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Investigating the nursery function of the Alboran MPA on the Mediterranean coast of Morocco

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Abstract

Coastal habitats provide shelter and food for juvenile fish, ensuring their survival and supporting a range of species that are both commercially and ecologically important. The Alboran Marine Protected Area (MPA) off the Mediterranean coast of Morocco has been identified as a nursery area, although this role has never been the subject of characterisation. This study investigates the nursery function of habitats at six sites, two of which have seasonally flooded rivers with small persistent lagoons (transition systems) actively connected to the sea. Mixed sand-and-gravel beaches and transition systems were surveyed using a beach seine (four hauls) during two consecutive summer periods (June 2019 and July 2020), and a beam trawl was used in July 2020 in order to survey shallow waters at three depths: 3, 5 and 7 m. The use of both fishing methods provided a comprehensive assessment of juvenile fish communities. Different habitats in these coastal areas supported juvenile fish of 31 different species, with higher species richness and densities of young-of-the-year (YOY; first year of life) fish in transition systems despite their limited surface area and depth. Shallow marine waters supported fish species with specific microhabitat requirements despite lower overall YOY fish densities. The Alboran MPA coast has a nursery function, with different habitats acting as nurseries for juveniles of different fish species, creating a seascape of interconnected nursery habitats. As low densities of juvenile fish were a common concern across species and habitats, protecting these nursery habitats through enforcement of their protection regime appears to be a priority.

Keywords: nursery habitats; young-of-the-year fish; juvenile fish; nursery seascape; conservation.

Introduction

Coastal habitats play a crucial role in the survival and growth of early life stages of commercial, recreational, and ecologically important species. These areas provide shelter and food to juveniles, promoting their survival and contributing to overall production and population stability (Cheminée *et al.*, 2015; Dahlgren & Eggleston, 2000; Scharf *et al.*, 2006). Juvenile fish settlement occurs throughout the year, although most Mediterranean species have a settlement peak between spring and early summer (Biagi *et al.*, 1998; Dulčić *et al.*, 1997; 2007; García-Rubies & Macpherson, 1995). Settlers supply and nursery habitat availability are key factors that affect settlement and recruitment processes, determining population renewal and shaping the structure of adult communities (Cheminée *et al.*, 2011). Understanding the role of habitat use is particularly valuable from a conservation and management perspective, given the increasing vulnerability of coastal habitats to anthropogenic stressors (Halpern *et al.*, 2008; Sala, 2004; Sala *et al.*, 2012).

In the Mediterranean coast of Morocco, studies devoted to fish nursery habitats are scarce. The Alboran Marine Protected Area (MPA) is recognised as a multispecies larval fish hotspot along the Moroccan Mediterranean coast (Diouri *et al.,* 2023; Masski, 2015). The Mar Chica lagoon, which is the largest on the Mediterranean coast of Morocco, has been the subject of research into its fish communities, but its function as a nursery has not been specifically studied (Jaafour, 2015; Selfati *et al.*, 2019). Studies conducted along the Spanish coast of the shared Alboran Sea with the Moroccan coast and other comparable ecosystems in the Mediterranean provide insights into the structure and functioning of nursery habitats in coastal areas. Studies have highlighted the influence of environmental factors and seasonal changes on the composition of juvenile fish populations. Furthermore, resource partitioning takes place in both space and time, with some species settling in distinct habitats while others use the same habitat but during different periods (Bariche *et al.,* 2004; Bussotti & Guidetti, 2011; Cheminée *et al.,* 2021; García-Rubies & Macpherson, 1995; Félix-Hackradt *et al.,* 2013; Harmelin-Vivien *et al.,* 1995; Matić-Skoko *et al.,* 2022).

Therefore, the Alboran MPA was designated in 2015, with particular emphasis on the nursery habitat function of the shallow coastal areas (Dahou *et al.,* 2023). During the consultation process that preceded the establishment of the MPA, surveys were conducted based on fishermen's local ecological knowledge, which highlighted the value of this area as a nursery for a wide range of species. This was confirmed by the analysis of professional beach seine (BS) catches, species composition, and fish length spectrum (Masski, 2015). However, no baseline survey has been carried out to characterise this nursery function and, to date, the MPA management plan has never been implemented, and no protection measures are in place (Dahou *et al.*, 2023).

The present study is the first attempt to address the knowledge gap about fish habitats along the Mediterranean coast of Morocco by investigating the nursery function of the shallow coastal areas of the Alboran MPA. Our objectives were (1) to identify the sites and habitats that contribute most to the nursery function of this area by analysing the structure of juvenile fish communities, (2) to determine the environmental factors that most influence these communities, (3) and to analyse the inter-annual variation in their composition. This study also aims to provide baseline information for future research into the performance of the MPA in protecting its nursery habitats.

Methods

The Alboran MPA and its nearby landscape

The Alboran MPA was established in 2015 and is classified as an IUCN Class VI MPA. It was established primarily for fisheries purposes and covers an coastline of approximately 52 km along the western Mediterranean coast of Morocco, extending 3 milles offshore. The landscape is characterised by cliffs, flood rivers, streams, and sand-and-gravel beaches. During the summer months, most rivers are dry or low-flowing, resulting in limited transition systems that are mainly influenced by marine waters. Within the MPA, fishing activities are restricted to small-scale fisheries, with two no-take zones established to protect biodiversity (2% of the area). To ensure sustainable fishing practices, fishing gear use is limited in time and space in accordance with the life cycle of the target species (Dahou *et al.*, 2023).

Sampling design

The surveys were designed to target primarily young-of-the-year (YOY) fish (i.e., fish from the current year's spawning run) from settlement to the first year of life. The individuals of more than one year age are referred to as juvenile1+ to distinguish them within juveniles, which include YOY fish.

Surveys were conducted in early summer because this was identified as the peak settlement period with the highest observed YOY densities of a wide range of fish species (Masski, 2015). The first survey took place from 16 June to 19 June 2019, while the second was conducted from 14 July to 22 July 2020, with a one-month delay due to COVID-19 restrictions in Morocco. A total of six sites were selected for fish sampling, four within the Alboran MPA and two immediately outside the MPA's eastern and western boundaries (Fig. 1). The selected sites are the main beaches along the Alboran MPA coastline where the use of a BS is possible. All sites had dry streams during the summer, but two of them inside the MPA had permanent transition systems. These sites were Oued Laou, which had a small lagoon with a maximum depth of 4 m, and Chmaala, which had a small stream and a marsh-like area that was submerged only during the second survey, with a maximum depth of 1 m. In this way, we distinguished between transition systems and the marine environment, and then in the first 2 m of depth, referred to here as shallow water, and the coastal environment between 3 and 7 m deep.

To sample YOY fish in transition systems and shallow marine waters less than 2 m deep, where recruits of bottom species are known to concentrate (García-Rubies & Macpherson, 1995; Planes *et al.,* 1999), a BS measuring 10 m long, 2.5 m high, and with a 5 mm square mesh size was used. The towing ropes were 20 m long, resulting in a theoretical swept area of 200 m^2. Four fishing points, spaced 50 m apart, were identified at each site, preferably around the connection area between the stream and the sea. The transition system of Oued Laou was surveyed using three points, while the stream and the Chmaala marsh were surveyed using one point each due to their small size.

Marine waters at 3 m to 7 m depths were investigated during the July 2020 survey using a beam trawl (BT) measuring 164 × 45 cm, equipped with 10 mm square mesh at the wings and back and 5 mm mesh at the cod-end. The BT was towed using a 4.5 m hard-hull inflatable boat with a 45 HP engine. Three fishing hauls were conducted at 3 m, 5 m, and 7 m depths, lasting between 19 and 29 minutes depending on beach configuration at about 1.2 knots, which was then standardised to 30 minutes (1771 m^2). The Aouchtem and Targha sites could not be surveyed with the BT due to the presence of rocks on the seabed, and a haul at 3 m depth at the Amtar site could not be carried out for the same reason.

In order to analyse the effect of bottom texture on fish community composition, the bottom sediment was analysed for grain size characteristics. Sampling was carried out using a 20 cm square hand core (400 cm^2) processed by a diver. A single sediment sample was taken at each BS fishing operation between 1 m and 2 m depths within the swept area. For each BT fishing haul, three samples were collected at the beginning, middle, and end. Samples were fixed using 4% formalin in the field.

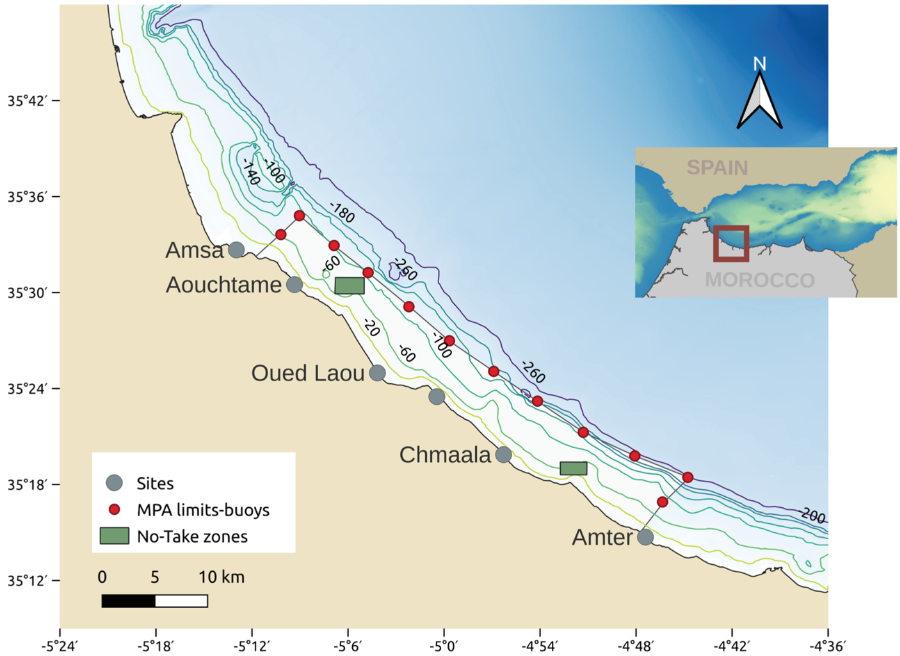

Fig. 1: Alboran Marine Protected Area site and boundaries on the western Mediterranean coast of Morocco and surveyed sites (Morocco, 2014).

Data collection

Samples from the hauls were processed in the field for species identification and estimation of fresh weight in grams, then fixed in a 70% ethanol solution. In the laboratory, fish were identified to species level, measured to the nearest millimetre for total length (TL), and individually weighed in milligrams. Benthic invertebrates were sorted into taxonomic groups and weighed.

To estimate size-at-age for each species, growth parameters ($L\infty$, K and t0) were extracted from FishBase (Froese & Pauly, 2023) for the nearest areas from the Mediterranean and Atlantic regions. The regression curves were used to estimate the length at the first year for each of the sampled fish species in order to separate YOY from older juvenile1+ (Table 1).

To prepare the sediment samples for laboratory analysis, they were washed three times with clear water to remove formalin and salt. After 12 hours of decantation, the water was carefully removed using a low-flow water pump to prevent the removal of silt. Macrobenthic invertebrates were removed, and sediment samples were dried at 80 °C for 48 hours and weighed. Where necessary, samples were homogenised using a wooden mortar. The samples were then dry sieved for 20 minutes using an electromagnetic sieving machine with 13 sieve columns and sieve sizes ranging from 0.04 mm to 40 mm. The fractions obtained from the sieving process were weighed for further analysis.

Statistical analyses

Sediment grain size comparisons were performed using the G2Sd package for sediment size analysis (Gallon & Fournier, 2013). The G2Sd package provides complete descriptive statistics and a physical description of the sediment.

Permutation analysis of variance was used to test how fish community composition varied by site, system, depth and year (PERMANOVA using ‘**adonis2**’ function in vegan package) (Oksanen *et al.*, 2022), and post-hoc pairwise PERMANOVA was used to test the significance of the differences between sites (function ‘**pairwise.perm.manova**’ in RVAideMemoire package, and ‘**pheatmap**’ package for graphical rendering) (Herve, 2023; Kolde, 2019). The Bray–Curtis dissimilarity matrix of the fish densities for each fishing haul was used as the response variable, and the period (year), the location (Site), the environment (marine or transition), and the bottom texture from grain size analysis, were used as independent variables for BS data. For the analysis of trawling data, the independent variables were location (site), depth (3, 5 or 7 m), algae densities (three levels: no algae, scattered algae clumps, algae beds), and gravel percentage, while the bottom texture, mud percentage and benthic invertebrate densities were removed from de model due to their negative effect on the explained variance.

For the BS catch data, the variability in fish community composition between and within sites showed significant effects with the highest explained variance from the PERMANOVA analyses. Hence, a between-class correspondence analysis (BCA; function ‘**bca**’ in ade4 package version 1.7-22) (Thioulouse *et al.*, 2018) was used for the analysis of the structure of the juvenile fish community among sites and years. The analysis maximises the differences between sites in order to better explore the dissimilarities between sites and estimates within-site variability using confidence ellipses.

Trawling data were analysed using distance-based re-

Table 1. Fish species occurrence (number and per cent) in the overall fishing operations carried out in transition systems and in shallow waters (0-2 m) using the beach seine and in coastal waters (3-7 m) using the beam trawl. TL-Y1: total length at first year from birth, from bibliographic Von Bertallanfy curves.

				Transition	**Marine**		
					Shallow	**Coastal**	
				Beach seine		**Trawl**	
		Fishing operations number		**9**	**46**	**11**	
Family	**Species**	**Com. status**	**TL-Y1 (cm)**				**Total Beach Seine**
Anguillidae	*Anguilla anguilla*	*C*	26	1 (11%)			1 (2%)
Atherinidae	*Atherina boyeri*	*LC*	4.2		1 (2%)		1 (2%)
	Atherina hepsetus	*LC*	4		1 (2%)		1 (2%)
	Atherina presbyter	*LC*	7.4	4 (44%)	6 (13%)		10 (18%)
Belonidae	*Belone belone*	*LC*	28.8		6 (13%)		6 (11%)
Blenniidae	*Aidablennius sphynx*	*NC*	-		3 (7%)		3 (5%)
Callionymidae	*Callionymus lyra*	*NC*	8.73			1 (9%)	
Carangidae	*Trachinotus ovatus*	*C*	*10*	2 (22%)	11 (24%)		13 (24%)
	Trachurus trachurus	*C-sp*	*8.87*		2 (4%)		2 (4%)
Clupeidae	*Sardina pilchardus*	*C-sp*	*14.07*	1 (11%)	1 (2%)		2 (4%)
Engraulidae	*Engraulis encrasicolus*	*C-sp*	*5.42*		4 (9%)		4 (7%)
Cyprinidae	*Luciobarbus nasus*	*NC*	-	2 (22%)			2 (4%)
Labridae	*Symphodus ocellatus*	*LC*	*6.62*			1 (9%)	
Moronidae	*Dicentrarchus punctatus*	*C*	*14.6*	1 (11%)	1 (2%)		2 (4%)
Sparidae	*Diplodus cadenati*	*C*	*11.5*	1 (11%)	6 (13%)		7 (13%)
	Diplodus sargus	*C*	*12.19*	1 (11%)	1 (2%)		2 (4%)
	Lithognathus mormyrus	*C*	*11.1*		1 (2%)		1 (2%)
	Pagellus acarne	*C*	*8.66*		1 (2%)		1 (2%)
Gobiidae	*Gobius niger*	*NC*	*8*	1 (11%)			1 (2%)
	Pomatoschistus microps	*NC*	*2.86*	4 (44%)		3 (27%)	4 (7%)
Mugilidae	*Chelon auratus*	*C*	*13.5*	7 (78%)	9 (20%)		16 (29%)
	Chelon labrosus	*C*	*16.7*	2 (22%)	4 (9%)		6 (11%)
	Mugil cephalus	*C*	*13*		1 (2%)		1 (2%)
Mullidae	*Mullus barbatus*	*C*	*11.4*		3 (7%)	5 (45%)	3 (5%)
	Mullus surmuletus	*C*	*17.65*	2 (22%)	9 (20%)	3 (27%)	11 (20%)
Scorpaenidae	*Scorpaena maderensis*	*C*	*8.1*			1 (9%)	
Bothidae	*Bothus podas*		*9.92*			6 (55%)	
Citharidae	*Citharus linguatula*	*C*	*7.9*			7 (64%)	
Scophthalmidae	*Scophthalmus maximus*	*C*	*22.9*		1 (2%)		1 (2%)
Soleidae	*Solea senegalensis*	*C*	*9*			1 (9%)	
Rajidae	*Raja brachyura*	*C*	*34.18*			6 (55%)	
Pomatomidae	*Pomatomus saltatrix*	*C*	*29.4*		1 (2%)		1 (2%)
Syngnathidae	*Hippocampus guttulatus*	*NC*	*13.2*			1 (9%)	
	Syngnathus abaster	*NC*	-	2 (22%)			2 (4%)

Com. (Commercial) Status—C: commercial; C-sp: commercial small pelagic; LC: low value; NC: non-commercial; Colours—yellow: YOY; blue: YOY and juvenile1+; grey: adults with YOY or juvenile1+; none: only adults.

dundancy analysis (function '**capscale**' in vegan packageversion 2.6-4; Bray–Curtis distance) (Oksanen *et al.*, 2022). This method was employed as a direct gradient approach in order to analyse the community structure of fish investigated using BT and to determine how much variation in fish assemblages could be explained by environmental variables. Juvenile fish species densities for each fishing haul were used as the input table for the analysis, and the environmental variables considered included depth, gravel percentage, mud percentage, benthic invertebrate biomass and algae densities (three levels).

All statistical analyses were performed using R software 3.4.1. (R Core Team, 2021).

Results

General description of fish assemblages

The surveys conducted during the summers of 2019 and 2020 using a BS and a BT yielded 34 fish species from 23 families. Juveniles constituted a dominant proportion of the densities of 31 species. Most families (70%) had only one species, while Sparidae had the highest number of species (4), followed by Atherinidae and Mugilidae (3), and Carangidae, Gobiidae, Mullidae and Syngnathidae (2). Shallow waters (less than 2 m deep) had the highest species count (21), followed by transition waters (13) and coastal waters (3 to 7 m deep, 11 species). The transition and shallow areas shared eight species, while coastal waters shared only one species with shallow waters and one species with transition systems.

The three most commonly caught species were *Chelon auratus, Mullus surmuletus*, and *Trachinotus ovatus*, with respective total occurrences of 16 (BS only), 14 (BS: 11, BT: 3), and 13 (BS only; Table 1), while 41% of species were caught only once. Most individuals caught were juveniles; 20 species had only YOY, and nine species had larger juvenile1+, of which six were caught by the BT. Adult individuals were present for three Atherinidae species: the common goby (*Pomatoschistus microps*) and *Hippocampus guttulatus*.

Shallow and transition waters

As a result of the BS operations, a total of 24 species were sampled, consisting mainly of juveniles, most of which were YOY. Of these, 14 species were identified in transition waters and 19 in shallow marine waters (Table 2). There was a difference in the number of species between the two sampling periods, with 14 species caught in the summer of 2019 (Sum.19) and 18 species sampled in the summer of 2020 (Sum.20). Fourteen species were common in both periods, two were only present in Sum.19, and nine were only observed in Sum.20.

BS individual haul densities varied between 5 and 1170 individuals per 1000 m^2 during Sum.19 and between 5 and 730 individuals per 1000 m^2 during Sum.20, with a clear difference between the two periods in terms of null hauls (no fish caught). During Sum.19, 18% of the BS hauls were empty, while all Sum.20 fishing hauls yielded fish. Fish densities were less than 60 individuals per 1000 m^2 in 68% of the hauls, while 10% exceeded 500 individuals per 1000 m^2.

The number of fish species observed at each site ranged from one to eight, with the highest values recorded at Amtar during Sum.20 and in the transition waters of Oued Laou during both surveys. The lowest species numbers were observed at Targha and Aouchtam, with one to three species recorded. Most species were observed at one or two sites during each survey (71%), and no more than four sites recorded the same species during the same survey, except for *Trachinotus ovatus*, which was observed at all sites and systems during Sum.20.

Fish densities at each site ranged from 1 to 68 individuals per 1000 m² for 83% of the species. Four species had mean densities greater than 100 individuals per 1000 m²: *Engraulis encrasicolus* at Amtar in both periods, *Pomatoschistus microps* in the transition waters of Oued Laou in Sum.19, *Chelon auratus* in the transition waters of Oued Laou and Chmaala in Sum.20, and *Pagellus acarne* in Amsa during Sum.20.

A PERMANOVA analysis revealed significant differences in fish community composition between surveys and between sites, as well as a significant effect of bottom texture at 2 m deep (Table 3). The presence of algae at the survey sites also had a significant effect. Between-site differences explained the largest proportion of the variance (20%), followed by bottom texture (13%) and between-survey differences (9%). No significant within-site differences were found between fishing operations or between marine and transitional systems. Pairwise comparisons between sites showed significant differences between Amtar and two sites, Chmaala and Oued Laou ($P = 0.008$ for both; Fig. 2).

The BCA focuses on the differences between sites (Fig. 3). A random test estimated that these differences accounted for 21% of the total inertia, which was highly significant ($P < 0.001$), confirming the importance of between-site variation. The first two axes of the BCA explain 64% of the inertia, and the first axis shows significant differences in within-site variability, estimated by the confidence ellipse area. The Amsa and Amtar sites show the greatest variation, while Chmaala, Oued Laou, and Targha show little within-site variability. The first axis is driven by the contrast between Amtar and two correlated sites, Chmaala and Oued Laou, while the second axis is driven by the opposition of Amsa and Amtar. The Amtar site is correlated with four species: *Engraulis encrasicolu*s, *Scophthalmus maximu*s, *Pomatopmus saltatrix*, and *Trachurus trachurus*. The Amsa site is correlated with two other species, *Pagellus acarne* and *Mullus barbatus*, which had the highest positive coordinate values on the axis.2. The Chmaala and Oued Laou sites correlated with the largest number of species grouped into a single group of 14 species.

Coastal waters at 3 m to 7 m deep

Juveniles were the main catch at the different sites. Six species were represented only by Juvenile1+ individuals, while three species had only YOY fish. Adults of *Syngnathus abaster* and *Pomatoschistus microps* were also caught. A single haul at Oued Laou at 3 m deep yielded a high density of unidentified fish larvae, which were entangled in dense macroalgal beds observed in the area (Table 4).

The composition of juvenile fish communities exhibited significant variations among sites, with the presence of algae and the proportion of gravel in the substrate emerging as significant factors influencing this composition (Table 5). The between-site differences had a prominent effect, explaining 55% of the total variance, followed by

Table 2. Fish species mean densities (per 1000 m^2) during the two summer periods in each of the prospected sites using the beach seine (Environment—T: transition; M: marine).

		Summer 2019								Summer 2020							
		Amsa	Aouchtam	O.Laou		Targha	Chmaala		Amtar	Amsa	Aouchtam	O.Laou		Targha	Chmaala		Amtar
	Environment	**M**	**M**	**T**	**M**	**M**	**T**	**M**	**M**	**M**	**M**	**T**	**M**	**M**	**T**	**M**	**M**
	Haul number	4	4	3	4	4	1	4	4	4	4	3	4	4	2	4	4
	Null hauls number	1	2		1	1		1									
Anguillidae	*Anguilla anguilla*											5					
Atherinidae	*Atherina presbyter**	3		5				3				35	1		40	11	
Belonidae	*Belone belone**				5	1		4					1				
Blenniidae	*Aidablennius sphynx*		1													3	1
Carangidae	*Trachinotus ovatus**									4	1	3	4	68	5	18	1
	*Trachurus trachurus**									1							3
Clupeidae	*Sardina pilchardus**			2				5									
Cyprinidae	*Luciobarbus nasus*						50					13					
Engraulidae	*Engraulis encrasicolus**								350								180
Gobiidae	*Gobius niger*			2													
Gobiidae	*Pomatoschistus microps*			463								2					
Moronidae	*Dicentrarchus punctatus*														23		1
Mugilidae	*Chelon auratus*	1		65	3							193	4		448	6	
	Chelon labrosus	34	15	8	1				8								
	Mugil cephalus												1				
Mullidae	*Mullus barbatus*									33				1			
	Mullus surmuletus				3				13	25		15	3				49
Pomatomidae	*Pomatomus saltatrix*																1
Scophthalmidae	*Scophthalmus maximus*								5								
Sparidae	*Diplodus cadenati*											13		8		5	1
	Diplodus sargus			2					3								
	Lithognathus mormyrus															3	
	Pagellus acarne									125							
Syngnathidae	*Syngnathus abaster*			3													
	Species number	3	2	8	4	1	1	3	5	5	1	8	6	3	4	6	8
	Density Pelagic species*	3	0	7	5	1	0	12	350	5	1	38	6	68	45	29	184
	Density Bottom species	35	16	543	7	0	50	0	29	183	0	241	8	9	471	17	53

Table 3. Permutational multivariate analysis of variance table of relative densities of the juvenile communities investigated using the beach seine in shallow waters in transition and marine environments.

	Df	Sum Of Sqs	R^2	F	Pr (>F)
Year	1	1.6307	0.09283	4.9001	0.001
Site	5	3.464	0.1972	2.0819	0.001
Bottom texture	4	2.294	0.13059	1.7233	0.011
Algae	1	0.5907	0.03363	1.775	0.024
Site: environment	2	0.8887	0.05059	1.3353	0.121
Site: fishing haul	21	6.0356	0.3436	0.8637	0.833
Residual	8	2.6622	0.15156		
Total	42	17.5659	1		

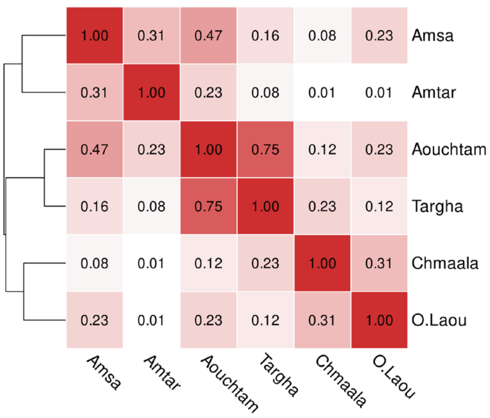

Fig. 2: Pairwise comparisons between sites (with P values) based on permutational multivariate analysis of variance of relative juvenile fish community composition surveyed by beach seine.

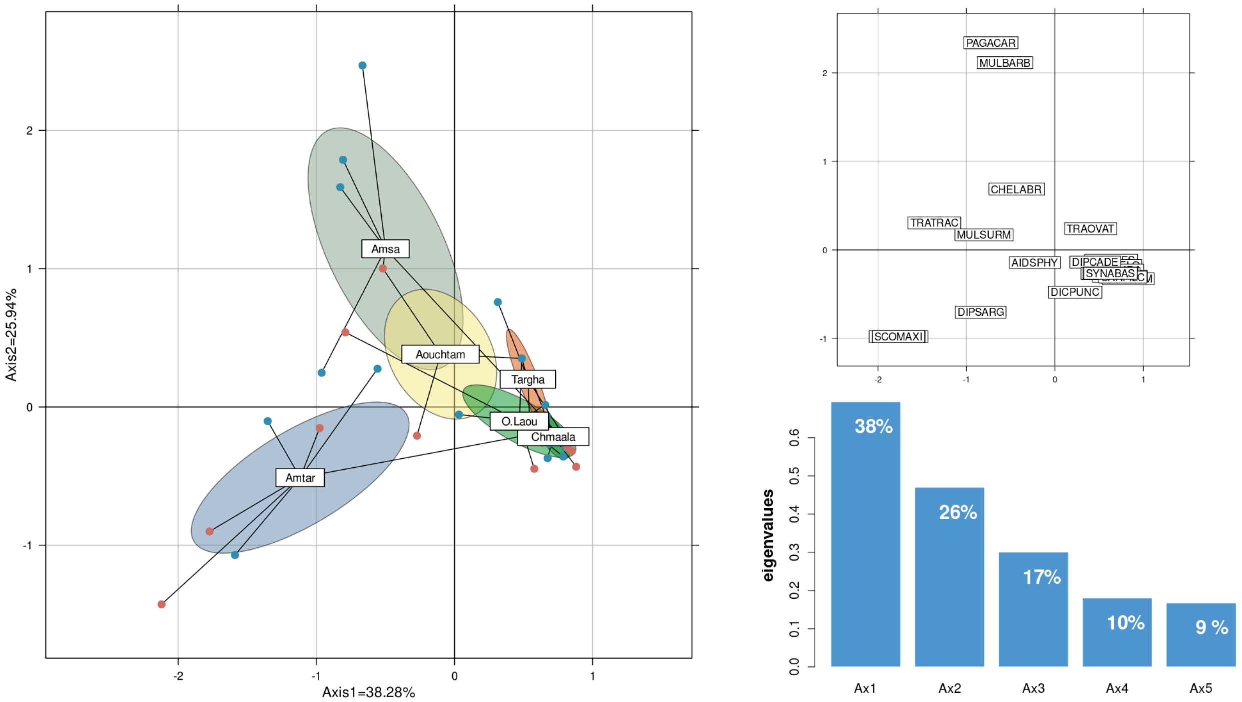

Fig. 3: Factorial map of the first two axes (64.2% of the total inertia) of the between-class correspondence analysis, which focuses on differences between sites. The Amsa and Amtar sites showed the greatest within-site variability in juvenile fish assemblages and differed from the other sites. Left: Factorial map of sites with fish hauls as points (red: summer 2019; blue: summer 2020). Top right: Species factorial map. Bottom right: Eigenvalues bar plot.

Table 4. Fish species and associated taxa densities (per 30 min) during the summer 2020 period in each of the prospected sites using the beam trawl. Associated taxa are shown at a lower taxonomic level.

		Site	**Amsa**			**O.Laou**			**Chmaala**			**Amtar**		
		Depth (m)	**3**	**5**	**7**	**3**	**5**	**7**	**3**	**5**	**7**	**5**	**7**	**Total**
Class	**Family**	**Species**												
Actinopteri	Callionymidae	*Callionymus lyra*					1							**1**
	Labridae	*Symphodus ocellatus*					2							**2**
	Gobiidae	*Pomatoschistus microps*			1		1					1		**3**
	Mullidae	*Mullus barbatus*							17	44	8	94	65	**228**
		Mullus surmeluttus						4	2			1		**7**
	Scorpaenidae	*Scorpeana maderensis*						1						**1**
	Bothidae	*Bothus podas*	5	1	4		2					8	1	**21**
	Citharidae	*Citharus linguatula*	4	1			1			14	16	3	5	**44**
	Soleidae	*Solea senegalensis*			1									**1**
	Rajidae	*Raja brachyura*						1	3	7	4	4	3	**22**
	Syngnathidae	*Hippocampus guttulatus*									1			**1**
		Fish Larvae				273								**273**
Asteroidea		Starfish								1				**1**
Cephalopoda	Sepiidae	*Sepia officinalis*		1										**1**
Gastropoda		Gastropods										1		**1**
Malacostraca		Shrimps				3		11			1			**15**
		Crabs		1		5		2		8		35	6	**57**
Ophiuroidea		Ophiuroids									31		8	**39**

Table 5. Permutational multivariate analysis of variance table of relative densities of the juvenile communities investigated using the beam trawl.

	Df	***Sum Of Sqs***	***R^2***	***F***	***Pr (>F)***
Site	3	2.0627	0.55402	4.1584	0.003
Gravel proportion	1	0.4915	0.13201	2.9725	0.002
Algae	2	0.6392	0.1717	1.9331	0.038
Depth	1	0.0337	0.00904	0.2036	0.986
Residual	3	0.496	0.13323		
Total	10	3.723	1		

the presence of algae (17%) and the proportion of gravel (13%). The first factorial plan of the redundancy analysis explained 88.84% of the total inertia and showed that the Oued Laou site had a highly variable catch composition, while the other sites had catches of similar composition. The fishing haul performed at 3 m depth at Oued Laou correlated with the presence of algae and the proportion of gravel in a gravelly-sand substrate. The Oued Laou 5 m sample had a composition close to that of the Amsa samples, which were grouped together apart from the other sites. The Chmaala and Amtar fishing hauls had a close fish community composition and correlated with the benthic invertebrate density and mud proportion (Fig. 4).

Discussion

The Alboran MPA's coastal areas are home to diverse geomorphological structures, including sandy beaches, pebble beaches and cliffs. In this study, only beaches were surveyed primarily due to the sampling method used, which involved a BS. This fishing gear has been successfully used in transition systems to study YOY fish (Nicolas *et al.,* 2010), which tend to concentrate in the first 2 m of depth (García-Rubies & Macpherson, 1995; Matić-Skoko *et al.,* 2022; Planes *et al.,* 1999). The BT was introduced during the second summer period to provide additional information on fish settlement in deeper waters. The surveys were conducted during the peak settlement period of many fish species, which occurs in spring and early summer (Masski, 2015), a pattern common to Mediterranean species (Biagi *et al.*, 1998; Dulčić *et al.*, 1997, 2007; García-Rubies & Macpherson, 1995). Two of the surveyed sites are outside the MPA, but the protection effect of the MPA on juveniles has not been tested as the MPA management plan has never been im-

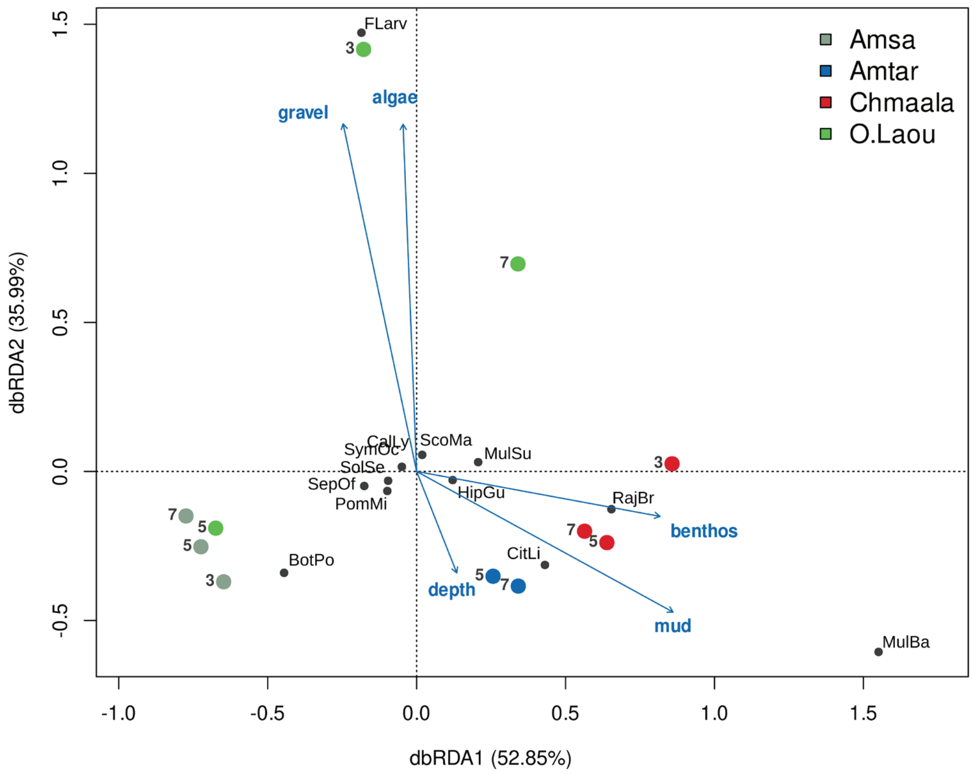

Fig. 4: Distance-based redundancy analysis of juvenile fish communities sampled with a beam trawl at four sites and three depths. Coloured dots with numbers: hauls with corresponding depth; arrows: explanatory variables (algae: density of algae; gravel: percentage of gravel in bottom texture; mud: percentage of mud in bottom texture; benthos: total biomass of benthic invertebrates), Black dots: species (BotPo: Bothus podas; CalLy: Callionymus lyra; CitLi: Citharus linguatula; HipGu: Hippocampus guttulatus; MulBa: Mullus barbatus; MulSu: Mullus surmuletus; PomMi: Pomatoschistus microps; RajBr: Raja brachyura; ScoMa: Scorpaena maderensis; SepOf: Sepia officinalis; SolSe: Solea senegalensis; SymOc: Symphodus ocellatus; FLarv: fish larvae).

plemented, and the protection measures are not enforced (Dahou *et al.*, 2023).

Juvenile fish were observed in various sampled habitats within the surveyed area, with variations in both species richness and fish densities occurring not only between sites but also within sites, particularly between transition systems and shallow coastal areas. The occurrence of YOY fish was particularly higher in areas at less than 2 m. Depths between 3 m and 7 m hosted larger juveniles, with the exception of a large number of fish larvae that were hosted in seaweeds and brought up from the 3 m depth at Oued Laou. These differences could result from differences in catchability between the two fishing gears, with the BT selectively targeting larger individuals. Such selection was not observed in French estuaries surveyed using a BT with the same characteristics (Selleslagh *et al.*, 2009), suggesting that YOY densities are lower in the deeper waters between 3 m and 7 m compared to shallow waters. The survey results obtained with these two fishing gears appeared to be complementary in assessing the community composition of juvenile fish in this coastal area. Indeed, the use of a multi-gear approach, in particular the combination of BS and BT, is recognised as a robust method for assessing the structure of fish communities in coastal areas (Adao *et al.*, 2022; Franco *et al.*, 2012).

The transition systems appeared to be the most favourable environment for YOY fish, with high species richness and the highest densities of economically important species (e.g., *Dicentrarchus punctatus*, *Diplodus cadenati*, and *Chelon auratus*). Estuaries and lagoons are known to be important nursery grounds (e.g., Able, 2005; Arevalo *et al.*, 2023; Beck *et al.*, 2001; Dahlgren *et al.*, 2006; Nagelkerken *et al.*, 2015; Sheaves *et al.*, 2015), and this importance is not compromised in the Alboran MPA due to their limited number, depth, and surface area. Shallow coastal areas were also important nursery grounds, which is a common feature in Mediterranean ecosystems (Cheminée *et al.,* 2021; García-Rubies & Macpherson, 1995; Matić-Skoko *et al.,* 2022; Planes *et al.,* 1999), with 45% of the species occurring only in these areas. Soft-bottom beaches with varying proportions of gravel within 2 m of depth showed variable species composition and densities in settling fish, resulting in clear differences in YOY fish communities composition, with significant year-to-year differences. Fish species showed variable distributions, with most species occurring at low densities in most sites, some at high densities in one site (e.g., *Pagellus acarne* in Amsa or *Engraulis encrasicolus* in Targha), and one at low densities in all the sites during the same survey (*Trachinotus ovatus*). Exclusive pebble and gravel beaches with clear water were the least attractive areas for YOY fish, showing the lowest number of species and densities within the first 2 m of depth. The juvenile fish communities from the deeper waters (3-7 m) showed a different species composition with the presence of rays and flatfish (Bothidae, Citharidae and Soleidae), and the bottom structure appeared to be the main driver of the composition and the spatial organisation of juvenile communities.

Our results suggest that, although there are clear differences between the surveyed habitats, all habitat types on the studied coast have the potential to serve as nursery areas for fish. Juvenile fish settle in specific micro-habitats according to their preferences (bottom structure and composition, food and shelter) and then expand their habitat use with their ontogenetic development (Félix-Hackradt *et al.*, 2014; Vigliola & Harmelin-Vivien, 2001; Welsh *et al.*, 2013). The observed spatial and temporal variability in juvenile communities is likely related to variations in abundance, growth, and mortality of juvenile fish due to natural stochastic processes (Planes *et al.,* 1999; Macpherson *et al.,* 1997; Vigliola *et al.*, 1998) associated with environmental conditions such as currents, winds, and hydrological parameters (Cuadros *et al.,* 2018; Félix-Hackradt *et al.,* 2013). Adult reproductive success, which can vary considerably between sites and years (Pankhurst & Munday, 2011), further influences these dynamics. Therefore, the effectiveness of a site's nursery function can vary over time (Vigliola *et al.,* 1998), and the productivity of a habitat as a nursery may vary from site to site (Cuadros *et al.,* 2018).

The concept closely in line with our results is the seascape nursery approach, which emphasises the importance of multiple functionally connected habitats for fish nurseries (Nagelkerken *et al*., 2015). The effectiveness of this concept has been observed in other Mediterranean areas, where the presence of diverse habitats and interfaces has been confirmed as crucial for the comprehensive development of all juvenile life stages of fish (Cheminée *et al.,* 2021). Early designations of nurseries referred to habitats with higher densities of juveniles (e.g., Gunter, 1967; McHugh, 1976; Weinstein, 1979; Weinstein *et al.,* 1980), underestimating habitats with large surface areas but low densities of organisms, despite their potentially high overall contribution to the adult population (Dahlgren *et al.,* 2006). Approaches that have traditionally considered nursery habitats as uniform entities have failed to quantify their role in the context of dynamic processes such as ontogenetic change, spatially explicit patch and corridor use, and food resource exchange (Childers *et al.,* 2002; Deegan *et al.,* 2002; Nagelkerken *et al.,* 2015). In our study, none of the sites or habitats surveyed had the appearance of being a hotspot of settling individuals of one or more species. Different species shared different habitats, from transition systems to coastal waters, while others were only present in a specific habitat. This situation is consistent with the view that the value of a nursery is often the result of a complex mosaic of multiple interacting habitats (Berkström *et al.,* 2012; Sheaves, 2009).

Conclusion

The Alboran MPA coastline acts as a nursery for a wide range of species. Different habitats surveyed within the transition systems, shallow and coastal waters down to 7 m deep, were valuable in contributing to this nursery function. Other coastal habitats that still need to be surveyed for a comprehensive assessment of the nursery function of the whole MPA may also provide optimal conditions for YOY fish, particularly cliff-side areas with underwater boulders. Considering that the effectiveness of the protection of fish nurseries relies on the sequence of habitats that a species uses during ontogeny, it is essential to improve the protection regime within this MPA, especially in waters less than 20 m deep where the use of commercial BS and artisanal dredges are still allowed in order to better protect juvenile fish and their habitat. The emergency to act is dictated by the low densities of juvenile fish, which appeared to be a common feature shared by all species and habitats.

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