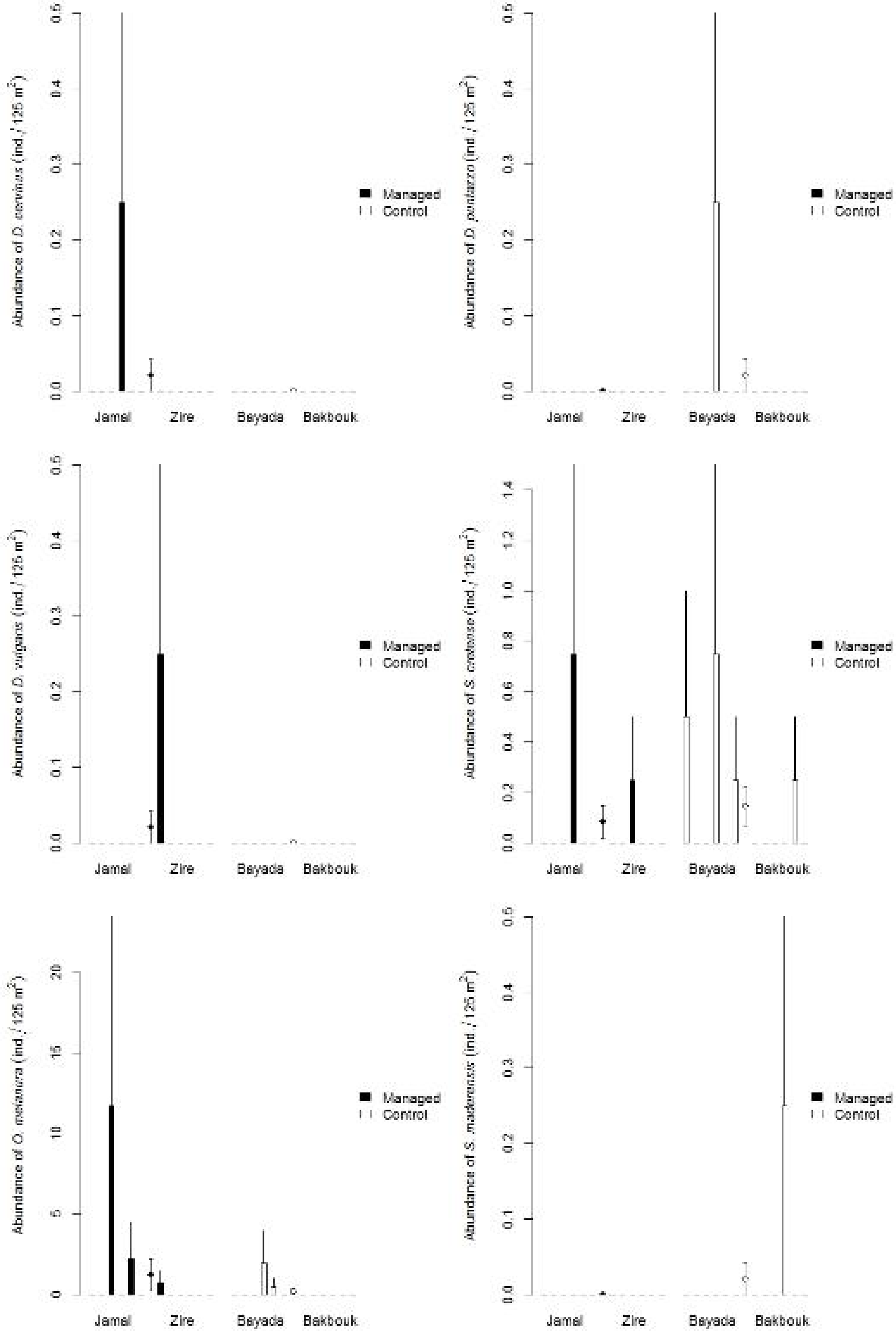


Figure 27. (Cont.) Mean abundance (individuals/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

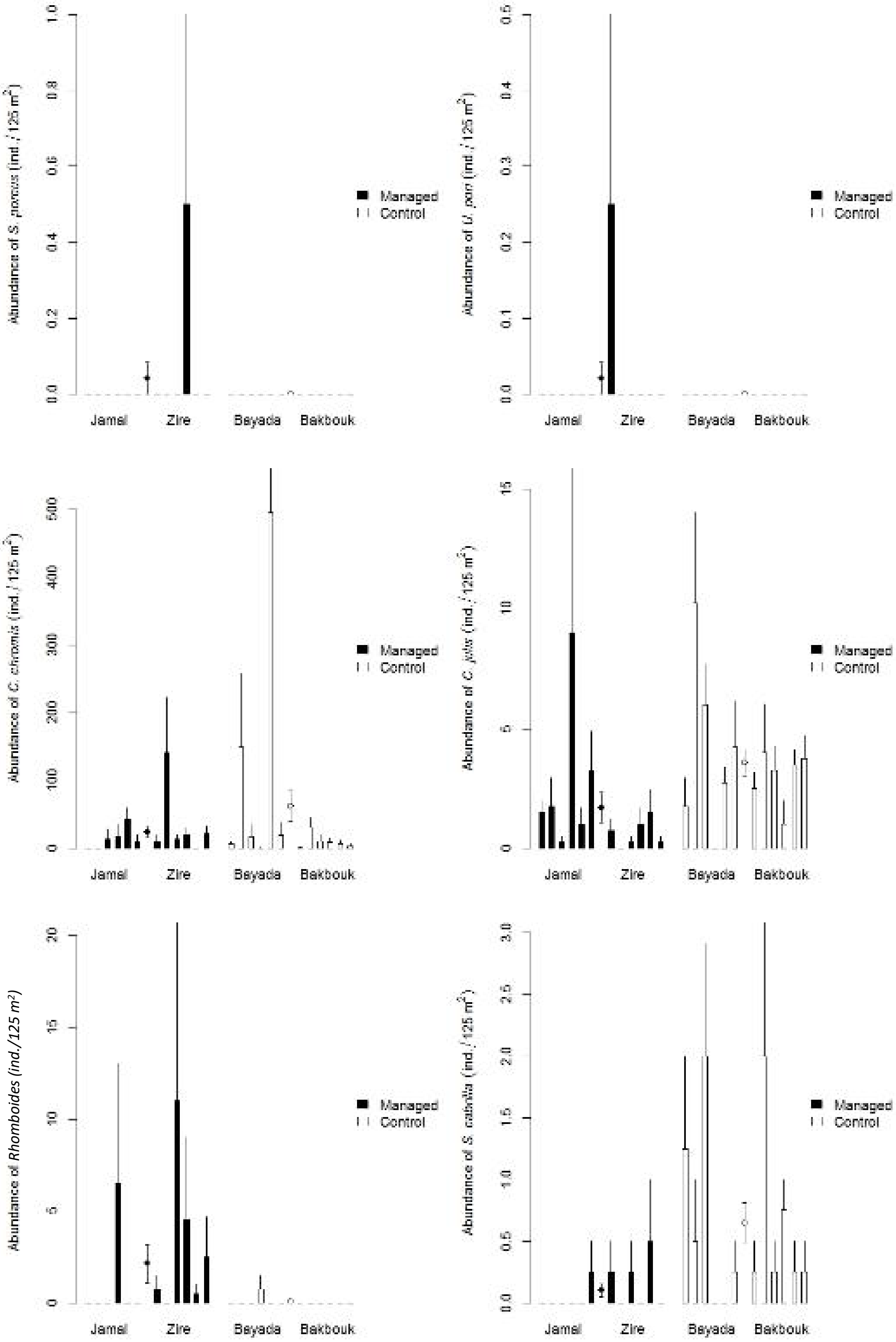


Figure 27. (Cont.) Mean abundance (individuals/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

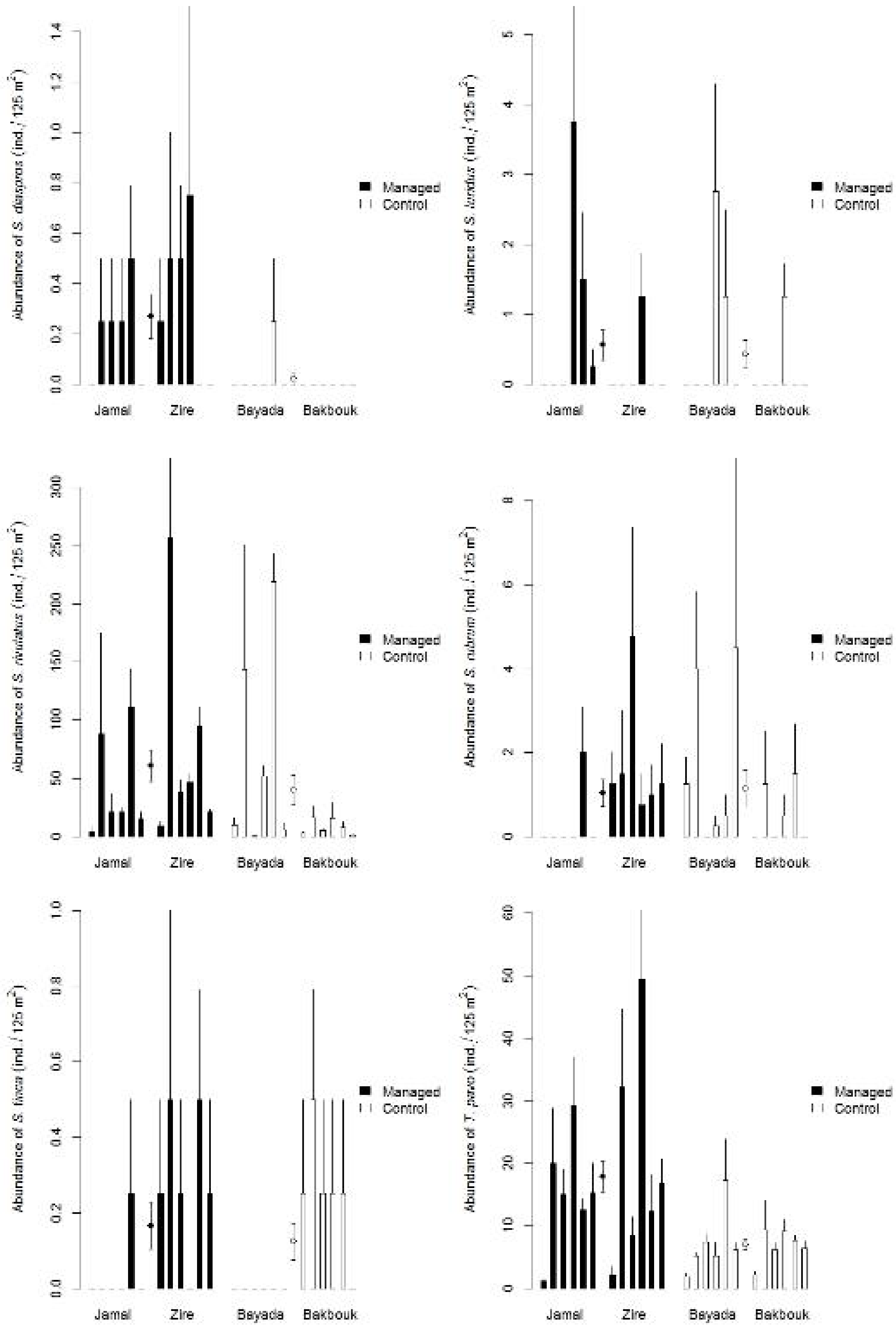


Figure 27. (Cont.) Mean abundance (individuals/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

Table 10. Results of the analysis of variance (ANOVA) with three factors (M: Management, L: locality, S: site), for the abundance of the most representative species (≥10%) and economically valuable, d.f.: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P-value < 0.05; ** = P-value< 0.01; *** = P-value < 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P-value < 0.01; ** = P-value < 0.001.

Sources of variation		Chromis chromis			Coris julis			Diplodus sargus			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	3.576	0.699	0.491	84.375	2.322	0.267	8.167	1.607	0.333	L(P)
L(M)	2	5.112	0.620	0.548	36.333	1.459	0.256	5.083	2.118	0.146	S(L(P))
S(L(M))	20	8.243	2.906	0.000***	24.896	1.773	0.041*	2.400	0.996	0.478	Residual
Residual	72	2.836			14.042			2.410			
Transformation		ln(x+1)			-ϖ			-ϖ			

Sources of variation		Mycteroperca rubra			Pempheris rhomboides			Serranus cabrilla			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	0.001	0.001	0.976	104.167	3.831	0.189	1.821	50.957	0.019*	L(P)
L(M)	2	0.722	5.637	0.011*	27.187	1.112	0.348	0.036	0.145	0.866	S(L(P))
S(L(M))	20	0.128	1.171	0.304	24.446	0.903	0.585	0.246	1.784	0.039*	Residual
Residual	72	0.109			27.076			0.138			
Transformation		ln(x+1)			-ϖ			ln(x+1)			

Sources of variation		Stephanolepis diaspros			Siganus luridus			Siganus rivulatus			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	1.500	14.400	0.063	0.375	0.088	0.795	24.458	1.455	0.351	L(M)
L(M)	2	0.104	0.758	0.482	4.271	1.047	0.369	16.811	2.394	0.117	S(L(M))
S(L(M))	20	0.137	0.639	0.870	4.079	2.952	0.000**	7.022	4.696	0.000***	Residual
Residual	72	0.215			1.382			1.495			
Transformation		-ϖ			-ϖ			ln(x+1)			

Sources of variation		Sargocentron rubrum			Symphodus tinca			Thalassoma pavo			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	0.260	0.013	0.921	0.013	0.037	0.865	8.386	136.998	0.007**	L(M)
L(M)	2	20.802	2.849	0.082	0.336	10.939	0.001**	0.061	0.029	0.972	S(L(M))
S(L(M))	20	7.302	1.090	0.378	0.031	0.466	0.971	2.134	6.844	0.000***	Residual

Residual	72	6.698	0.066	0.312
Transformation		-	-	ln(x+1)

4.2.2.3. Biomass of the most representative species

Siganus rivulatus, Mycteroperca rubra and Diplodus sargus were present in high relative biomass and are economically valuable species for fishing (Tables 5 and 8). Diplodus sargus, D. cervinus, D. vulgaris, O. melanura, S. porcus, U. pori, P. rhomboides, S. diaspros and T. pavo had higher biomasses in managed sites, while E. costae, D. annularis, D. puntazzo, S. maderensis, C. chromis, C. julis, and S. cabrilla biomasses were higher in control sites (Figure 28). On the other hand, M. rubra, S. cretense, S. rivulatus, S. luridus S. rubrum and S. tinca showed similar biomasses in managed and control localities. However, ANOVA only showed these significant trends for S. cabrilla, S. diaspros and T. pavo (Table 11). Additionally, C. chromis, S. luridus, S. rivulatus and T. pavo showed significant spatial variability among sites, while M. rubra, S. rubrum and S. tinca among localities (Table 11).

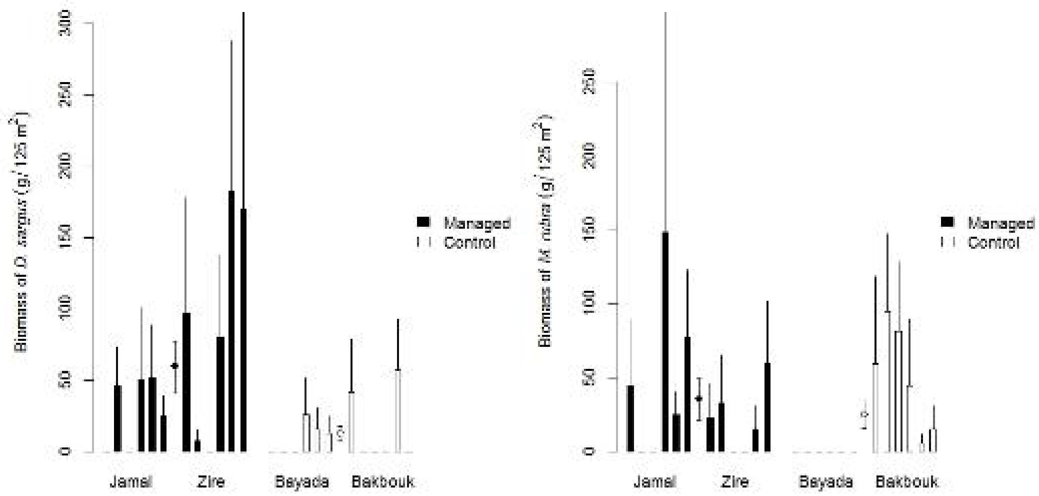


Figure 28. Mean biomass (g/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

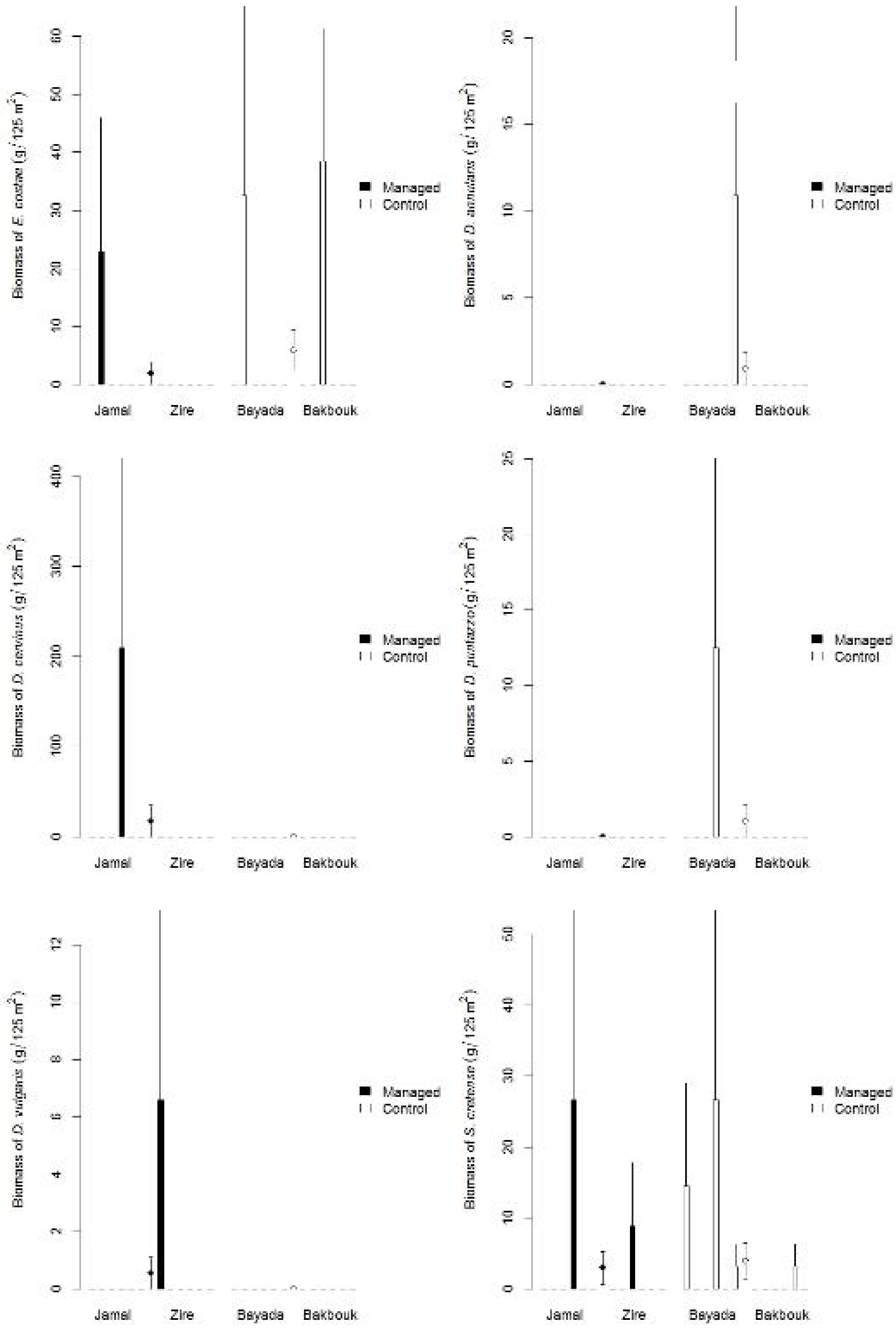


Figure 28 (Cont). Mean biomass (g/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

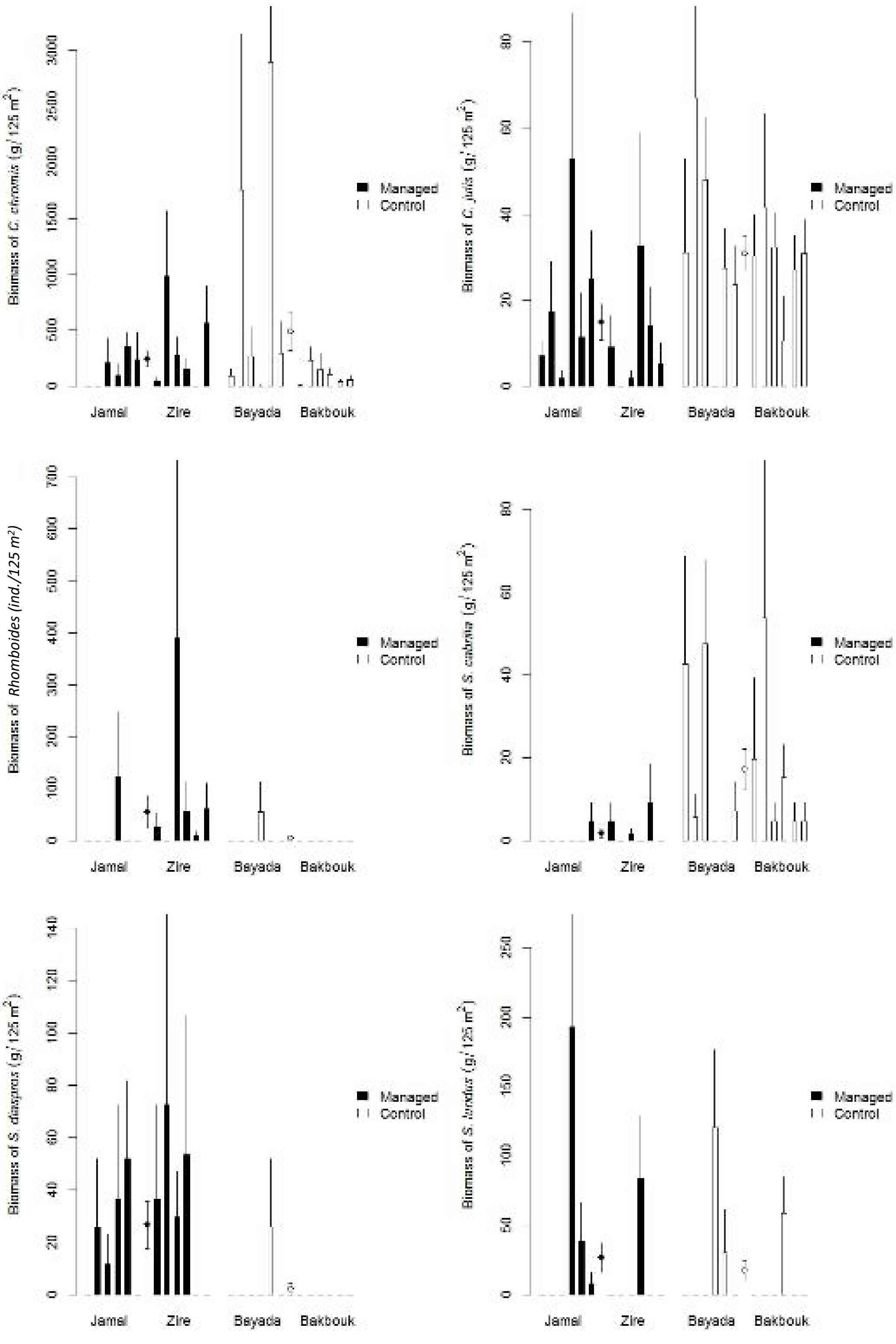


Figure 28 (Cont.). Mean biomass (g/125 m^2 of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

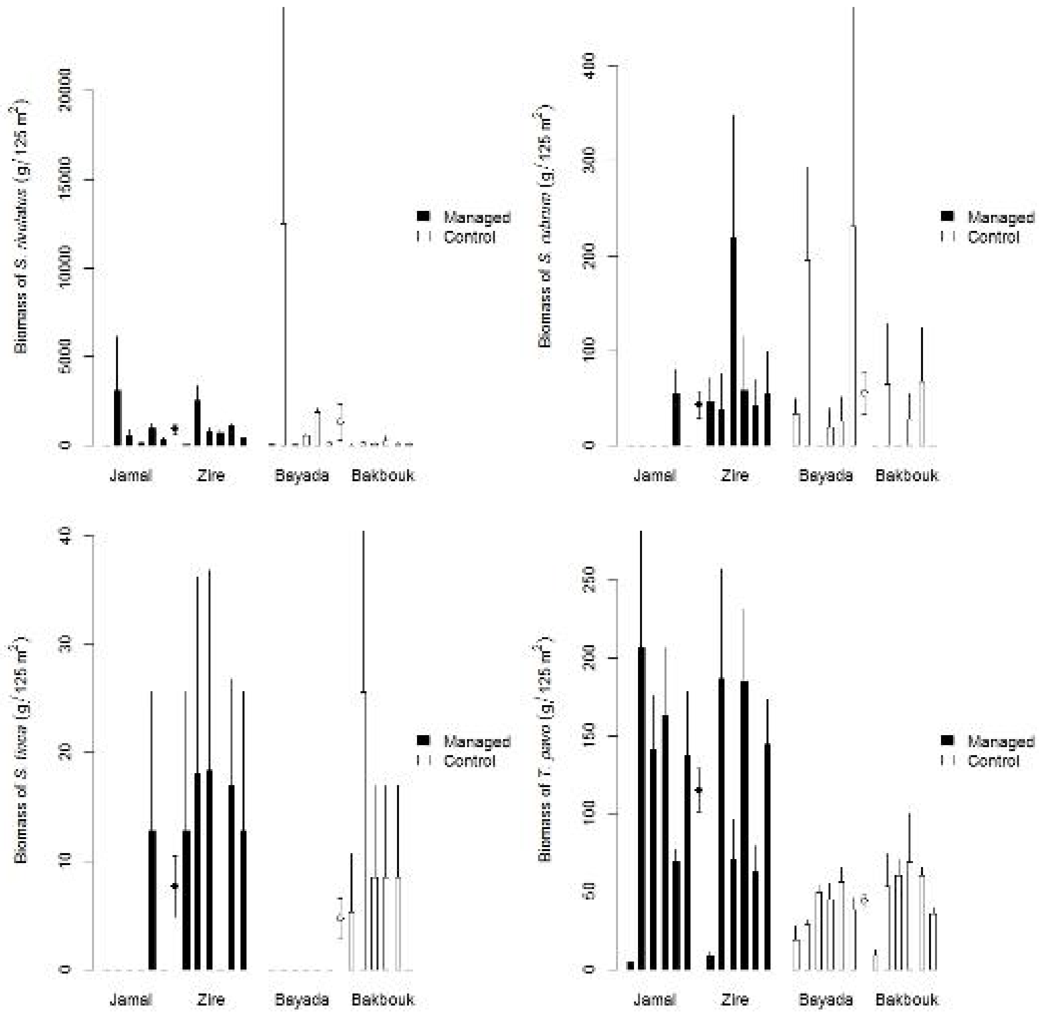


Figure 28 (Cont.). Mean biomass (g/125 m^2) of the most representative species (≥10%) per site in managed and control areas. Points indicate the total mean of managed and control areas. Error bars represent standard error.

Table 11. Results from the analysis of variance (ANOVA) with three factors (M: Management, L: locality, S: site), for the biomass of the most representative species (≥10%) and economically valuable species, df: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P < 0.05; ** = P < 0.01; *** = P < 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P < 0.01; ** = P < 0.001.

Sources of variation		Chromis chromis			Coris julis			Diplodus sargus			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	6.314	0.500	0.553	100.663	17.471	0.053	26.309	7.402	0.113	L(M)
L(M)	2	12.638	0.781	0.472	5.762	0.531	0.596	3.555	0.785	0.470	S(L(M))
S(L(M))	20	16.192	2.285	0.006**	10.857	1.600	0.076	4.529	1.191	0.287	Residual
Residual	72	7.086			6.786			3.802			
Transformation		ln(x+1)			sqrt(x+1)			ln(x+1)			

Sources of variation		Mycteroperca rubra			Pempheris rhomboides			Serranus cabrilla			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	1.207	0.065	0.822	62016.667	2.090	0.285	25.284	38.600	0.025*	L(M)
L(M)	2	18.478	6.512	0.007**	29670.058	1.181	0.327	0.655	0.252	0.779	S(L(M))
S(L(M))	20	2.837	0.765	0.744	25113.340	1.055	0.414	2.594	1.429	0.138	Residual
Residual	72	3.707			23796.313			1.816			
Transformation		ln(x+1)			-ϖ			-ϖ			

Sources of variation		Stephanolepis diaspros			Siganus luridus			Siganus rivulatus			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
M	1	18.662	76.171	0.013*	2158.407	0.392	0.595	44.292	1.594	0.334	L(M)
L(M)	2	0.245	0.146	0.865	5503.401	0.556	0.582	27.789	1.983	0.164	S(L(M))
S(L(M))	20	1.677	0.732	0.781	9890.059	4.181	0.000***	14.016	3.547	0.000***	Residual
Residual	72	2.292			2365.235			3.952			
Transformation		ln(x+1)			-ϖ			ln(x+1)			

Sources of variation	d.f.	Sargocentron rubrum M.S.	F	P-value	Symphodus tinca M.S.	F	P-value	Thalassoma pavo M.S.	F	P-value	F versus
M	1	0.121	0.005	0.948	1.709	0.085	0.798	265.716	110.008	0.009**	L(M)
L(M)	2	22.792	4.291	0.028*	20.146	9.471	0.001***	2.415	0.064	0.938	S(L(M))
S(L(M))	20	5.312	1.269	0.228	2.127	0.507	0.955	37.740	5.673	0.000***	Residual
Residual	72	4.185			4.192			6.652			
Transformation		ln(x+1)			sqrt(x+1)			sqrt(x+1)			

4.2.2.4. Multivariate structure of fish assemblage

Overall, MDS realized on the resemblance matrix of abundance (Figure 29) and biomass (Figure 30) showed a slight differentiation between managed and control locations in species abundance and biomass. Statistical tests showed only significant differences among sites within locations but no significant difference in abundance, neither in biomass, between managed and control locations (Table 12).

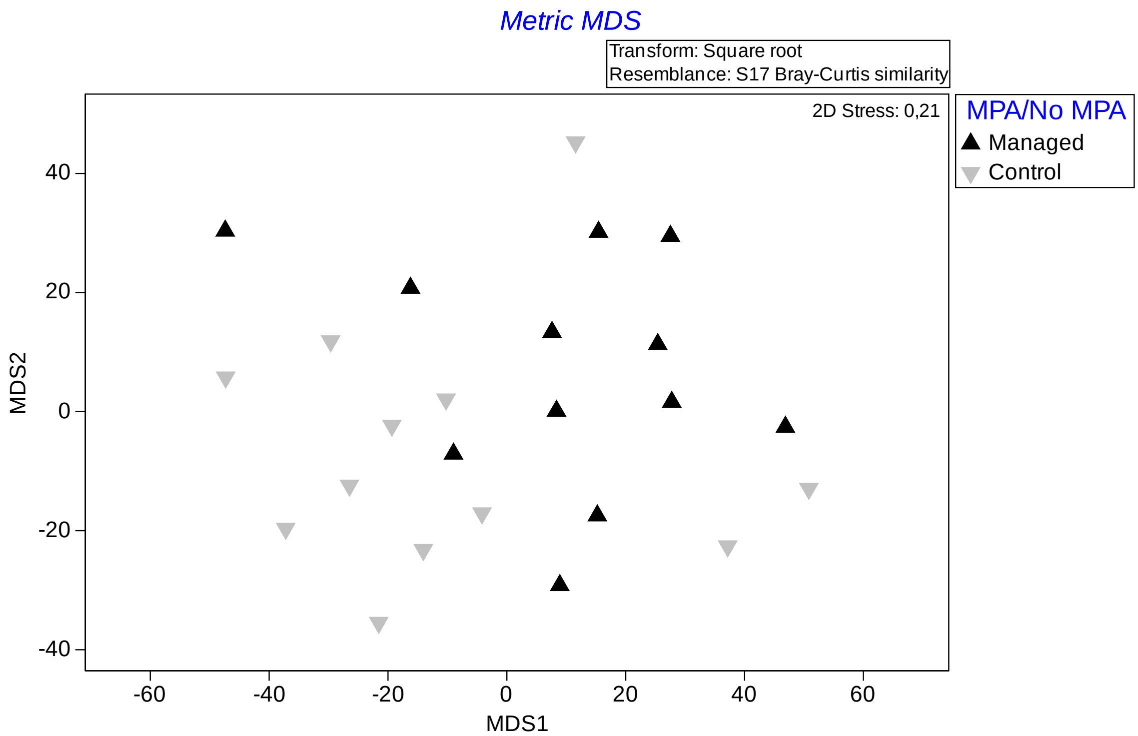


Figure 29. Metric Multi-Dimensional Scaling (MDS) realized on the resemblance matrix of abundance.

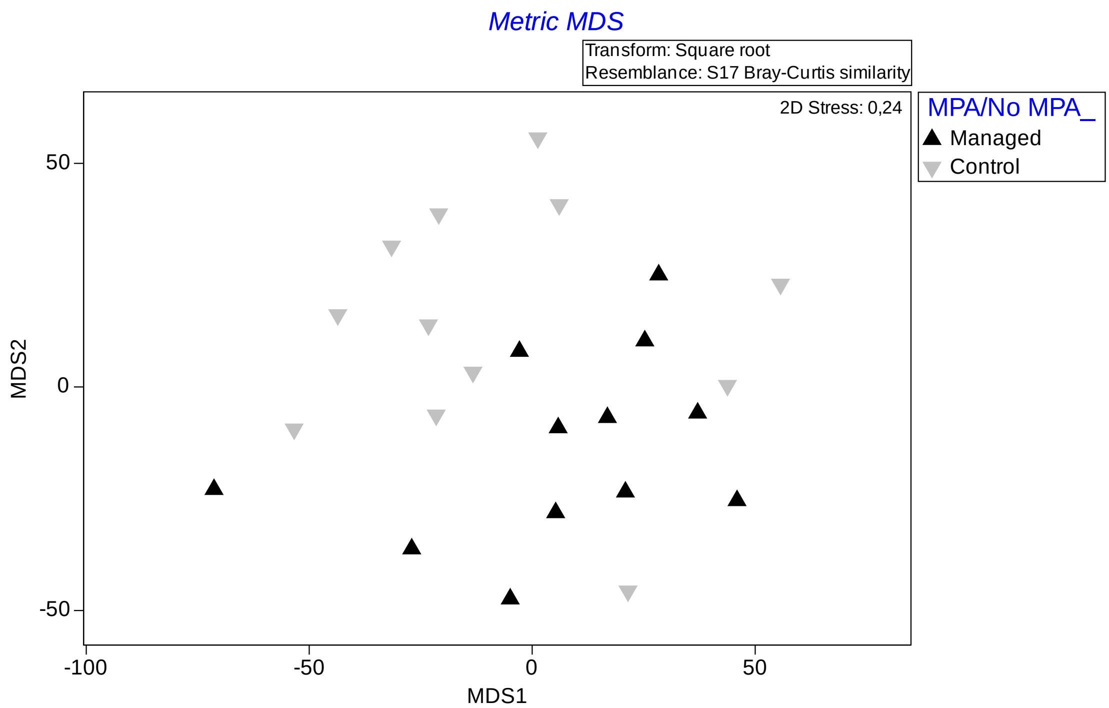


Figure 30. Metric Multi-Dimensional Scaling (MDS) realized on the resemblance matrix of biomass.

Table 12. PERMANOVA results applied on resemblance matrix using Bray-Curtis dissimilarities of three factors (M: Management, L: locality, S: site), df: degrees of freedom; F: F ratio; P-value: level of significance (* = P < 0.05; ** = P < 0.01; *** = P < 0.001).

Main test		Abundance		Biomass	
Source	df	Pseudo-F	P-value	Pseudo-F	P-value
M	1	1.7035	0.3283	1.7489	0.3308
L(M)	2	1.8346	0.0771	1.7972	0.0733
S(L(M))	20	2.855	0.000***	2.3187	0.000***
Residuals	72				
Total	95				

4.2.3. Fish assemblage in 2013 vs 2017

4.2.3.1. Number of species, total abundance, total biomass and economical value

The number of species and total abundance were higher in 2013 in both *Bayada* and *Qasmieh* springs, while in *East Zire* they were higher in 2017 (Figure 31a-b). These differences were however significant only in *Qasmieh* Springs as shown by the post-hoc analysis of the significant interaction among factors "Year" and "Locality" (Table 13). On the other hand, total biomass and economic value of fish assemblages were higher in 2017 in all locations (Figure 31c-d). This is due to the larger size of the recorded individuals. The ANOVA allowed to detect significant differences among localities in total abundance and total biomass (Table 13), showing significant higher abundance in *Bayada* and significant lower biomass in *East Zire*. On the contrary, no significant differences were found when economic values were considered (Table 13).

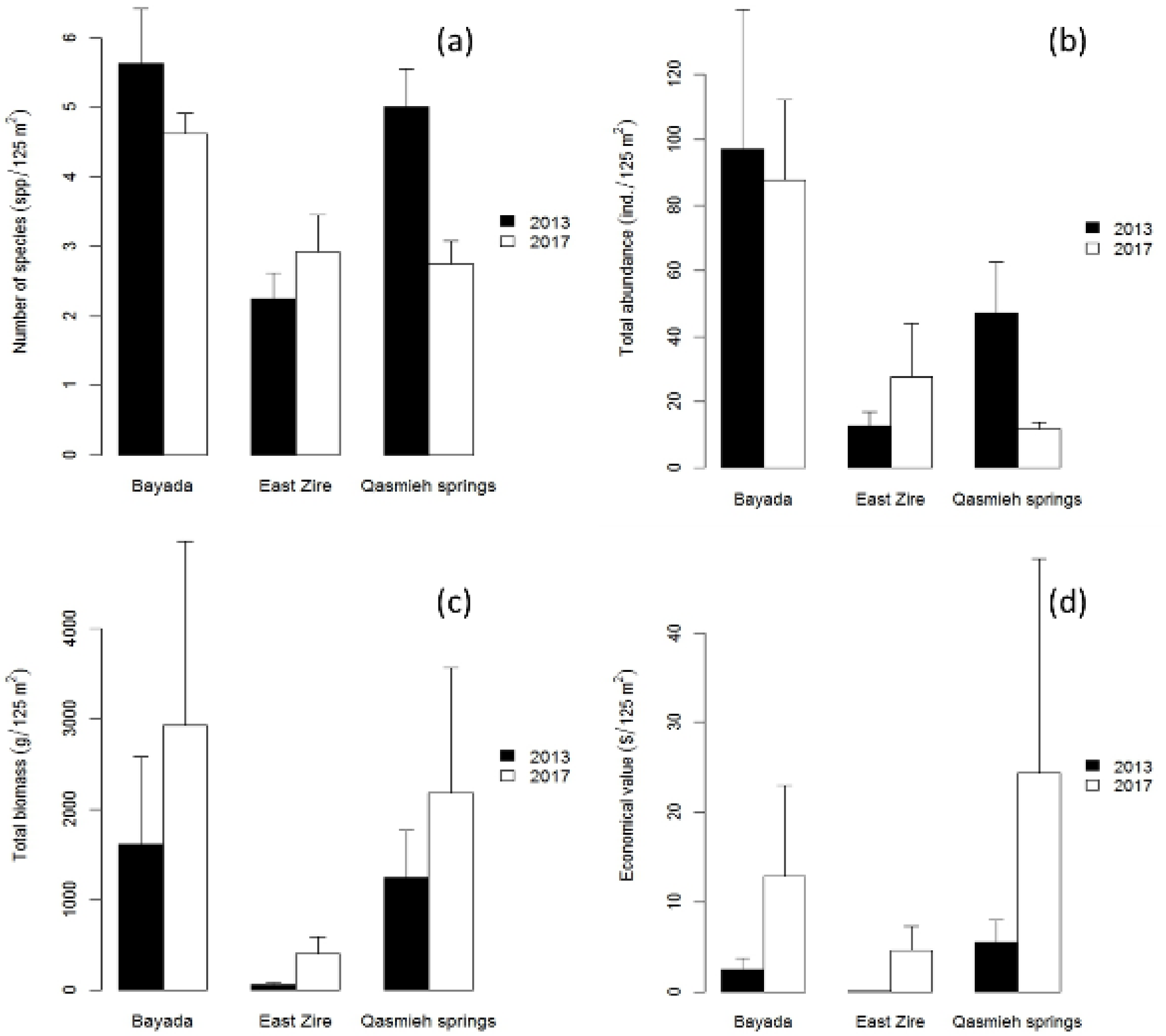


Figure 31. a) Number of species (species/125 m^2), b) total abundance (individual /125 m^2), c) total biomass (gram/125 m^2) and d) economic value ($/125 m^2) per locality in 2013 and 2017

Table 13. Results from the analysis of variance (ANOVA) with two factors (Y: year, L: locality), for the number of species, total abundance, total biomass and economical value. d.f.: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P-value < 0.05; ** = P-value < 0.01; *** = P-value < 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P-value < 0.01; ** = P-value < 0.001.

Sources of variation		Number of species			Abundance			Biomass			F versus
	d.f.	M.S.	F	P	M.S.	F	P	M.S.	F	P	
Y	1	3.109	1.340	0.251	0.717	0.642	0.426	2.345	0.737	0.394	Residual
L	2	35.301	15.215	0.000***	16.131	14.438	0.000***	32.529	10.220	0.000***	Residual
Y×L	2	8.975	3.868	0.026*	1.694	1.516	0.227	2.449	0.769	0.468	Residual
Residual	63	2.320			1.117			3.183			
Transformation		-			ln(x+1)			ln(x+1)			

Sources of variation	Economic value				F versus
	d.f.	M.S.	F	P	
Y	1	1920.216	0.919	0.341	Residual
L	2	1027.233	0.492	0.614	Residual
Y×L	2	204.986	0.098	0.907	Residual
Residual	63	2088.369			
Transformation		-ϖ			

4.2.3.2. Abundance of most representative species

Overall, 10 fish species were the most abundant in the studied localities. Among them, only three species had a commercial value (S. rivulatus, S. luridus and S. cretense) (Table 7). Most of the species showed a very high heterogeneous pattern, with differences among localities and years (Figure 32). Regarding differences between years, ANOVA showed significant differences in the factor Year only for C. julis and T. pavo (Table 14). The abundance of C. julis was significantly higher in 2013 while the abundance of T. pavo was significantly higher in 2017. Additionally,

the interaction among Year and Locality was significant for S. luridus (Table 14), with higher biomasses in 2013 in *Qasmieh* spring exclusively. Significant differences in abundance among localities were only found in C. julis, T. pavo, C. chromis, S. cretense and S. rivulatus (Table 14). The Dunnet-Tukey-Kramer test indicated that C. chromis, S. rivulatus and T. pavo were more abundant in *Bayada*, meanwhile C. julis in *East Zire* and S. cretense in *Qasmieh* springs.

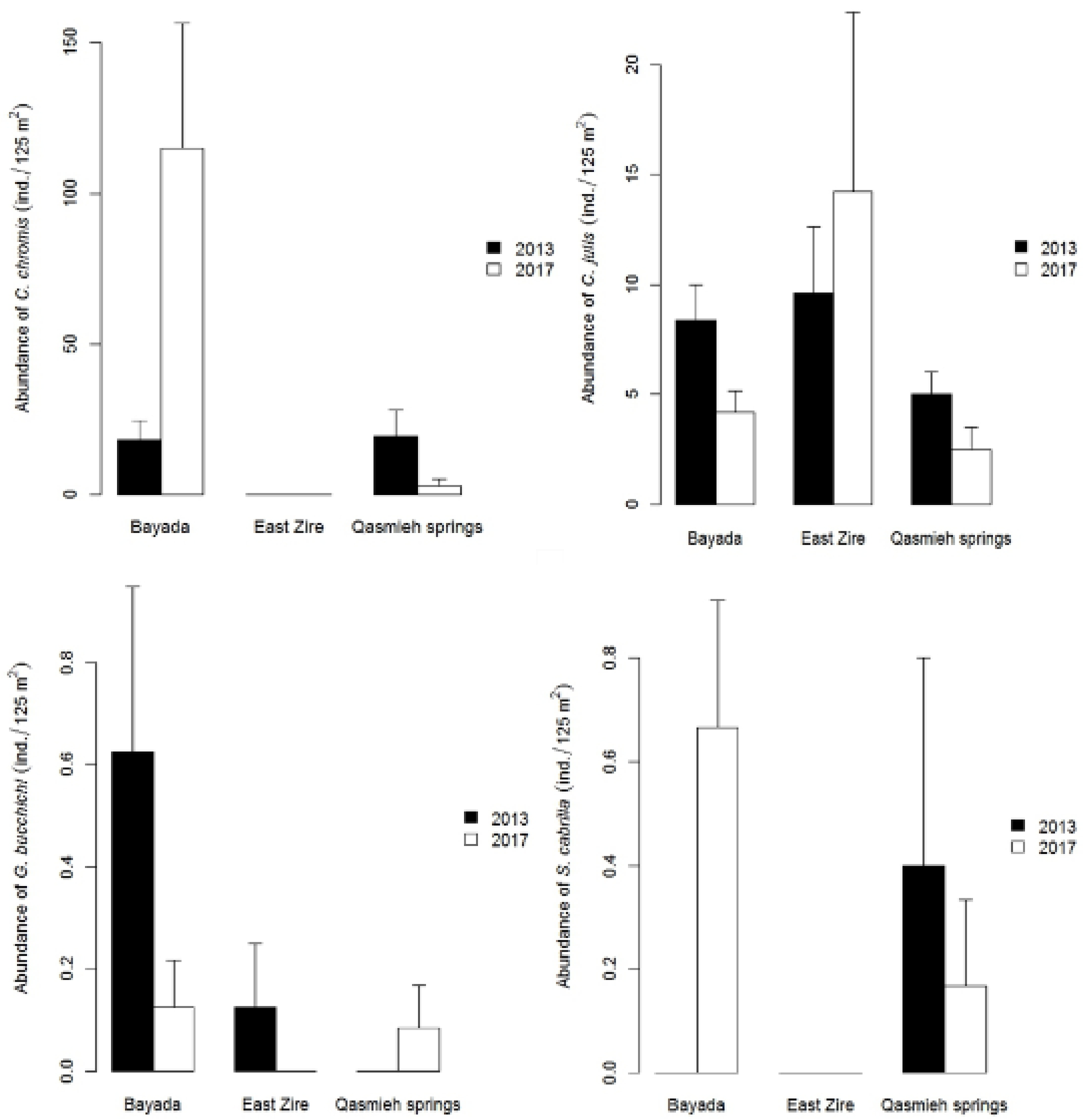


Figure 32. Mean abundance (individuals/125 m^2) per locality before and after management for the most representative species (≥10%).

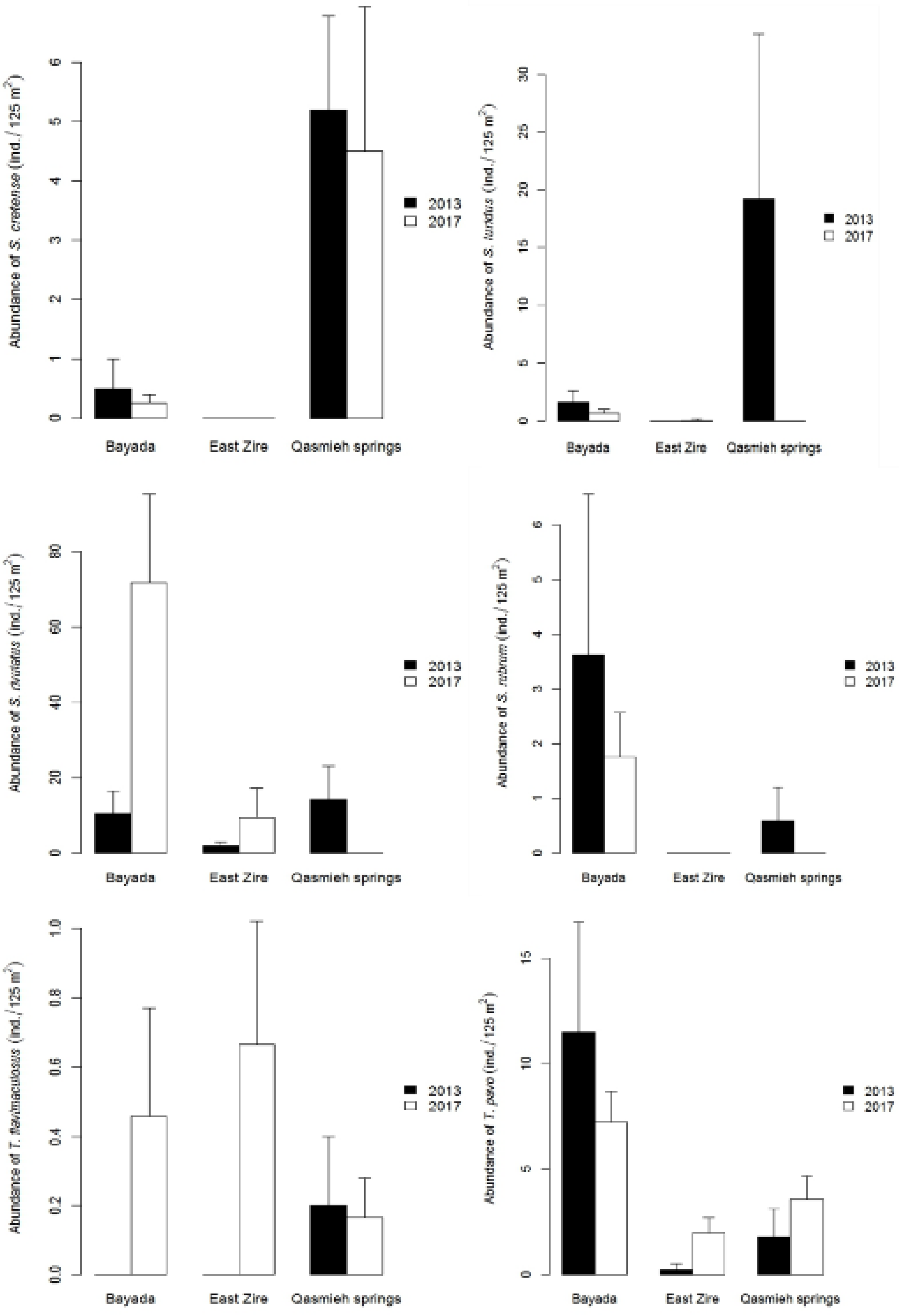


Figure 32 (cont.). Mean abundance (individuals/125 m^2) per locality before and after management for the most representative species (≥10%).

Table 14. Results from the analysis of variance (ANOVA) with two factors (Y: year, L: locality), for the abundance of the most representative species (≥10%). d.f.: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P-value < 0.05; ** = P-value < 0.01; *** = P-value< 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P-value < 0.01; ** = P-value < 0.001.

Sources of variation		Chromis chromis			Coris julis			Gobius bucchichi			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
Y	1	32119.568	2.098	0.152	6.911	8.187	0.006**	0.598	3.067	0.085	Residual
L	2	59077.339	3.859	0.026*	2.746	3.253	0.045*	0.412	2.111	0.130	Residual
Y×L	2	19139.560	1.250	0.293	0.684	0.810	0.449	0.418	2.145	0.126	Residual
Residual	63	15308.867			0.844			0.195			
Transformation		-ϖ			ln(x+1)			-ϖ			

Sources of variation		Serranus cabrilla			Sparisoma cretense			Siganus luridus			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	M.S.	F	P-value	
Y	1	1.143	1.792	0.186	0.466	0.034	0.855	341.696	5.076	0.028*	Residual
L	2	1.352	2.119	0.129	131.419	9.491	0.000**	184.864	2.746	0.072	Residual
Y×L	2	1.077	1.688	0.193	0.502	0.036	0.964	466.782	6.934	0.002*	Residual
Residual	63	0.638			13.846			67.316			
Transformation		-ϖ			-ϖ			-ϖ			

Sources of variation		Siganus rivulatus			Sargocentron rubrum			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	
Y	1	13176.537	2.598	0.112	6.150	0.448	0.506	Residual
L	2	20207.159	3.984	0.023*	42.510	3.094	0.052	Residual
Y×L	2	7429.302	1.465	0.239	4.947	0.360	0.699	Residual
Residual	63	5071.720			13.739			
Transformation		-ϖ			-ϖ			

Sources of variation		Torquigener flavimaculosus			Thalassoma pavo			F versus
	d.f.	M.S.	F	P-value	M.S.	F	P-value	
Y	1	2.221	1.914	0.171	2.376	4.120	0.047*	Residual
L	2	0.325	0.280	0.757	12.325	21.371	0.000***	Residual
Y×L	2	0.512	0.441	0.645	1.184	2.053	0.137	Residual
Residual	63	1.160			0.577			
Transformation		-ϖ			ln(x+1)			

4.2.3.3. Biomass of most representative species

Different patterns in localities between 2013 and 2017 were observed in each species (Figure 33). Regarding differences between years, ANOVA showed significant differences only for T. pavo (Table 15), with significantly higher biomass in 2017. S. luridus showed significant interaction between the factors Year and Locality (Table 15), with higher biomass in 2013 only in *Qasmieh* springs. Although no statistical differences were detected, the biomass of T. flavimaculosus was higher in 2017 for the three localities (Figure 28). With regard to differences among localities, significant differences were only found for the biomasses of T. pavo and S. cretense (Table 15). The biomass of T. pavo was significantly higher in *Bayada*, while the biomass of S. cretense was higher in *Qasmieh* springs.

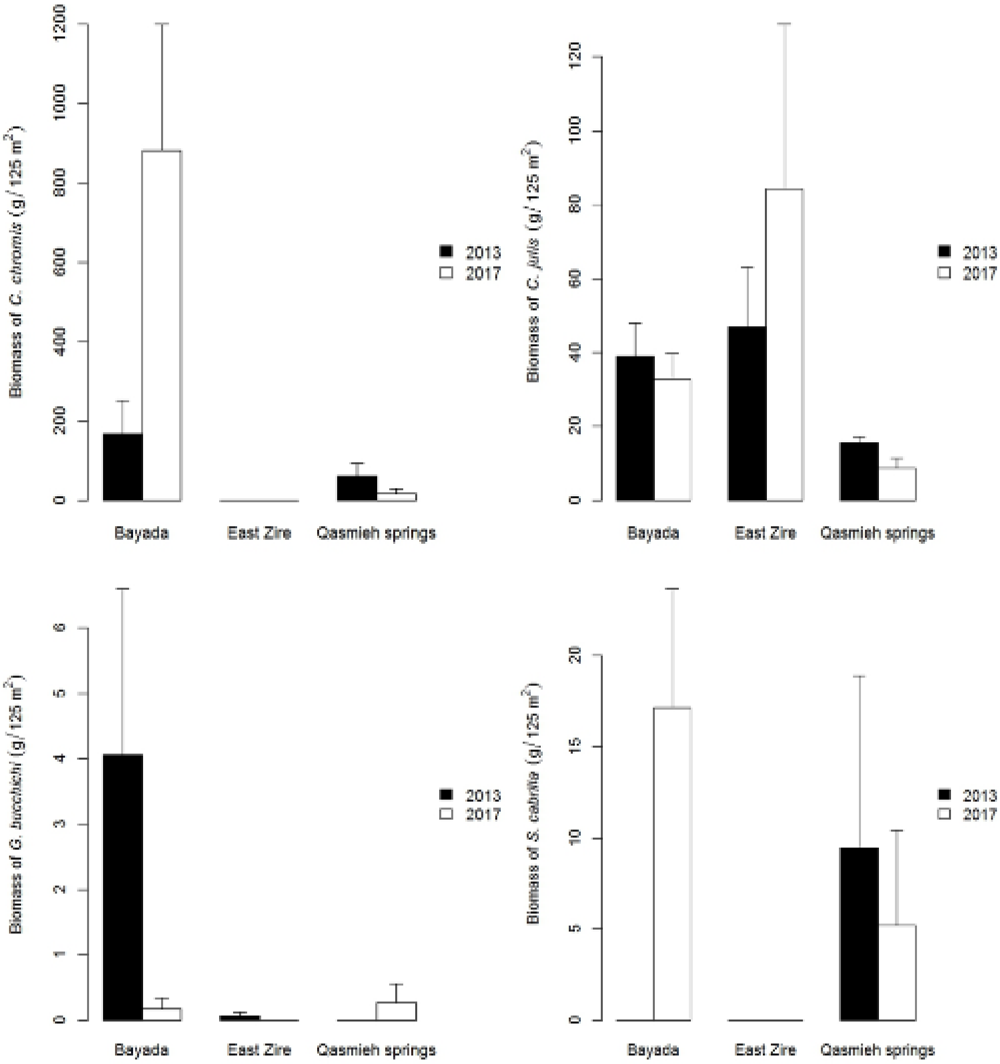


Figure 33. Mean biomass (individuals/125 m^2) per locality before and after management for the most representative species (≥10%).

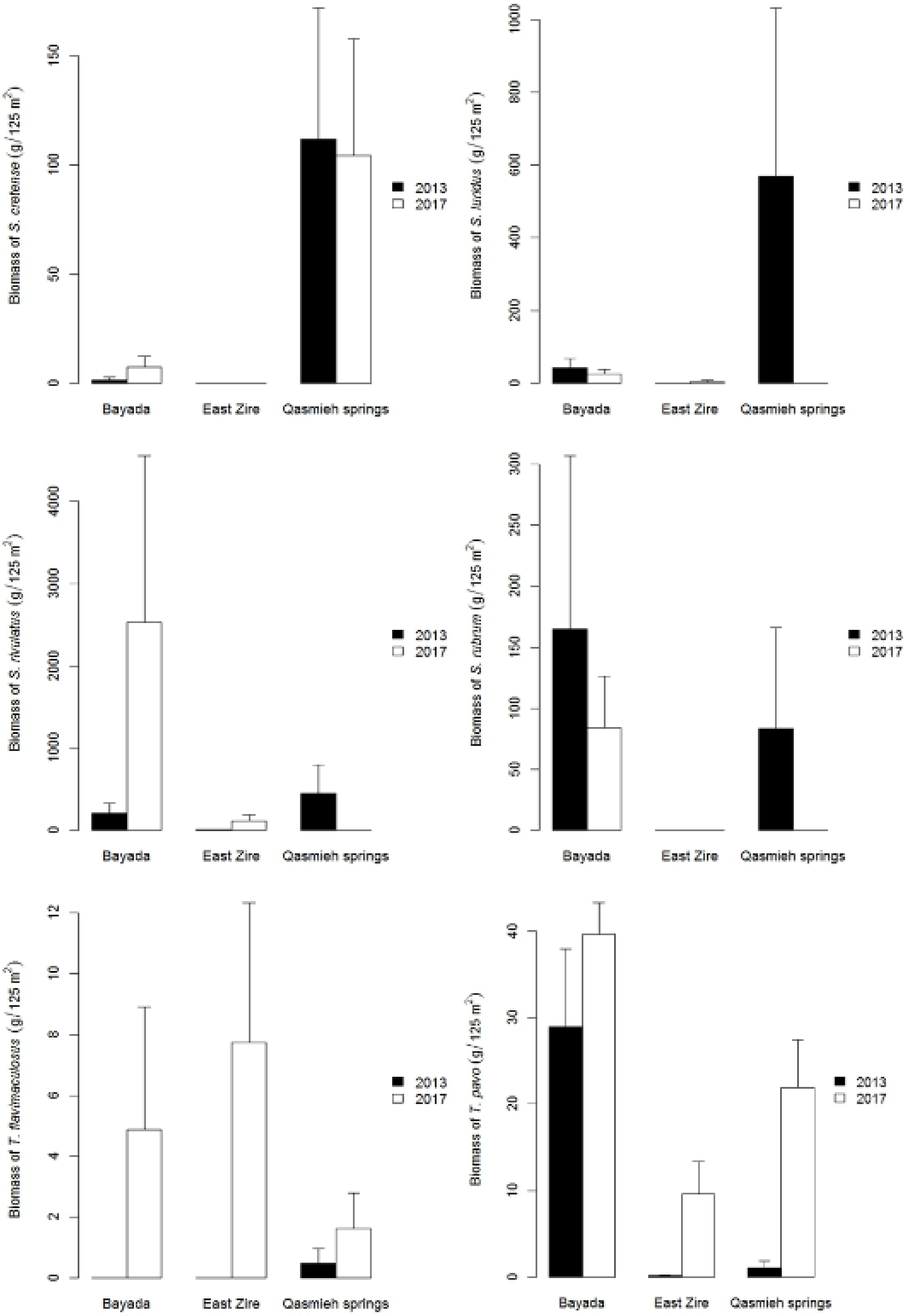


Figure 33 (cont). Mean biomass (individuals/125 m^2) per locality before and after management for the most representative species (≥10%).

Table 15. Results from the analysis of variance (ANOVA) with two factors (Y: year, L: locality), for the biomass of the most representative species (≥10%). d.f.: degrees of freedom; M.S.: mean square; F: F ratio. P-value: level of significance (* = P-value < 0.05; ** = P-value < 0.01; *** = P-value < 0.001). ϖ indicates that there is not homogeneity of variance, the level of significance being: * = P-value < 0.01; ** = P-value < 0.001.

Sources of variation	d.f.	Chromis chromis M.S.	F	P-value	Coris julis M.S.	F	P-value	Gobius buicchichi M.S.	F	P-value	F versus
Y	1	1962247.374	2.188	0.144	152.670	0.031	0.861	29.171	4.757	0.033	Residual
L	2	3698661.706	4.124	0.021	16757.154	3.414	0.039	12.825	2.091	0.132	Residual
Y×L	2	935433.678	1.043	0.358	3089.203	0.629	0.536	27.515	4.487	0.015	Residual
Residual	63	896829.025			4907.755			6.132			
Transformation		-ϖ			-ϖ			-ϖ			

Sources of variation	d.f.	Serranus cabrilla M.S.	F	P-value	Sparisoma cretense M.S.	F	P-value	Siganus luridus M.S.	F	P-value	F versus
Y	1	848.364	1.840	0.180	103.884	0.014	0.906	279208.498	3.980	0.050	Residual
L	2	876.334	1.901	0.158	68112.970	9.311	0.000**	159238.426	2.270	0.112	Residual
Y×L	2	644.734	1.398	0.255	202.310	0.028	0.973	420304.061	5.992	0.004*	Residual
Residual	63	461.076			7315.625			70144.425			
Transformation		-ϖ			-ϖ			-ϖ			

Sources of variation	d.f.	Siganus rivulatus M.S.	F	P-value	Sargocentron rubrum M.S.	F	P-value	F versus
Y	1	17865727.963	0.494	0.485	23959.096	0.669	0.416	Residual
L	2	26233388.496	0.725	0.488	86188.611	2.408	0.098	Residual
Y×L	2	10789451.436	0.298	0.743	10626.574	0.297	0.744	Residual
Residual	63	36174036.346			35797.937			
Transformation		-ϖ			-ϖ			

Sources of variation	d.f.	Torquigener flavimaculosus M.S.	F	P-value	Thalassoma pavo M.S.	F	P-value	F versus
Y	1	317.901	1.670	0.201	3901.822	13.477	0.000**	Residual
L	2	68.465	0.360	0.699	5724.327	19.772	0.000**	Residual
Y×L	2	44.149	0.232	0.794	152.442	0.527	0.593	Residual
Residual	63	190.381			289.516			
Transformation		-ϖ			-ϖ			

4.2.3.4. Multivariate structure of fish assemblage

Overall, MDS realized on the resemblance matrix of abundance (Figure 34) and biomass (Figure 35) showed a slight difference in the fish assemblage structure between 2013 and 2017 for *East Zire* and *Qasmieh* springs, while for *Bayada* both years were quite similar. Statistical tests showed significant differences in the multivariate structure of the abundance of the fish assemblage between 2013 and 2017, and also among locations (*Qasmieh* springs) (Table 16). On the other hand, the multivariate structure of the biomass was significantly different between 2017 and 2013 in *East Zire* and *Qasmieh* springs but not in *Bayada* (Table 17).

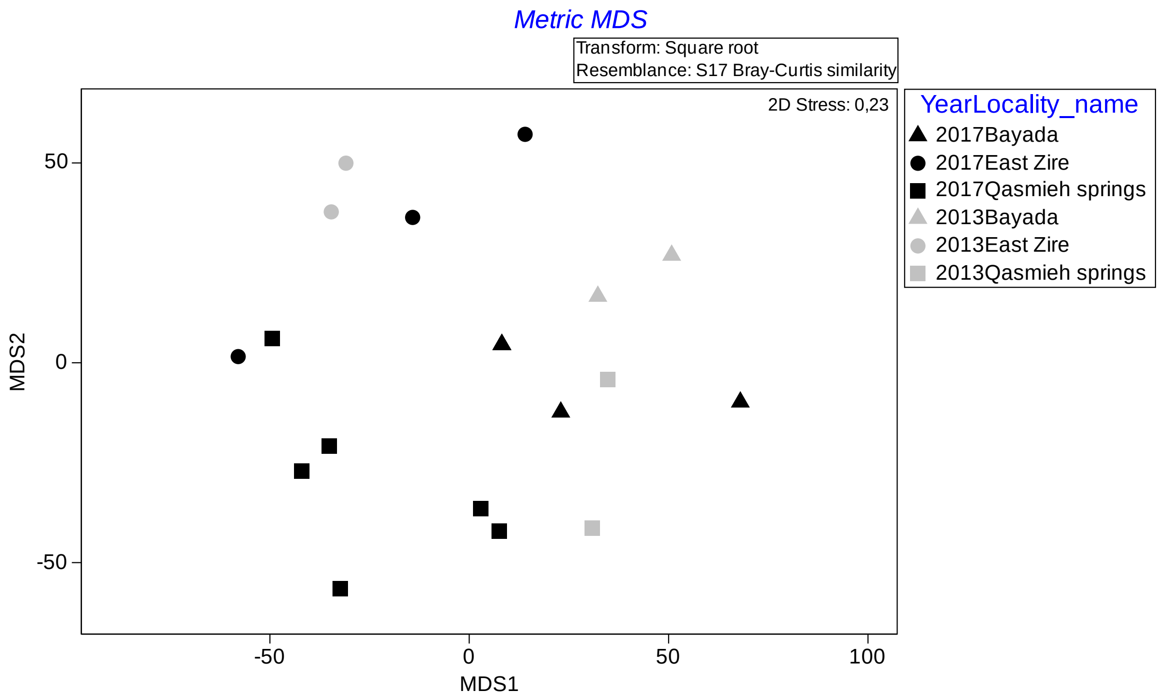


Figure 34. Metric Multi-Dimensional Scaling (MDS) realized on the resemblance matrix of abundance.

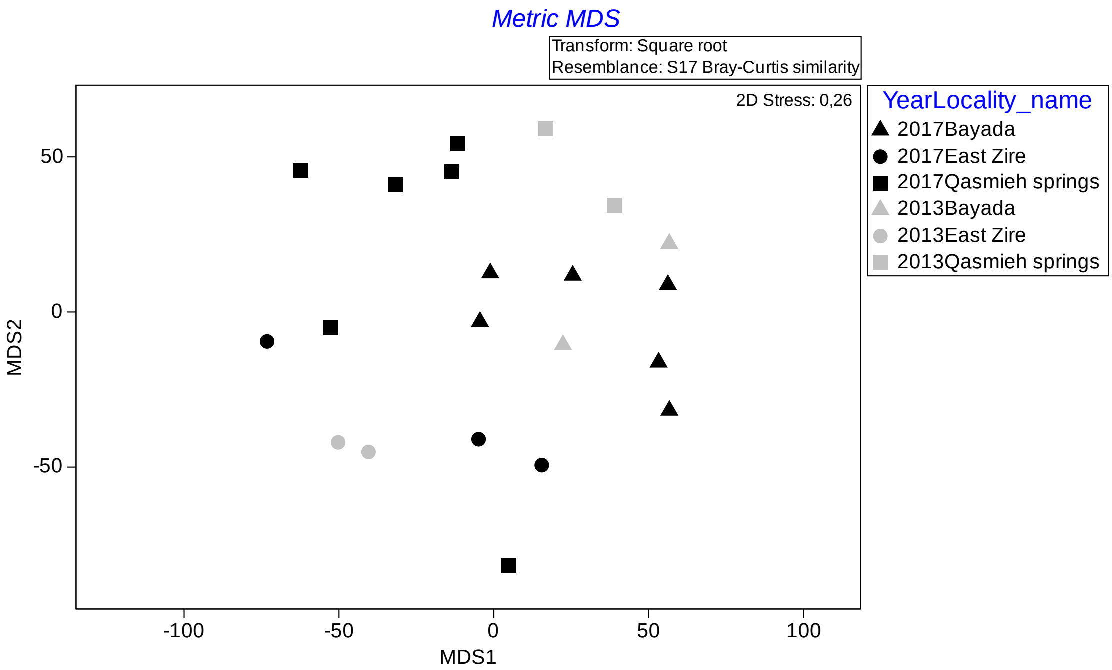


Figure 35. Metric Multi-Dimensional Scaling (MDS) realized on the resemblance matrix of biomass

Table 16. PERMANOVA results applied on resemblance matrix using Bray-Curtis dissimilarities of twos (Y: Year, L: locality). df: degrees of freedom; F: F ratio; P-value: level of significance (* = P < 0.05; ** = P < 0.01; *** = P < 0.001).

Main test		Abundance		Biomass	
Source	df	Pseudo-F	P-value	Pseudo-F	P-value
Y	1	3.3534	0.0057**	2.8256	0.0082**
L	2	6.4356	0.0001***	5.8559	0.0001***
Y×L	2	1.6609	0.0656	1.7471	0.0341*
Residual	63				
Total	68				

Table 17. Pairwise test applied on the significant interaction between factors Year and Location for the variable total biomass.

Years	2013 Vs 2017

Location	t	P-value
Bayada	1.1349	0.2332
East Zire	1.4926	0.0351
Quasmieh springs	1.5579	0.0207

4.3. Fish market

A high diversity of fishes was encountered in local fish market of Tyre. Among the species that were landed in Tyre, Sparidae (bogue Boops boops, common pandora Pagellus erythrinus, sand steenbras Lithognathus mormyrus, as well as sea breams Diplodus annularis, Diplodus sargus and Diplodus vulgaris) were relatively common. Moreover, speared groupers were frequently present in small body size (< 40 cm). These were the mottled grouper Mycteroperca rubra, the dusky grouper Epinephelus marginatus and the goldblotch grouper Epinephelus costae.

(a)

(b)

Figure 36. Epinephelus costae (a), and Mycteroperca rubra (b) at the local fish market of Tyre (©E. Ben Lamine)

The fishing industry of Lebanon is mainly considered as a small scale (artisanal) and traditional. It is based mainly on bottom stationary fishing gears (mainly trammel nets, gill nets, longlines and wire traps) and seine nets (purse seines and beach seines) (Majdalani, 2004). In addition, some particularly destructive fishing methods such as fishing with explosives (blast fishing) or poisons, fixed nets (Messlayeh) and spearfishing (with or without scuba gears) have significantly developed in the last few decades. In fact, disorder and anarchy during the civil war significantly impacted human civic behaviour and fishing practices and destructive fishing methods have emerged over the years and some are still used.

There are very limited numbers of gear regulations and restrictions in the Lebanese fisheries legislation. The legislation concerns the size of the gear, mesh-size of nets, maximum depth for stationary and surrounding nets and other gears. In general, there is no limitation on net length and height in Lebanese legislation. The same applies to hook size and number for longlines or size, mesh and number of traps used.

The legislation forbids the use of beach seines and air compressors. There is no specific regulation for commercialization of spearfishing or recreational angling products.

The Lebanese fishing fleet has been estimated in 2004 to about 2,800 registered vessels (Majdalani, 2004) but it is currently expected to be significantly higher and well above 3,000 fishing boats. The fishery landing is mainly constituted of small pelagic fishes (Clupeidae and Engraulidae) and medium pelagic fishes (e.g. Scombridae, Carangidae, Sphyraenidae, Mugilidae). Sparidae, Serranidae and Mullidae constitute also a significant part of the commercial catches (Bariche et al., 2006; 2007; Carpentieri et al., 2009; Nader et al, 2014). Among the most common fish species caught by recreational anglers are Siganidae, Sparidae, Serranidae, Scombridae, Mugilidae, Holocentridae, Fistulariidae, Nemipteridae, and Tetraodontidae (Bariche, personal communication).

Fishing methods, vessels and landings in Tyre and the south Governorate are comparable to the rest of the country since Lebanon has a narrow coastline of about 220 km. The southern part of Lebanon marine environment was relatively in good condition, but has suffered major setback particularly during the 2006 war, which was followed by a prolonged political impasse lasting several years. Some of the most important specific local threats to the Tyrian waters are the misuse of traditional fishing methods (e.g. small mesh sizes, fishing close to the coast) and some illegal fishing practices (e.g. blast fishing, spearfishing at night or with scuba).

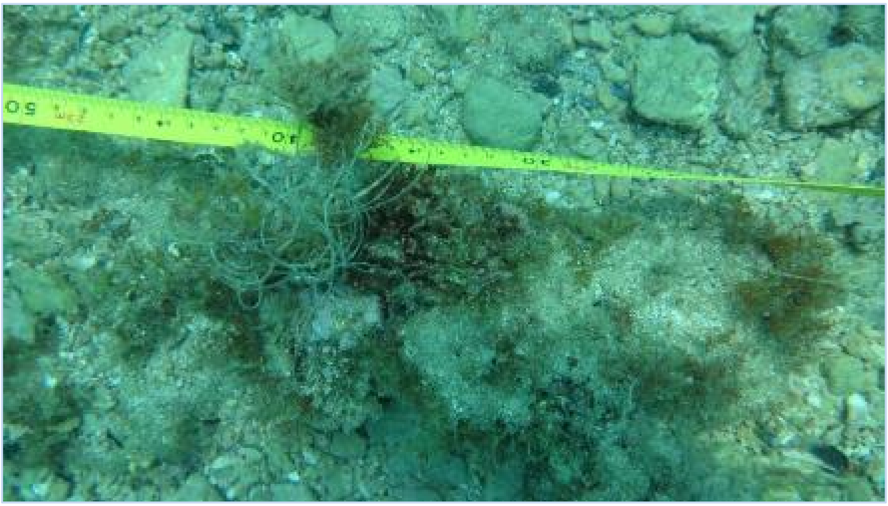
4.4. Marine uses and main impacts in the study area

Tyre city is known to be very populated and subject to a high touristic pressure. The coast includes sandstone rocky zones in the north and centre. Several small islets and a lagoon are also present, in addition to a wide sandy beach south of the city, where the Tyre Coast Nature Reserve is located. The beach is known to be a nesting area for marine turtles (Chelonia mydas and Caretta caretta).

The marine zone around the city of Tyre is subject to multiple human activities (industry, artisanal and recreational fisheries, tourism)(UNEP and RAC/SPA, 2013). During the present survey, some anthropogenic impacts were observed (Figure 32):

- Pollution coming from human activities, mainly plastic bags, tires, and lost nets (ghost fishing with lines and trammel nets);
- Recreational fishing (spearfishing and line fishing), with the commercialization of catch (noticed from the fish market where many M. rubra and E. costae were encountered with spear marks);
- Professional fishing (artisanal, using nets);
- High presence of invasive species (fishes and invertebrates), especially inedible ones without any commercial interest of Red Sea origin.

With analogy to the list of threats for the Tyrian coasts, which was reported in UNEP and RAC/SPA (2013), there was no sewage discharge, or use of blast fishing during the survey time.


(a)


(b)


(c)

Figure 37. Fishing line in Jamal (a) and solid waste pollution in Zire (b and c) (©E. Ben Lamine)

4.5. Training on fish assemblage sampling by visual census: the transect method

(See appendix)

5. Discussion

The ecological characterization of Tyre marine environment from 2013 showed a marine zone with high ecological interest (RAC/SPA and UNEP/MAP, 2013). In addition, the history and potential touristic importance of the Tyrian coast makes protection and efficient management crucial for the preservation of biodiversity and for the fishery, to enhance human economic activity.

This work constituted a precedent in the ecological monitoring process, essential for the future of the marine protected area of Tyre. It considers two major biotic aspects highly affected by protection and management measures: key habitats and fish assemblages.

Since 2014, some areas of Tyre coasts (*Zire* and *Jamal*), have been protected by the municipality of Tyre, supported by the Sustainable Fisheries Project, to secure them from illegal fishing. This study included those managed areas *Jamal* and *Zire*, but also other localities of ecological interest, such as *Qasmieh* springs and *Turtle reef*, as well as the control areas (*Bayada* and Bakbouk), where no protection existed.

The highest species richness and mean biomass were found in *Jamal deep* location, the highest abundance in both *Turtle reef* and *Zire*, and the highest economic value in the vicinity of *Qasmieh* springs. Thereby, to expand the protection to these sites could be interesting in order to obtain better results in the management of fish resources, particularly for *Qasmieh* springs, for various reasons (e.g. the presence of the springs). It is also the place where the largest individuals of groupers (M. rubra) were censused. We also suggest extending the limits of the current managed areas *Zire* and *Jamal* to also cover *East Zire* and "Jamal deep" locations respectively. This would result in protecting a wider depth range, and ensure the protection of further habitats used by larger individuals and also protect some nursery areas observed. To illustrate the importance of these areas, our study showed that the highest abundances and biomasses of the most valuable species (Epinephelus costae and Mycteroperca rubra) were in *Jamal deep*, *Turtle reef*, *East Zire* and *Qasmieh* springs.

Regarding the differences observed between 2013 and 2017, the total biomass and economic value were significantly greater in 2017 among all the locations compared (*Bayada*, *Qasmieh* springs, *East Zire*). Significant differences were also detected between the multivariate structure of the fish assemblage observed in 2013 and 2017 in *Qasmieh* Springs and *East Zire*. More cartilaginous species were encountered in 2017 than in 2013; these were Dasyatis centroura and Dasyatis marmorata. However, Epinephelus marginatus and Mullus surmuletus were censused in 2013 but not found in 2017. The same non-indigenous species were censused in both 2017 and 2013, except Apogonichthyoides nigripinnis and Atherinomorus lacunosus, which were not encountered in 2017. The logical interpretation of these differences

could be the seasonal aspect of fish assemblages in temperate systems especially that the survey of 2013 was done in the summer, while the present study occurred in the spring.

In all localities, fish seemed to be afraid when encountering divers, particularly those species that are subject to spearfishing. These observations can be due to a high fishing pressure occurring in this area. Even though only total abundance exhibited higher values in the managed areas, this difference was not statistically significant, and the number of species, total biomass and economic value showed similarity in both managed and control areas. These results suggest that further management measures (such as more patrolling, or increase in the surface of the managed areas) have to be considered to reach the full benefits of the protection and thereby, to obtain an increase in the captures of the artisanal fisheries of the area. Furthermore, a proper assessment of the benefits of the protection requires also a continuous temporal monitoring of the habitats and fish assemblages over the years. The landing of the local fishery should also be monitored.

The data presented in this report is expected to be used for future comparisons. Nonetheless we strongly suggest further monitoring and management of the region. The challenge for a future protected marine area is to know how to implement an MPA with restricted human activities and multi-use adjacent zones, but with controlled anthropogenic activities. One advantage of managed areas is the presence of managers in charge of patrolling and monitoring species of ecological

interest (sea turtles or sharks for instance). At this stage, enforcement is a very important step. From well-protected MPAs around the Mediterranean Sea, fish assemblages recovered from fishing pressure when enforcement and control were optimal. For Tyre, it is crucial that the proposed sites would be grouped within a MPA in which "no-take" zones are present and restrictions enforced. This will result in an increase in profits, resulting from artisanal fishing activities and in facilitating the development of other sustainable activities such as recreational diving.

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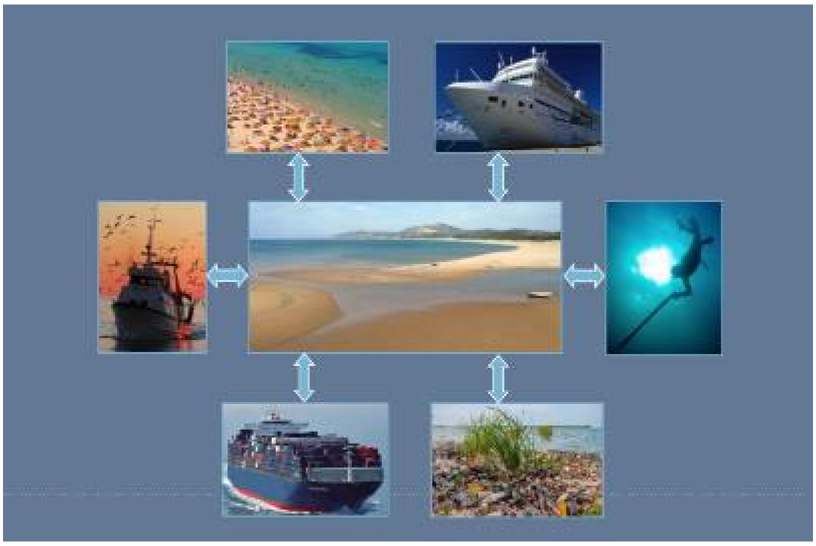
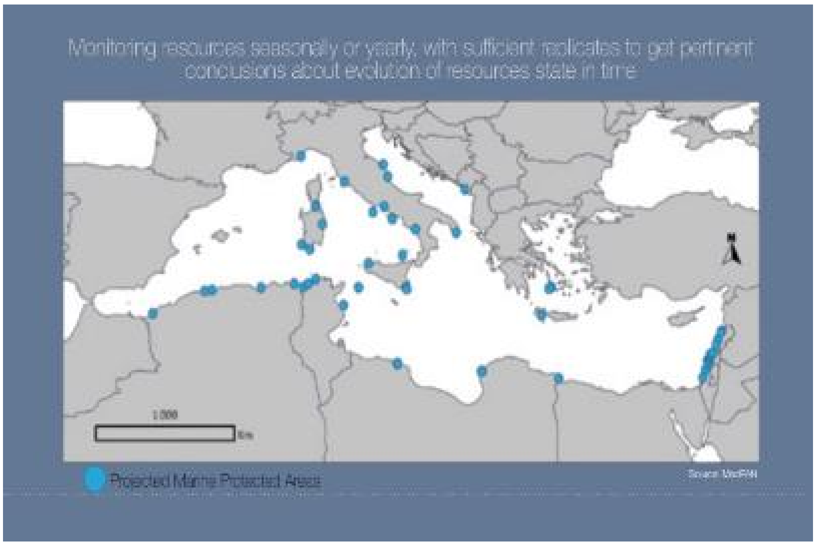
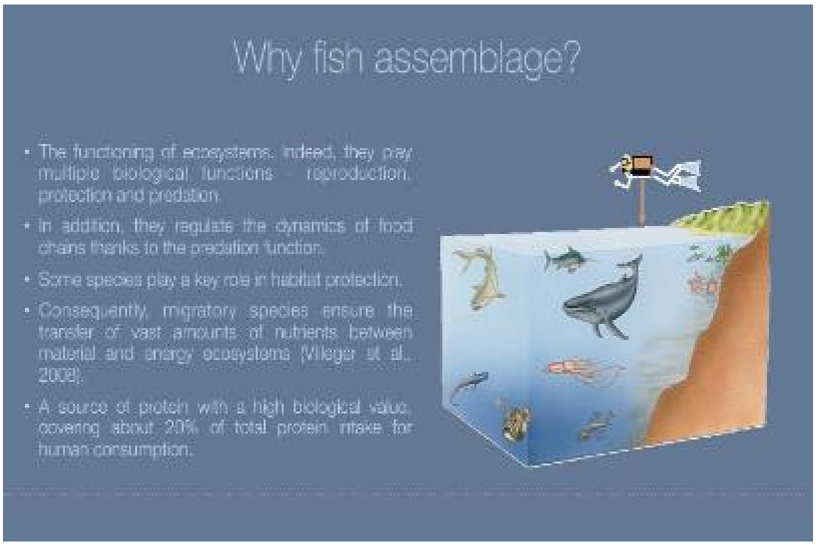
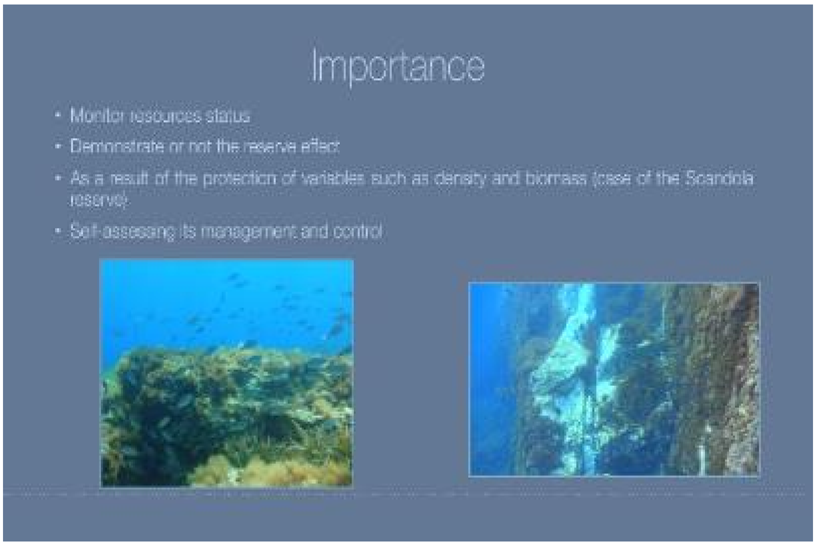
Appendix 1: Training on fish assemblage monitoring

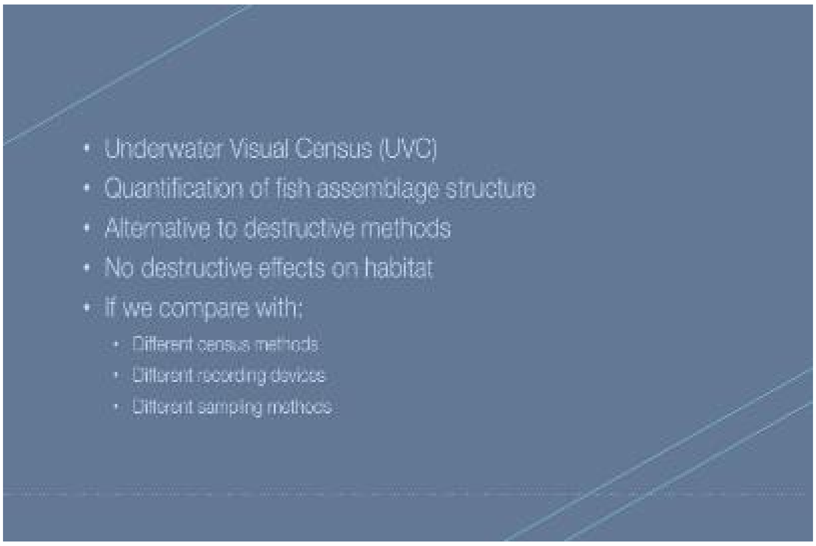


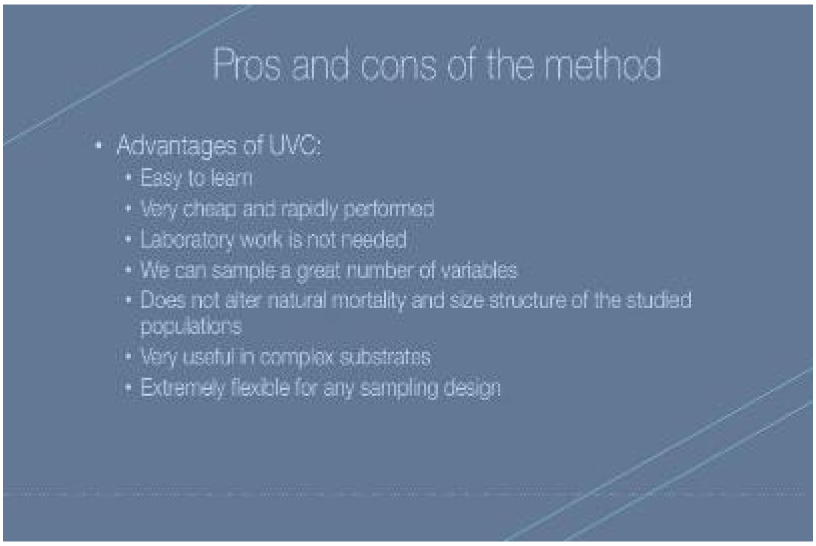


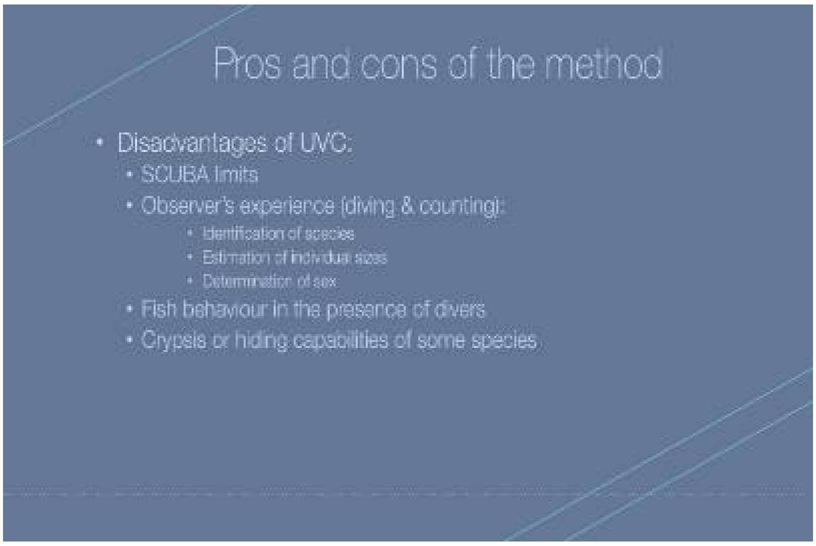

Why fish assemblage?
• The functioning of ecosystems. Indeed, they play multiple biological functions - reproduction, protection and predation.
• In addition, they regulate the dynamics of food chains thanks to the predation function.
• Some species play a key role in habitat protection.
• Consequently, migratory species ensure the transfer of vast amounts of nutrients between material and energy ecosystems (Villeger et al., 2008).
• A source of protein with a high biological value, covering about 20% of total protein intake for human consumption.

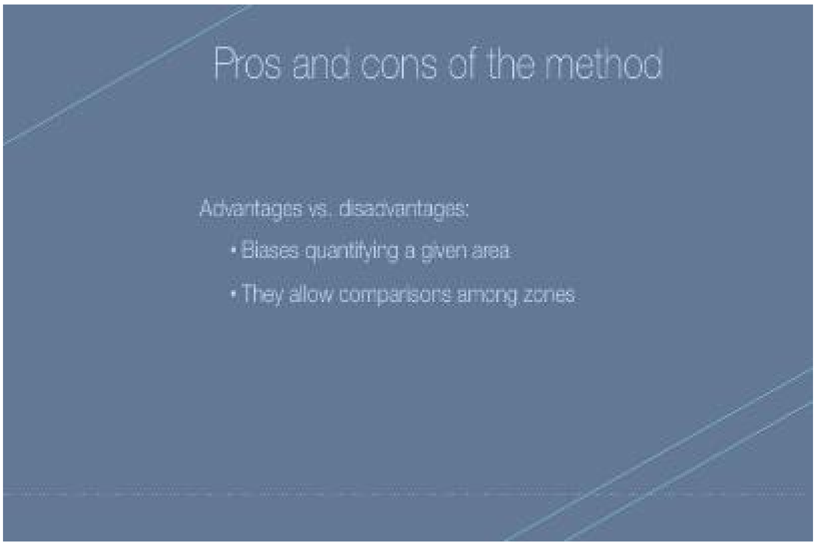

Importance
• Monitor resources status
• Demonstrate or not the reserve effect
• As a result of the protection of variables such as density and biomass (case of the Scandola reserve)
• Self-assessing its management and control

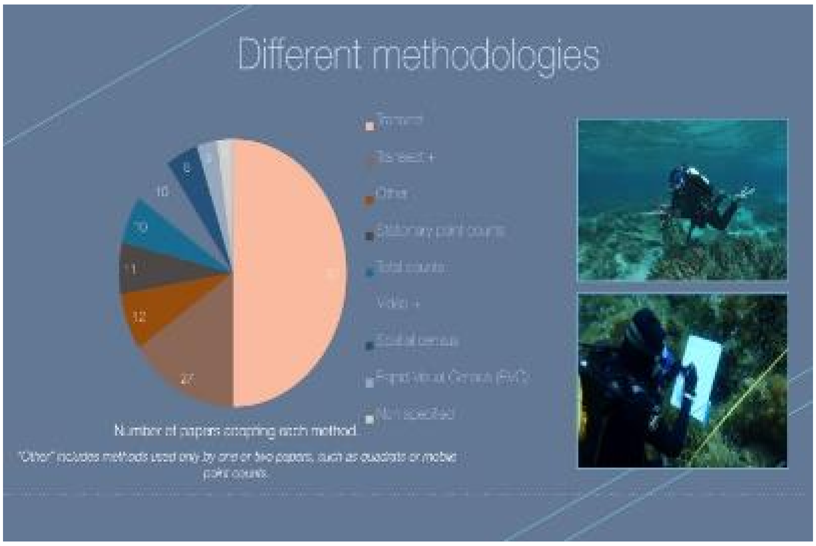

HOW?
Fish Visual Census Methodology

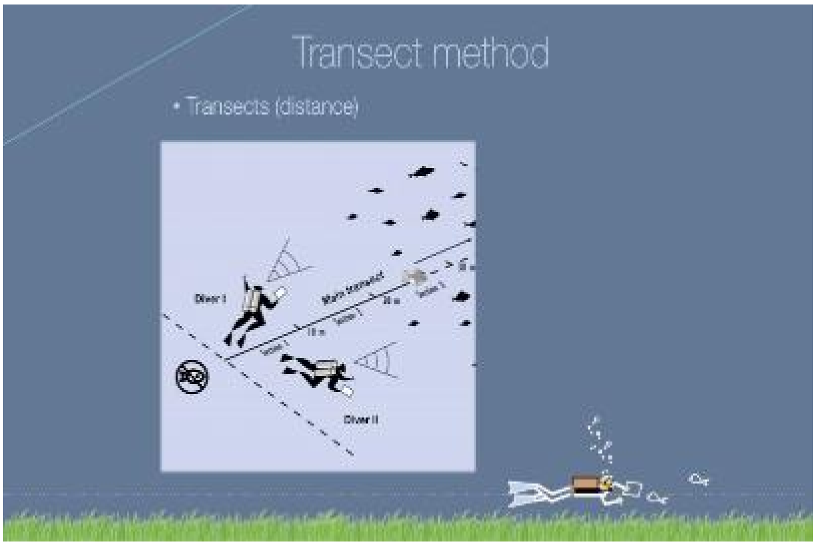

Underwater Visual Census (UVC)
Quantification of fish assemblage structure
Alternative to destructive methods
No destructive effects on habitat
If we compare with:
Different census methods
Different recording devices
Different sampling methods

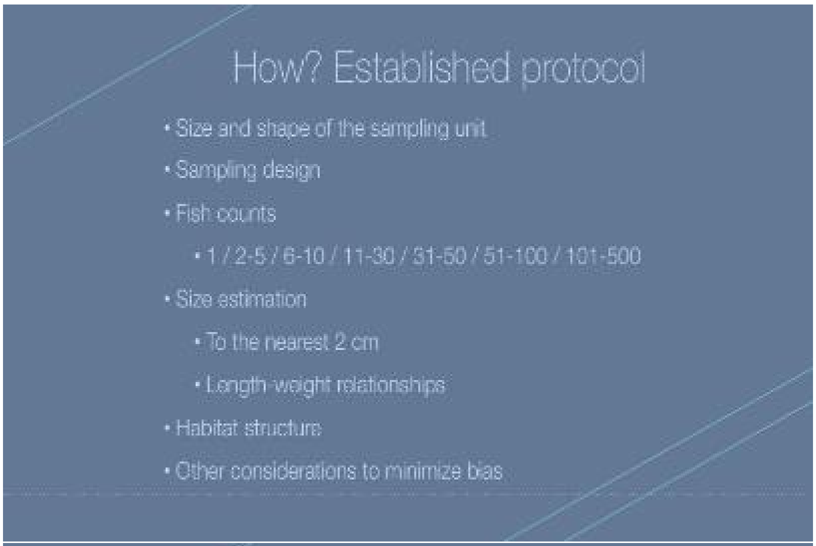

Pros and cons of the method
Advantages of UVC:
Easy to learn
Very cheap and rapidly performed
Laboratory work is not needed
We can sample a great number of variables
Does not alter natural mortality and size structure of the studied populations
Very useful in complex substrates
Extremely flexible for any sampling design

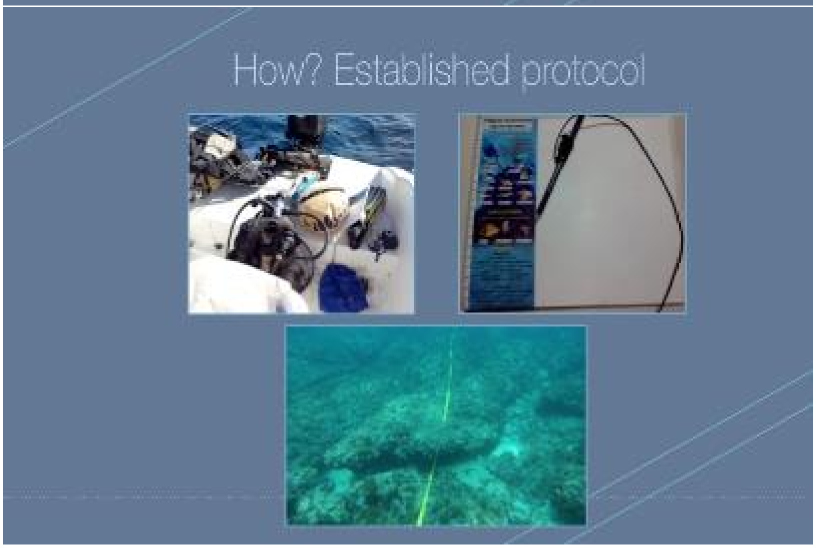

Pros and cons of the method
Disadvantages of UVC:
SCUBA limits
Observer's experience (diving & counting):
Identification of species
Estimation of individual sizes
Determination of sex
Fish behaviour in the presence of divers
Crypsis or hiding capabilities of some species


Pros and cons of the method
Advantages vs. disadvantages:
• Biases quantifying a given area
• They allow comparisons among zones


Different methodologies
Other
Total counts
Video +
27
12
11
10
10
8
Number of papers adopting each method.


Transect method
• Transects (distance)
Diver I
Diver II


How? Established protocol
• Size and shape of the sampling unit
• Sampling design
• Fish counts
• 1 / 2-5 / 6-10 / 11-30 / 31-50 / 51-100 / 101-500
• Size estimation
• To the nearest 2 cm
• Length-weight relationships
• Habitat structure
• Other considerations to minimize bias


How? Established protocol

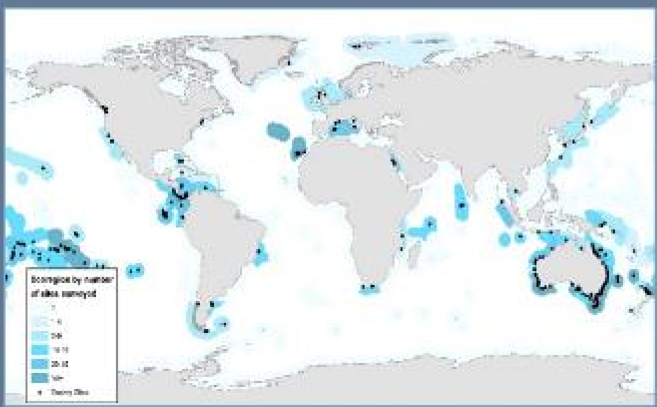
After the dive…

- Data treatment
- Calculating fish assemblage parameters (density per m^2, biomass (kg), economic value…)
- Software use (ECOCEN)

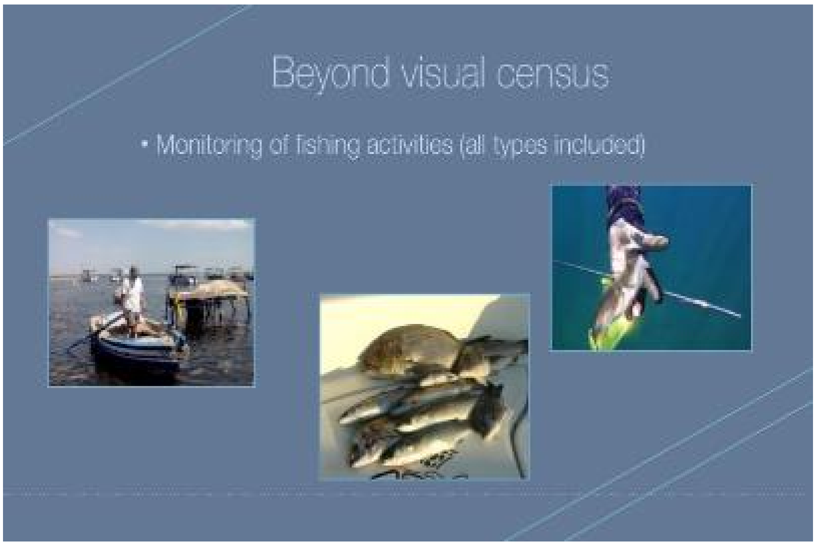
Volunteer contribution to rely on…

- Regular fish monitoring is constricted by the limited number of local scientific divers
- The need for new tools and mechanisms to support citizen engagement in collecting data was highlighted (Bird et al. 2014; Dickinson et al. 2012, Silvertown, 2009).

It is necessary to have adapted and standardized methods for non-scientist use to monitor fish assemblages. These adapted methods are expected to be low-training needing and pertinent.



87 MPAs were investigated, with approximately half located in Australia (36) and New Zealand (8)
Edgar et al., 2014)


Beyond visual census
• Monitoring of fishing activities (all types included)

Appendix 2: Cartography of benthic habitats

CARTOGRAPHIC TOOLS

TRANSECT

TRANSECT BY DIVE OR APNOEA

Consists in following a tape measure placed perpendicularly to the coast.

The distance along the tape measure and the depth are noted for each change in the nature of the seabed (Posidonia, Cymodocea, rocks, blocks, sand, coralligenous).

TRANSECT WITH THE UNDERWATER OBSERVATION DEVICE

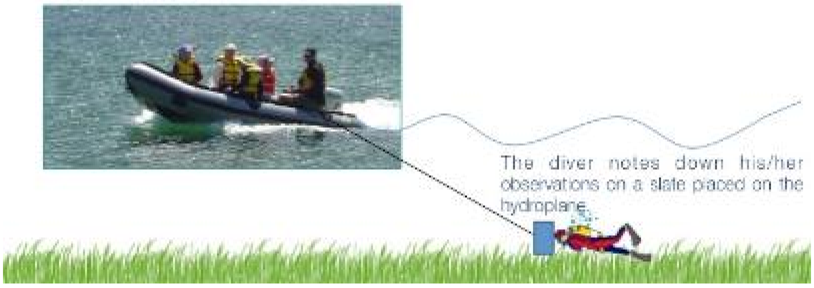
For a quick and extensive observation of the superficial zones, prospecting is performed with an Underwater Observation Device. Transects are carried out at a depth between 0 and 18m (depending on water transparency)

TRANSECT WITH THE UNDERWATER OBSERVATION DEVICE

TRANSECT WITH THE HYDROPLANE

This method consists in dragging a diver with an inflatable boat (Zodiac) at a speed of 2 knots. The hydroplane enables performing transects of between 1,500 to 3,000m length in depths of between 3 to 27m.

The team on the inflatable boat marks the GPS position, the direction, the speed and the depth every 3 minutes.



REMOTE SENSING

AERIAL PHOTOGRAPHY

This cartography method is based on the exploitation of aerial photographies.

The use of these photographies for the study of the seabed may be limited by the turbidity of water.

SATELLITE IMAGERY

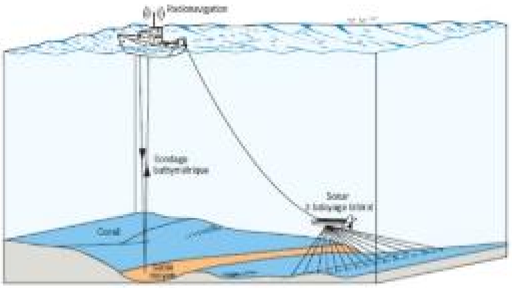
Satellite imagery may also be used in order to identify different types of seabeds, up to a depth of 10 to 12m.

ACOUSTIC METHODS

SIDE-SCAN SONAR

The side-scan sonar is made of a « fish », towed at a speed of about 5 knots, that sends an acoustic signal towards the seabed through two emitters.

This signal, sent back with more or less intensity depending on the nature and the morphology of the seabed, is received by the fish, that relays it through an electrocarrier cable with numeric and graphic recorders, placed aboard the boat.



For technical reasons, the use of this towed tool is limited to depths above 10 meters.

SIDE-SCAN SONAR

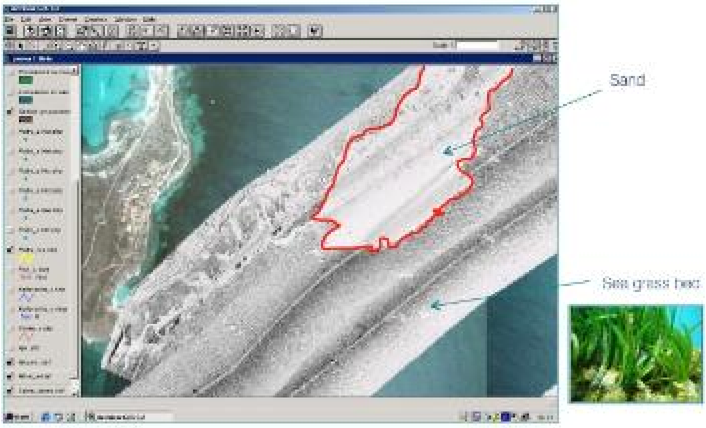
«Fish»

Electrocarrier cable

Control unit

SIDE-SCAN SONAR

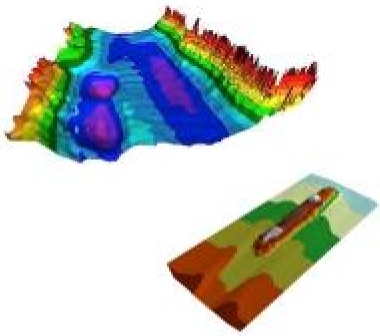
Sonograms show the limits (contours) of the different components of the seabed (rocks, sediments...), characterized by various shades of grey.



MULTIBEAM ECHOSOUNDER

The multibeam echosounder is a quick and precise way of obtaining:

- Topographic data of the submarine relief (bathymetry)
- Sonar images showing the nature of the bed (imagery)



R.O.V (REMOTELY OPERATED VEHICLE)

drosos (...)

IUCN