

## Digenea community structure of the Salema, *Sarpa salpa* (Linnaeus, 1758) (Teleostei, Sparidae), from the Central coast of Algeria

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### Summary

The main goal of the current work was to describe and analyse the Digenean community structure in *Sarpa salpa*. A total of 114 specimens of *S. salpa* were collected from the Central Coast of Algeria at six localities. The fish were immediately transported to the laboratory to be examined for digeneans. From 107 of the 114 *S. salpa* examined, a total of 8,722 specimens of seven species belonging to three families were recovered. Among them, *Robphildollfusium fractum* and *Mesometra orbicularis* were the most prevalent and abundant species. Moreover, *Lepocreadium album* was found for the first time in *S. salpa* from the coast of Algeria, and *Centroderma spinosissima* and *Wardula capitellata* represent new parasites to the Algerian digenean fauna that infect teleost fish. The component community of these Digeneans is characterised by *R. fractum* as its dominant species representing 62% of the total number of collected Digeneans, as well by a Shannon diversity index ( $H'$ ) and Dominance Simpson index ( $D$ ) of 1.03 and 2.23, respectively. According to Spearman's correlation test, *Mesometra brachycoelia* and *W. capitellata* were negatively correlated to the host biological factors. On the other hand, *R. fractum* showed a positive correlation between its mean abundance and the total length of the fish. With these findings, we provided the component structure of the Digenean fauna of *S. salpa* and highlighted their diversity, contributing to the biodiversity of the parasitic Platyhelminthes in Algeria.

**Keywords:** *Sarpa salpa*; Digenea; Algeria; component community; infracommunity

### Introduction

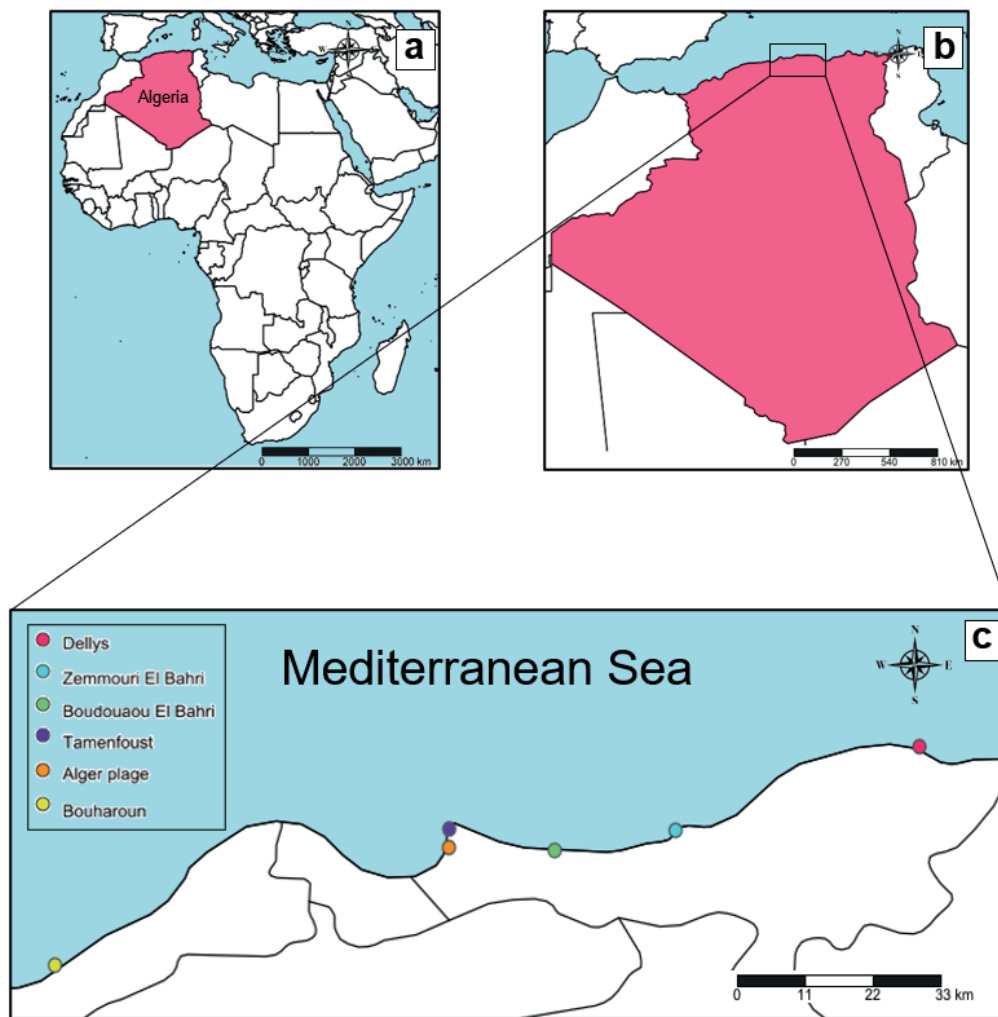
Parasitism is one of the most successful modes of life. Every free-living metazoan carries at least one species of parasite (Poulin & Morand, 2000). The latter's diversity is an important selective force shaping communities and ecosystems (Poulin, 2015). Parasitology seems to be a rising discipline in Algeria, especially fish parasitology. Over the past ten years, researchers have developed a keen interest in the parasitic Platyhelminthes of fish, notably in

their Digenean fauna. Several fish families have been examined in Algerian shores including Sparidae (Marzoug, 2012; Bellal *et al.*, 2016; Benhamou *et al.*, 2017; Hadjou *et al.*, 2017; Rima *et al.*, 2017; Bellal *et al.*, 2018; Ider *et al.*, 2018; Abid-Kachour *et al.*, 2019), Mugilidae (Marzoug *et al.*, 2014), Moronidae (Brahim Tazi *et al.*, 2016), Mullidae (Brahim Tazi *et al.*, 2009; Hassani *et al.*, 2014; Gharbi *et al.*, 2023), Carangidae (Ichalal *et al.*, 2017), and Phycidae (Hassani *et al.*, 2020). This group of parasites (i.e. trematodes) is known to include the highest number of species among

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endoparasitic helminths. Carlson *et al.* (2020) estimated the existence of 103,078 species of helminths endoparasites with 44,262 trematodes, of which only 14 % have been described to date. The focus of this study is the digenean species of *Sarpa salpa* (Linnaeus, 1758), also known as Salema or Chelba in Algeria, which is a common Sparidae found along the eastern Atlantic Ocean and Mediterranean Sea shores. It is the only representative species of the genus *Sarpa* Bonaparte, 1831 (Parenti, 2019). Early works on the Digenean parasites of this fish were focused on Italian waters and were limited to taxonomic studies (Rudolphi, 1819; Stossich, 1883, 1887, 1888; Monticelli, 1892; Stossich, 1898). Researchers have studied the distribution and characteristics of these parasites in various geographical locations. Noteworthy contributions include investigations conducted in France by Timon-David and Bartoli

(Timon-David, 1937; Bartoli, 1987b, 1987a; Bartoli *et al.*, 2005). Additionally, research efforts have been documented in Spain (López-Roman & Guevara Pozo, 1974; Gijon-Botella & Lopez-Roman, 1989; Lozano *et al.*, 2001), in Greece (Papoutsoglou, 1976), in Turkey (Akmirza, 2001, 2013; Tepe & Oğuz, 2013), in Tunisia (Gargouri Ben Abdallah & Maamouri, 2008; Gargouri Ben Abdallah *et al.*, 2011; Derbel *et al.*, 2012), in Montenegro (Radujkovic & Sundic, 2014) and in Senegal (Diagne, 2016). Moreover, the most recent was undertaken by Santoro *et al.* (2020) in Italy. In the Algerian coastline, there hasn't been any research on the Digenean fauna parasitising this fish other than Dollfus's study in 1947 (Dollfus, 1947), leaving these parasites unexplored. Therefore, the main goal of the current work is to describe and analyse the Digenean community structure infecting *Sarpa salpa*.



(a) Africa, Algeria in pink, (b) Central coast of Algeria, (c) Collection sites

Fig. 1. Collection sites of *Sarpa salpa* (n=114) from the Central coast of Algeria [Created by <https://www.simplemappr.net>. Accessed June 04, 2023]

## Material and Methods

### Study area and fish sampling

Between April 2021 and May 2023, a total of 114 fresh specimens of *S. salpa* were bought from local fish markets in the Central coast of Algeria at six localities, where the temperature of the water ranged between 13°C and 26°C (Fig. 1): Alger plage (36° 46' 52.180" N, 3° 13' 45.644" E), Tamenfoust (36° 48' 19.962" N, 3° 13' 47.193"), Boudouaou El Bahri (36° 46' 38.232" N, 3° 23' 1.975" E), Bouharoun (36° 37' 33.625" N, 2° 39' 12.444" E), Zemmouri El Bahri (36° 48' 11.596" N, 3° 33' 39.165" E), and Dellys (36° 54' 54.512" N, 3° 55' 0.240" E).

The fish were immediately brought to the laboratory (Laboratoire de Biodiversité et Environnement: Interactions - Génomes (LBEIG), FSB - USTHB) for examination. The weight and the total length were noted and expressed as the range followed by the mean  $\pm$  the standard deviation in parentheses. The digestive tract was removed from each fish and observed under a stereomicroscope (Carl Zeiss™Stemi™2000 Stereomicroscope, Germany) in order to collect the Digenean parasites.

### Digenea processing and identification

All the Digenean found were slightly flattened between a slide and coverglass, fixed with Bouin-Hollande fixative, stored in 70 % ethanol and then stained in boracic carmine, dehydrated in an ethanol series with increasing concentrations (70, 96 and 100 %), cleared in clove oil, and mounted in Canada balsam. We identified the Digenean species via the keys given by Gibson *et al.* (2005) and deposited representative specimens of each species in the collection of the Natural History Museum (NHM), London, United Kingdom.

### Parasitological and biodiversity descriptors of Digenea communities

We analysed the structure of the Digenean communities of *S. salpa* at two levels: the component community, i.e., all the parasite species exploiting a host population and the infracommunity, i.e., all the parasite species found in an individual host (Bush *et al.*, 1997). The ecological descriptors for both levels were calculated as Margolis *et al.* (1982) and Bush *et al.* (1997) indicated, those are: prevalence, mean abundance, infection's mean intensity and range. In addition to that, the Digenean species were categorised based on their prevalence into core (prevalence  $\geq$  66.6 %), secondary (33.3 % < prevalence < 66.6 %), and satellite species (prevalence  $\leq$  33.3 %) (Bush & Holmes, 1986).

We also analysed the component community in terms of biodiversity indices, typically employed to compare communities, following Magurran (2004). We used the species richness (S), Shannon-Wiener Species Diversity Index (H'), Evenness Shannon-Wiener (J) to describe the variability in species abundances, Dominance Simpson index (D) to measure the dominance of species within the community, and Berger-Parker index (BP) to express the proportional abundance of the most abundant species. For the

infracommunity, we calculated the mean species richness and the mean number of parasites per host.

Species accumulation curve was generated by R software version 4.2.2 (Team, 2022) with the aid of the package 'vegan' version 2.6-2 (Oksanen *et al.*, 2022). We also estimated the species richness of the component community by using Chao, Jackknife 1 and Jackknife 2 estimators by the same package.

### Statistical analysis

The Sturges' rule was applied to determine the weight and length classes, and accordingly, two statistical tests were performed: a Chi-square test (Pearson, 1900) to evaluate any significant differences regarding prevalence between hosts of different weight / total length classes and a Spearman's correlation test to assess how the host's weight or length affect the mean abundance and mean intensity of each species. All tests were conducted using IBM SPSS Statistics (Version 26) (IBM, 2019) and a significance level of  $p \leq 0.05$  was applied.

### Ethical Approval and/or Informed Consent

Ethical approval is not applicable to this study as fish samples used were bought from fisheries and fish markets in Algeria.

## Results

### Morphological description of the Digenean species

Using morphological features, seven Digenean belonging to three families were identified to the species level: *Lepocreadium album* (Stossich, 1890) Stossich, 1904; *Centroderma spinosissima* (Stossich, 1883) Lühe, 1901; *Elstia stossichianum* (Monticelli, 1892) Bray, 1984; *Mesometra brachycoelia* Lühe, 1901; *Mesometra orbicularis* (Rudolphi, 1819) Lühe, 1902; *Wardula capitellata* (Rudolphi, 1819) Poche, 1926 and *Robphildollfusium fractum* (Rudolphi, 1819) Paggi and Orecchia, 1963 (Fig. 2). While *L. album* is collected for the first time from *S. salpa* at the coast of Algeria, *C. spinosissima* and *W. capitellata* are new parasites to the Algerian Digenean fauna that infect teleost fish.

**Family:** Lepocreadiidae Odhner, 1905

**Species:** *Lepocreadium album* (Stossich, 1890) Stossich, 1904 (Fig. 2a)

**Voucher material:** 1 voucher specimen deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.5).

**Description:** Based on 20 whole-mount specimens. Body elongated. Eye-spot pigment present, scattered at the level of pharynx. Tegument spined. Oral sucker subterminal, round. Ventral sucker subglobular, smaller than oral sucker, in mid-body. Prepharynx present. Pharynx muscular, large. Oesophagus short. Caeca terminating close to posterior extremity. Testes two, entire, rounded, intercaecal. Excretory pore dorso-subterminal ; vesicle I -shaped reaches to intestinal bifurcation.

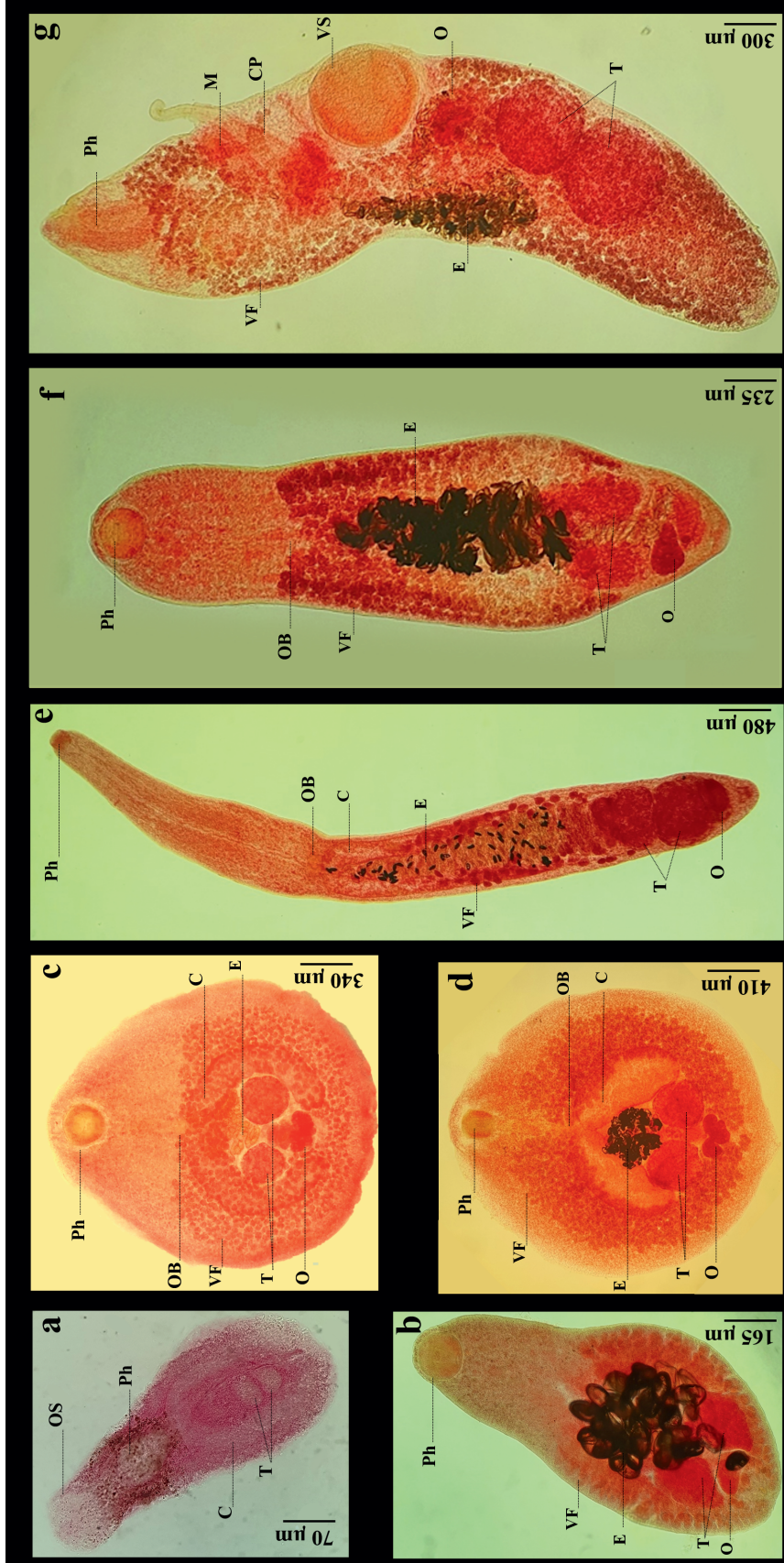


Fig. 2. The Digenean parasites infecting *Sarpa salpa* from the Central coast of Algeria: (a) *Lepocreadium album* (Ventral view), (b) *Centroderma spinosissima* (Ventral view), (c) *Mesometra orbicularis* (Ventral view), (d) *Mesometra orbicularis* (Lateral view), (e) *Elsia sfossichianum* (Ventral view), (f) *Robophilolusium fractum* (Lateral view), (g) *Robophilolusium fractum* (Ventral view). (Ph) Pharynx, (OB) Oesophageal bulb, (T) Testes, (O) Ovary, (M) Metaterm, (CP) Cirrus pouch, (C) Ceraea, (VS) Ventral sucker, (VF) Vitellarium follicles, (E) Eggs

**Family:** Mesometridae Poche, 1926

**Species:** *Centroderma spinosissima* (Stossich, 1883) Lühe, 1901 (Fig. 2b)

**Voucher material:** 1 voucher specimen deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.8).

**Description:** Based on 10 whole-mount specimens. Body elongate, slightly constricted at level of intestinal bifurcation. Tegument spined. Pharynx round, subterminal. Oesophagus long, narrow. Oesophageal bulb present, barely visible. Caeca almost parallel, diverge around testes. Testes two, oval, entire, symmetrical, pre-ovarian, separated by uterine coils, in posterior third of body. Ovary oval, entire, post-testicular, near posterior extremity. Uterus intercaecal, pre-ovarian filled with eggs. Vitellarium follicles, reaching from level of intestinal bifurcation to posterior extremity, confluent in post-ovarian region. Eggs numerous, large, without polar filament.

**Family:** Mesometridae Poche, 1926

**Species:** *Mesometra orbicularis* (Rudolphi, 1819) Lühe, 1901 (Fig. 2c)

**Voucher material:** 2 voucher specimens deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.1-2).

**Description:** Based on 25 whole-mount specimens. Body flattened, discoid. Tegument spined only on ventral surface. Pre-oral lobe distinct. Pharynx subterminal, spherical. Oesophagus long, narrow. Oesophageal bulb present. Caeca terminating near the posterior end, enclosing testes and ovary. Testes two, rounded, symmetrical, separated by uterus, intercaecal, pre-ovarian, in the posterior third of the body. Ovary tetralobed, median, post-testicular, Uterus intercaecal, pre-ovarian. Vitellarium follicles extending from oesophageal bulb to the posterior end, confluent in post-ovarian region. Eggs small, oval, without polar filament.

**Family:** Mesometridae Poche, 1926

**Species:** *Mesometra brachycoelia* Lühe, 1901 (Fig. 2d)

**Voucher material:** 1 voucher specimen deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.9).

**Description:** Based on 25 whole-mount specimens. Body flattened, disk-shaped. Tegument spined only on ventral surface. Pre-oral lobe distinct. Pharynx subterminal, spherical. Oesophagus long, narrow. Oesophageal bulb present. Caeca terminating near the anterior margin of the testes. Testes two, rounded, symmetrical, separated, intercaecal, pre-ovarian, in the posterior third of the body. Ovary tetralobed, median, post-testicular. Uterus intercaecal, pre-ovarian. Vitellarium follicles extending from near posterior margin of pharynx to posterior end, confluent in post-ovarian region. Eggs small, oval, without polar filament.

**Family:** Mesometridae Poche, 1926

**Species:** *Wardula capitellata* (Rudolphi, 1819) Poche, 1926 (Fig. 2e)

**Voucher material:** 1 voucher specimen deposited in the Natural

History Museum, London, United Kingdom (NHM 2023.6.8.6).

**Description:** Based on 15 whole-mount specimens. Body elongate with rounded extremities. Tegument armed. Eye-spot pigment present, in the anterior third of body. Pharynx terminal. Oesophagus very long. Oesophageal bulb small, well developed. Caeca straight, narrow, reaching level of anterior margin of anterior testis. Testes two, oval to rounded, entire, in tandem, contiguous, pre-ovarian. Genital pore immediately posterior to pharynx. Ovary spherical, entire, post-testicular, contiguous with posterior testis or separated from it by loop of uterus, near posterior extremity. Uterus intercaecal, pre-ovarian. Vitellarium follicles in 2 lateral fields, in small number, extending between anterior testis and mid-body. Eggs numerous, without polar filament.

**Family:** Mesometridae Poche, 1926

**Species:** *Elstia stossichianum* (Monticelli, 1892) Bray, 1984 (Fig. 2f)

**Voucher material:** 1 voucher specimen deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.7).

**Description:** Based on 20 whole-mount specimens. Body elongate, slightly constricted at level of intestinal bifurcation. Tegument spined. Pharynx rounded, subterminal. Oesophagus long, narrow. Oesophageal bulb present. Caeca almost parallel, reaching anterior margin of testes. Testes two, oval, entire, symmetrical, pre-ovarian, separated by uterus, in posterior third of body. Ovary oval, entire, post-testicular, near posterior extremity. Uterus intercaecal, pre-ovarian filled with eggs. Vitellarium follicles, reaching from level of intestinal bifurcation to mid-level of testes. Eggs numerous, large, with long polar filament.

**Family:** Gyliuchenidae Fukui, 1929

**Species:** *Robphildollfusium fractum* (Rudolphi, 1819) Paggi & Orecchia, 1963 (Fig. 2g)

**Voucher material:** 2 voucher specimens deposited in the Natural History Museum, London, United Kingdom (NHM 2023.6.8.3-4).

**Description:** Based on 25 whole-mount specimens. Body fusiform, long, with both ends tapered. Tegument smooth, lacking spines. Oral sucker absent. Pre-oral lobe distinct. Ventral sucker subspherical, usually protuberant at mid-body level or slightly posterior. Pharynx subterminal, long. Oesophagus sigmoid, long, with a thick wall surrounded by glandular cells. Oesophageal bulb well developed, oval. Intestinal bifurcation in mid-forebody, immediately posterior to the oesophageal bulb. Caeca terminating at the posterior third of the body. Testes two, oval to round, entire, in tandem, contiguous, post-ovarian, in mid-hindbody. Cirrus-sac present, in forebody, anterior to ventral sucker. Ovary trilobate to tetralobate, entire, pre-testicular. Metraterm present, surrounded by glandular cells. Uterus filled with numerous eggs. Vitellarium follicles, extending from posterior margin of pharynx to posterior end.

#### **Analysis of the Digenean community structure**

A total of 8,722 specimens of seven Digenean species were recovered from 107 of the 114 *S. salpa* examined, representing an

overall prevalence of 93.86 % and a mean intensity of 81.51 parasites per fish.

Each Digenean's prevalence, mean intensity, mean abundance, and range of intensity are listed in Table 1. *Robphildollfusium fractum* (88.6 %) and *M. orbicularis* (81.58 %) were the two most prevalent species which also had the highest mean abundances of 47.61 and 13.73, respectively. Both of them are considered core species (prevalence  $\geq 66.6$  %). The remaining Digenean are referred to as satellite species (prevalence  $\leq 33.3$  %) with the exception of *M. brachycoelia*. Moreover, *R. fractum* showed the highest mean intensity with 53.74 individuals per infected host and *W. capitellata* presented the least.

No single infected fish has been found to be parasitized with all the species at once. Regardless, all of them had at least one Digenean species: 10.28 % had one, 28.97 % had two, 36.45 % had three, 18.96 % had four and 5.61 % had five. The most encountered infection was the one with three Digenean species with *R. fractum*, *M. orbicularis* and *M. brachycoelia* as the most frequent species composition. Co-infections with only *R. fractum* and *M. orbicularis* were the second most frequent composition, whereas the least prevalent composition is observed in a single fish (0.93 %) which might involve two, three or five species (Table 2).

The examined fish weighed 73.5 – 752 g ( $304.57 \text{ g} \pm 140.25$ ) and measured (Total length) 17.5 – 37.8 cm ( $27.22 \text{ cm} \pm 4.35$ ). Using

### Species accumulation curve

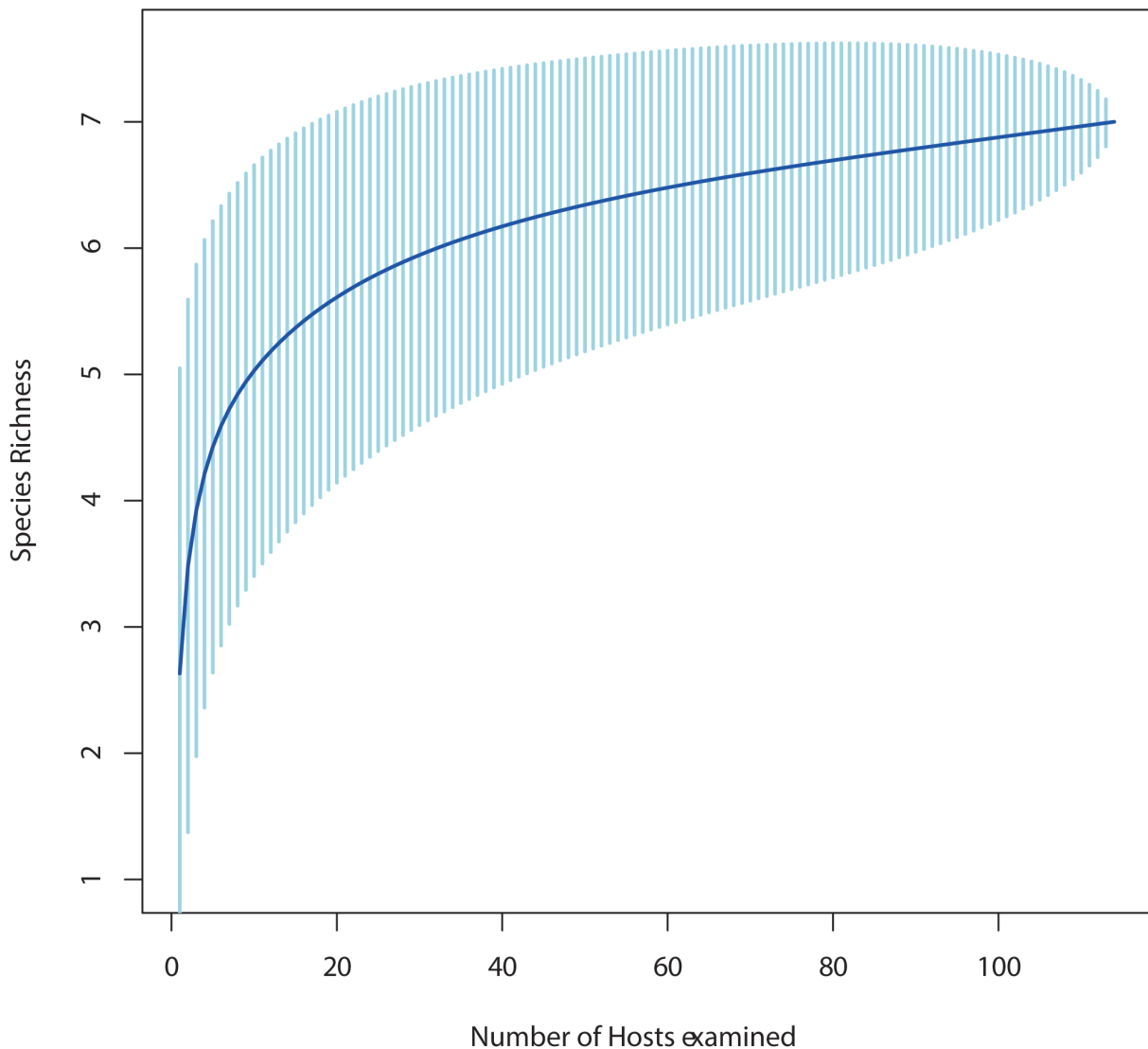


Fig. 3. Species accumulation curve used to evaluate the sampling effort of *Sarpa salpa* (n = 114) from the Central coast of Algeria and the number of species found.

the Sturges' rule, 7 classes were obtained for both weight and total length. The relative data for each class are given in Tables 3 and 4. The Chi-Square test revealed that there were no significant differences between species prevalence with either the host's weight and/or its total length except for one species, *W. capitellata* with ( $\chi^2 = 22.475$ ,  $p = 0.001$ ) and ( $\chi^2 = 24.229$ ,  $p = 0.000$ ), respectively (Table 5). According to Spearman's correlation test, a significant correlation was observed in 3 species (see Table 6). *Robphildollfusium fractum* was the only species presenting a positive strong correlation ( $r_s = 0.786$ ,  $p = 0.036$ ) between its mean abundance and the total length of the host. Additionally, the mean intensity of *M. brachycoelia* seems also correlated negatively to the host's length ( $r_s = -0.857$ ,  $p = 0.014$ ). A relatively strong negative correlation is also observed between the mean abundance of *W. capitellata* and both weight and total length of the fish examined, as well as between its mean intensity and the weight and length.

The component community of these Digeneans is characterised by *R. fractum* as its dominant species representing 62 % of the total number of collected Digeneans, as well by a Shannon diversity index ( $H'$ ) and Dominance Simpson index ( $D$ ) of 1.03 and 2.23, respectively (Table 7). Although the Chao estimator expected the same species richness as the one observed (Table 8), this was not the case for Jackknife 1 and Jackknife 2, indicating that more species are ought to be found. And, according to the species accumulation curve (Fig. 3), the majority of the Digenean species of the component community are retrieved, however the sampling effort wasn't quite enough; the curve didn't reach a plateau.

## Discussion

Seven Digenean species that infect Salema *S. salpa* were identified in this study. All their morphological features agree with the diagnosis provided by Gibson *et al.* (2005). But, we also relied on other descriptions to confirm the identification of these species (Palombi, 1931; Bartoli, 1987a). Furthermore, *C. spinosissima* and *W. capitellata*, two of the recovered species, are reported for the first time on the coast of Algeria, unlike *L. album* which has

previously been collected from the Algerian coastline (Marzoug, 2012; Bellal *et al.*, 2016; Benhamou *et al.*, 2017; Bellal *et al.*, 2018; Abid-Kachour *et al.*, 2019) but never from *S. salpa*; therefore, this is its second encounter in this host since 1980 (Fischthal, 1980). The remaining 4 species were already found by Dollfus in 1947 (Dollfus, 1947). However, he identified two specimens as *C. spinosissima* but he clearly stated that their eggs had polar filament. The latter is a key character of another mesometrid found also in *S. salpa*, *E. stossichianum*, this has led us to conclude that the specimens that he collected are indeed *E. stossichianum* and not *C. spinosissima*. With this finding, our study extended the knowledge of the biodiversity of the Algerian digenean fauna infecting *S. salpa* from four to seven species.

In this work, *R. fractum* exhibited the highest values in terms of prevalence, mean abundance and mean intensity. Similar tendency was observed in the study carried out by Bartoli *et al.* (2005) in Corsica as well as the one conducted by Santoro *et al.* (2020) along the Italian coast; while in other investigations, this species was either the most prevalent and abundant (Gargouri Ben Abdallah & Maamouri, 2008) or it displayed the highest values of mean abundance and mean intensity (Derbel *et al.*, 2012; Diagne, 2016). In comparing our results with prior studies, we noted variations in the values of parasitological descriptors. Our findings revealed the lowest values for *C. spinosissima* and the highest values for *R. fractum* compared to previous investigations (Lozano *et al.*, 2001; Bartoli *et al.*, 2005; Gargouri Ben Abdallah & Maamouri, 2008; Gargouri Ben Abdallah *et al.*, 2011; Derbel *et al.*, 2012; Antar & Gargouri Ben Abdallah, 2018; Santoro *et al.*, 2020). For *E. stossichianum*, except for the studies conducted by Lozano *et al.* (2001) and Gargouri Ben Abdallah *et al.* (2011), the prevalence value was higher than those reported in Corsica (Bartoli *et al.*, 2005), Tunisia (Gargouri Ben Abdallah & Maamouri, 2008), Turkey (Akmirza, 2013) and Italy (Santoro *et al.*, 2020). We also reported for this Digenean the highest mean abundance value among these works, following those of Bartoli *et al.* (2005) and Gargouri Ben Abdallah *et al.* (2011). The mean intensity of *E. stossichianum* surpassed those documented in three localities : Spain (Lozano *et al.*, 2001), Tun-

Table 1. Digenea species composition in *Sarpa salpa* (n = 114) from the Algerian Central coast

Digenea species	Number of infected fish	Number of parasites	Prevalence %	Mean abundance	Mean intensity	Range of intensity	Importance value
<i>Lepocreadium album</i>	1	30	0.88	0.26	30.00	30	Satellite
<i>Centroderma spinosissima</i>	4	13	3.51	0.11	3.25	1 - 8	Satellite
<i>Elstia stossichianum</i>	35	170	30.70	1.49	4.86	1 - 18	Satellite
<i>Mesometra brachycoelia</i>	55	1495	48.25	13.11	27.18	1 - 167	Secondary
<i>Mesometra orbicularis</i>	93	1565	81.58	13.73	16.83	1 - 115	Core
<i>Wardula capitellata</i>	11	21	9.65	0.18	1.91	1 - 4	Satellite
<i>Robphildollfusium fractum</i>	101	5428	88.60	47.61	53.74	1 - 242	Core

Table 2. Species composition of the Digenea communities infecting *Sarpa salpa*.

Species number (P %)	Species composition	Infected hosts	
		n	P %
1 (10.28 %)	R. f	9	8.41
	M. o	2	1.87
2 (28.97%)	R. f - M. o	24	22.43
	R. f - M. b	2	1.87
	R. f - E. s	2	1.87
	M. o - M. b	1	0.93
	M. o - E. s	1	0.93
	M. o - W. c	1	0.93
	3 (36.45%)	R. f - M. o - M. b	29
R. f - M. o - E. s		7	6.54
R. f - M. o - W. c		1	0.93
R. f - E. s - C. s		1	0.93
M. o - W. c - E. s		1	0.93
4 (18.96%)	R. f - M. o - M. b - E. s	15	14.02
	R. f - M. o - M. b - W. c	3	2.80
	R. f - M. o - E. s - W. c	2	1.87
5 (5.61)	R. f - M. o - M. b - E. s - C. s	3	2.80
	R. f - M. o - M. b - E. s - W. c	2	1.87
	R. f - M. o - E. s - L. a - W. c	1	0.93

P, prevalence; n, number of hosts; **C. s.**, *Centroderma spinosissima*; **E. s.**, *Elstia stossichianum*; **M.b.**, *Mesometra brachycoelia*; **M. o.**, *Mesometra orbicularis*; **L. a.**, *Lepocreadium album*; **R. f.**, *Robphildollfusium fractum*; **W. c.**, *Wardula capitellata*

sia (Gargouri Ben Abdallah & Maamouri, 2008) and Italy (Santoro *et al.*, 2020). Aside from the investigation of Bartoli *et al.* (2005), *M. brachycoelia* displayed the highest values in terms of prevalence, mean abundance and mean intensity; as for the congeneric species *M. orbicularis*, its prevalence, mean abundance and mean intensity exceeded all the values found in the studies mentioned previously except for the work of Akmirza (2013) where our mean intensity was slightly lower to the one reported. Herein, *W. capitellata* had the lowest prevalence, a mean abundance that was lower than the one reported by Derbel *et al.* (2012) but higher than the other works, and a mean intensity that was higher than values observed in most studies conducted in Tunisia (Gargouri Ben Abdallah & Maamouri, 2008; Derbel *et al.*, 2012; Antar & Gargouri Ben Abdallah, 2018). It appears that these species are frequently found in *S. salpa*, and it is possible that the variations observed in their parasitological descriptors could be explained by the different geographical locations. Additionally, factors related to the host, such as sociality and diet, could potentially influence the prevalence and abundance of parasites (Kolodziej-Sobocińska, 2019). Since there was no ecological data on *L. album* known from *S. salpa*, we compared it with the ones obtained from other Sparid fish mentioned in the same studies. The prevalence and mean

abundance of this parasite in *S. salpa* had the lowest values observed but its mean intensity was the highest value recorded. It is important to mention that several authors have reported congeneric species: *L. pegorchis* (Stossich, 1901) Stossich, 1904 (Bartoli, 1987b; Bartoli *et al.*, 2005; Gargouri Ben Abdallah & Maamouri, 2008; Gargouri Ben Abdallah *et al.*, 2011; Derbel *et al.*, 2012; Diagne, 2016; Antar & Gargouri Ben Abdallah, 2018). The latter is an accidental parasite of *S. salpa*, according to Gargouri Ben Abdallah *et al.* (2011) and Diagne (2016). So, the individuals of *L. album* recovered here raises the possibility that it was likewise accidental. Given that *S. salpa* has an age-related mixed diet in which juveniles are plankton feeders, young, sub-adults and adults are herbivorous (Havelange *et al.*, 1997), and *Lepocreadium* species are heteroxenous with gastropods as the first intermediate host and medusae, ctenophores, polychaetes, and turbellarians as the second intermediate hosts (Bray, 2005), ingesting the metacercariae of *L. album* by *S. salpa* may simply be a coincidence. The low values reported could potentially be explained by this as well. Based on the studies published on the Digenean communities of *S. salpa*, *E. stossichianum* and *M. brachycoelia* appear to have a narrow specificity to this host, or, as defined by Pojmańska and Niewiadomska (2012) and Combes *et al.* (2018), an oixenous



Table 3. Data relative to weight classes of *Sarpa salpa*.

Weight classes	73.5 – 170.42 g	170.43 – 267.35 g	267.36 – 364.28 g	364.29 – 461.21 g	461.22 – 558.14 g	558.15 – 655.07 g	655.08 – 752 g
<b>Host examined</b>	18	37	21	22	12	2	2
<b>Host infected</b>	17	35	20	22	9	2	2
<b>Number of parasites</b>	725	2456	1970	2663	591	171	146
<i>L. album</i>	0	30	0	0	0	0	0
<i>C. spinosissima</i>	0	1	8	4	0	0	0
<i>E. sfossichianum</i>	13	46	66	39	6	0	0
<i>M.brachycoelia</i>	153	600	367	263	60	6	46
<i>M. orbicularis</i>	190	450	452	406	43	13	11
<i>W. capitellata</i>	14	2	5	0	0	0	0
<i>R. fractum</i>	355	1327	1072	1951	482	152	89
<b>Number of parasites per species</b>							

Table 4. Data relative to length classes of *Sarpa salpa*.

Length classes	17.5 – 20.40 cm	20.41 – 23.31 cm	23.32 – 26.22 cm	26.23 – 29.13 cm	29.14 – 32.04 cm	32.05 – 34.95 cm	34.96 – 37.86 cm
<b>Host examined</b>	5	18	33	17	30	6	5
<b>Host infected</b>	5	16	32	16	29	5	4
<b>Number of parasites</b>	278	947	2492	1147	3187	354	317
<i>L. album</i>	0	0	30	0	0	0	0
<i>C. spinosissima</i>	0	0	1	8	4	0	0
<i>E. stossichianum</i>	1	22	46	44	51	6	0
<i>M.brachycoelia</i>	112	165	667	165	288	46	52
<i>M. orbicularis</i>	70	164	424	400	436	47	24
<i>W. capitellata</i>	7	7	7	0	0	0	0
<i>R. fractum</i>	88	589	1317	530	2408	255	241

Number of parasites per species

Table 5. Relationship between the species prevalence and the host's weight and length using the Chi square test.

Digenea	Prevalence			
	Weight (g)		Total length (cm)	
	$\chi^2$	<i>p</i>	$\chi^2$	<i>p</i>
<i>Lepocreadium album</i>	0.136	0.910	2.476	0.871
<i>Centroderma spinosissima</i>	3.43	0.674	2.425	0.877
<i>Elstia stossichianum</i>	8.301	0.217	5.390	0.495
<i>Mesometra brachycoelia</i>	4.455	0.615	7.647	0.265
<i>Mesometra orbicularis</i>	4.825	0.566	2.967	0.813
<i>Wardula capitellata</i>	22.475	0.001*	24.229	0.000*
<i>Robphildolfusium fractum</i>	8.005	0.238	7.454	0.281

$\chi^2$ , Chi-Square test; *p*, significance level; \*, significant values  $p \leq 0.05$

specificity, while the other five species are known to infect wider host range. In addition to *S. salpa*, *C. spinosissima* and *R. fractum* are known to infect also *Boops boops* (Linnaeus, 1758), another Sparid fish (Sey, 1970; Bartoli *et al.*, 2005; Gargouri Ben Abdallah & Maamouri, 2008; Radujkovic & Sundic, 2014). This could be related to the feeding habits of these hosts. Both of them consume a lot of benthic algae compared to other species of the family Sparidae (Escalas *et al.*, 2021), and it is known that the cercariae of the members of Mesometridae, *C. spinosissima*'s family, use algae or marine flowering plants to encyst (Jousson *et al.*, 1998; Jousson & Bartoli, 1999). For *R. fractum*, a gyliauchenid species, no information regarding its life cycle or even a life cycle of a member of its family is available, but Hall and Cribb (2005) suggested that the parasites of this family could follow a biological cycle with a cercaria that encysts on algae due to their high prevalence in herbivorous fishes. Despite this, the possibility that there is a second intermediate host that lives among algae should not be excluded for this family. Another explanation for the specificity of the two parasites to *S. salpa* and *B. boops* is their phylogenetic relatedness. Abbas *et al.* (2017) determined that these two fish have a close genetic distance of 0.11. Several works have demonstrated that closely related hosts share more comparable parasite

communities (Gupta *et al.*, 2020). While, *W. capitellata* is usually found in *S. salpa*, Williams and Bunkley-Williams (1996) reported this mesometrid from the Scrombrid *Scomber scombrus* Linnaeus, 1758. This is odd giving that this fish is pelagic and preys mostly on arthropods (Taylor, 2019). Therefore, further research is needed to determine the validity of this fish as a host for *W. capitellata*. Regarding *M. orbicularis* specificity, it appears that this digenean infects not only *S. salpa* but also *Boops boops* (Linnaeus, 1758) (Sey, 1970; Radujkovic & Sundic, 2014), *Oblada melanurus* (Linnaeus, 1758) (Barbagallo & Drago, 1903; Barbagallo & Drago, 1904) and *Lobotes surinamensis* (Bloch, 1790) (Linton, 1898). Once more, as explained previously, the presence of this mesometridae species in *B. boops* might be due to the host's feeding habit. This is not the case for *O. melanurus*, as its diet consists primarily on zooplankton (Escalas *et al.*, 2021) However, it does share a trait with *S. salpa*, they are both potential prey and seek refuge in *Posidonia oceanica* meadows (Zubak *et al.*, 2017). In spite of being an unlikely host for this parasite, Linton (1898) collected 14 specimens of *M. orbicularis* from the intestine of *L. surinamensis*. Whether or not this fish might be regarded as a definitive host for this Digenean remains a question.

The species composition of digeneans in *S. salpa* seems to favour

Table 6. The Spearman's correlation test evaluating the mean abundance and mean intensity of species with the host parameters (weight and total length).

Digenea	Mean abundance				Mean intensity			
	Weight (g)		Total length (cm)		Weight (g)		Total length (cm)	
	$r_s$	<i>p</i>	$r_s$	<i>p</i>	$r_s$	<i>p</i>	$r_s$	<i>p</i>
<i>Lepocreadium album</i>	-0.408	0.363	-0.204	0.661	-0.408	0.363	-0.204	0.661
<i>Centroderma spinosissima</i>	-0.374	0.408	0.039	0.933	-0.374	0.408	0.039	0.933
<i>Elstia stossichianum</i>	-0.667	0.102	-0.143	0.76	-0.523	0.229	0.036	0.939
<i>Mesometra brachycoelia</i>	0.000	1.000	0.179	0.702	-0.643	0.119	-0.857	0.014*
<i>Mesometra orbicularis</i>	-0.571	0.18	-0.429	0.337	-0.393	0.383	-0.429	0.337
<i>Wardula capitellata</i>	-0.867	0.012*	-0.906	0.005**	-0.788	0.035*	-0.896	0.006**
<i>Robphildolfusium fractum</i>	0.536	0.215	0.786	0.036*	0.464	0.294	0.75	0.052

$r_s$ , Spearman's coefficient; *p*, significance level; \*, significant values  $p \leq 0.05$ ; \*\*, significant values  $p \leq 0.01$

Table 7. Biodiversity parameters of the component community and infracommunity of Digenea species infecting *Sarpa salpa* from the Central coast, Algeria.

Component community					Infracommunity		
Species richness (S)	Shannon Diversity Index (H')	Evenness Shannon-Winner (J)	Dominance Simpson (D)	Dominant species	Berger-Parker Index (BP)	Mean species richness (mean ± SD)	Mean number of parasites per host (mean ± SD)
7	1.03	0.53	2.23	<i>R. fractum</i>	0.62	2.62 ± 1.21	76.37 ± 76.5

co-infection with *R. fractum*, *M. orbicularis* and *M. brachycoelia*, in contrast to the findings of Diagne (2016), who reported the most frequent parasitic association formed by 4 species, including *E. stossichianum*, *M. orbicularis*, *R. fractum*, and *W. capitellata*. These differences observed in the species composition could be a result of how some parasites cope to the host immune system or the interspecific interaction occurring within the infracommunities (Rigaud *et al.*, 2010; Hoffmann *et al.*, 2016). In a community, the most frequently inferred interaction is probably the competition (Delić & Fišer, 2019). The latter may be observed in parasites, since they occupy the same microhabitats and share common resources (Telfer *et al.*, 2010). As stated by Adamson and Cairn (1994), there are two forms of competition that can be observed. The first form is when parasites may change their microhabitat use in the presence of each other, known as interactive site selection. The second form is when parasites tend to avoid coexisting in the same host individuals, which is referred to as competitive exclusion.

The influence of the host's length and weight on the mean abundance and mean intensity of Digenea revealed a negative correlation for *W. capitellata* and *M. brachycoelia*. This correlation is also seen in other studies infecting various hosts (Poulin, 1999; Villalba-Vasquez *et al.*, 2018; Gharbi *et al.*, 2023; Ibrahim & Alghamdi, 2023) and it could be related to the host's immune system; larger fish are more likely to have a more efficient immune response than the smaller ones. Furthermore, Kotb *et al.* (2014) and Villalba-Vasquez *et al.* (2018) seem to support this point of view as well. However, a positive correlation can also occur, and it is observed in *R. fractum*, which means the mean abundance or mean intensity of the parasite increases along with the length or weight of the host. Previous studies have noted the same tendency (Poulin & Rohde, 1997; Sasal *et al.*, 1997; Poulin, 1999; Poulin, 2000; Vidal-Martínez & Poulin, 2003; Villalba-Vasquez *et al.*, 2018; Ibra-

him & Alghamdi, 2023), and it could be explained by the fact that larger host can harbour more number of parasites than small ones (Guégan *et al.*, 1992; Poulin, 2000; Valtonen *et al.*, 2010; Timi & Poulin, 2020). In fact, several research have indicated that there is a positive correlation between the length of the gut and the total length of the fish (Ribble & Smith, 1983; Karachle & Stergiou, 2010; Hafiz *et al.*, 2023). Given that the Digenean species inhabit the digestive tract, a longer gut not only provides more resources for the parasite but also offers more space to colonize. As result, the effect of the host's biological factors cannot be neglected as they seem to shape the parasites communities. In Luque *et al.* (2004) investigation, not only the fish size proved to be the main predictor of total parasite species richness but the feeding habits of the fish had also an impact on this richness.

In terms of biodiversity parameters, species richness is the most convenient and widely available measure (Luque *et al.*, 2004). Poulin (2015) pointed out that parasite diversity is a lot more than counting the number of parasites infecting a host species. Consequently, a measure of biodiversity other than species richness must be used. The Evenness Shannon-Winner is the ratio of observed diversity, which is the Shannon-Wiener Species Diversity Index, to maximum diversity (Magurran, 2004). Therefore, it can assess the equitability in the distribution of species within a community. The closer its value to 1, the more the distribution is even. In our work, this index yielded a value of 0.5 indicating a moderate level of evenness in the distribution of Digenean species. As for the Dominance Simpson index, we have obtained a value of 2.23. According to Magurran (2004), the value of this index will increase as the assemblage of the species becomes more evenly distributed. Additionally, with a Berger-Parker Index (BP) value of 0.62, it can be inferred that the species *R. fractum*, which is the most abundant, makes up a significant proportion of the community, but it does not indicate absolute dominance. Some of these biodiversity indices are used by Santoro *et al.* (2020) in their investigation on the metazoan parasite community of *S. salpa* from the Italian coast. Despite the fact that we were unable to compare their biodiversity measurements to our own, we were nevertheless able to calculate the mean species richness, which was almost identical to their value.

Species accumulation curves are useful tool in diversity ecology (Dove & Cribb, 2006) that illustrate the rate at which new species are found (Magurran, 2004). In the current work, the curve gene-

Table 8. The species richness estimated by Chao 1, Jackknife 1 and Jackknife 2.

	Number of species
Observed	7
Chao 1	7
Jackknife 1	7.99
Jackknife 2	8.97

rated was nonasymptotic implying an insufficient sampling effort and more sampling is needed. However, reaching a plateau could be sometimes impossible particularly if the number of individuals that must be sampled is too large. At La Selva in Costa Rica, the species accumulation curve of a tropical rain forest ant assemblage has still not reached an asymptote after nearly 30 years of sampling. This serves as an illustration of how difficult it can be to reach an asymptote in some cases (Gotelli & Colwell, 2011). Species estimation is really all about finding and coping with the rare species (Dove & Cribb, 2006). Chao algorithm predicted the same number of species observed, which is 7, but, Jackknife 1 and Jackknife 2 estimated 1 to 2 species remain to be found in the Algerian coastline. It is important to note that *S. salpa* is known to harbour at least 13 Digenean species according to the literature (Morozov, 1955; Papoutsoglou, 1976; Orecchia & Paggi, 1978; Fischthal, 1980; Bartoli, 1987a; Gijon-Botella & Lopez-Roman, 1989; Pellicer, 1991; Akmirza, 2001; Lozano *et al.*, 2001; Bartoli *et al.*, 2005; Bartoli & Gibson, 2007; Gargouri Ben Abdallah & Maamouri, 2008; Gargouri Ben Abdallah *et al.*, 2011; Tepe & Oğuz, 2013; Diagne, 2016; Santoro *et al.*, 2020). After Dollfus's attempt (1947), the current study is the second to investigate the Digenean of *S. salpa* in Algeria. We analysed the component community and infracommunity structural levels and assessed the relationship between host biological factors and parasitism. We have also helped to increase the knowledge of the digenean diversity and to highlight the diversity of parasites, contributing to a better understanding of the parasitic Platyhelminthes in Algeria.

### Conflict of Interest

Authors have no potential conflict of interest pertaining to this submission to Helminthologia.

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