JJBS

Jordan Journal of Biological Sciences

Volume 17, Number 2,June 2024
ISSN 1995-6673
Pages 277 – 285
https://doi.org/10.54319/jjbs/170207

Infectious Parasites in Coral Reef Fish and Their Potential Use for Habitat Quality Assessment in Jordan's Gulf of Aqaba, Red Sea

Mohammad Al-Zibdah[1,*], Mohammad Wahsha[2], Raid Al-Jawasreh[2], Marouf Khalaf[1]

[1] School of Basic and Marine Science, The University of Jordan, Aqaba; [2] Marine Science Station, The University of Jordan, Aqaba, Jordan

Received: September 11, 2023; Revised: December 14, 2023; Accepted: December 16, 2023

Abstract

Incidents of parasitic infections of coastal (0-40m deep) fish species were investigated to assess ecosystem health and stability along Jordan's Gulf of Aqaba (GoA). The aim was to compare sites of probable anthropogenic impacts using the extent of infections and species richness indices. A total of 828 fish belonging to 60 species were collected and examined from 7 sites. Fish were brought to laboratory and examined for skin and gill lesions and/or parasites. Fish necropsy was undertaken to assess organ-specific parasitic infections. The infection prevalence (IV) of 8 disease agents pooled from all sites was *Psuedodactylogyrus sp.*, *Dactylogyrus sp.*, Copepod (*Gnathia sp.*), *Ergasilus sp.*, Maxillopoda, Nematodes (*Anisakis sp*), Isopods and Platy helminthes. The highest IV was reported in fish gills by Flukes (helminthes), and Isopods and monogeneans were recorded in 88% of the examined fish. However, the highest % of infection was the copepods, *Ergasilus sp.* and *Psuedodactylogyrus sp.*, while the lowest % was the helminthes (fish flukes). The gut parasites *pseudodactylogyrus sp.* and *dactelogyrus sp*. prevailed highest in fish collected at northern sits of GoA. These together with one nematode dominated sites of increasing urban activities. By comparing species richness indices of heteroxenous vs. monoxenous parasites in some fish, results suggest increased incidents of monoxenous parasite in fish collected at areas likely impacted by human activities along the coast.

Keywords: Anthropogenic, Coastal quality, Fish parasites, Gulf of Aqaba, Heteroxenous, Infection prevalence, Monoxenous, Red Sea

1. Introduction

The Gulf of Aqaba is fringed by a rich and well developed yet very diverse coral reef. Consequently, it supports a broad variety of bio-fauna. Existence of this highly diverse and complex ecosystem depends exclusively on the stability of the prevailing natural conditions represented here by the oligotrophic nature of this body (Rasheed et al. 2012; Badran and Foster 1998). The coastal ecosystem of the northern Gulf of Aqaba (Red Sea) has been under constant anthropogenic environmental impacts for the last 3 decades due to the profound effects of rapid growth and development at Jordan's major urban city of Aqaba. This process, along with global environmental changes, is attributed to a list of varieties of human borne causes (Wahsha et al. 2017). These include crowded maritime activity, airborne phosphate dust due to export, incidental sewage effluents together with coastal siltation and land runoff, large scale tourism as well as extensive scuba diving activity (Lacerda et al. 2018; Rasheed et al. 2012; Badran and Foster 1998; Abelson et al. 1999). In view of the fact that the Gulf was a nearly pristine body of water as recently as the mid 70's, the rate of habitat degradation in recent years could be considered quite alarming.

Fish populations are an integral part of the coastal ecosystem of GoA. Since extensive parts of the original shallow coastal habitats around this area have been modified, some to the extent of near destruction, it is hardly surprising that fish abundance and diversity have changed and are on a noticeable decline (Al-Ma'ayta 2015; Al-Zibdah and Odat 2007; Golani and Diamant 1999). Hence, detailed studies on the condition of reef fish communities in GoA are crucial for the management and conservation of regional coral reef ecosystems (Khalaf 2004; Khalaf and Kochzius 2002). Coastal localities that previously supported sizeable fish communities seem to have been largely abandoned by many species. Although there is a rarity of coral reef fish studies in the region, historic evidence suggests that mature individuals belonging to larger reef species (e.g., Serranidae, Labridae, Scaridae, Lethrinidae) are in continuous decline (Al-Zibdah 2013; Khalaf 2004).

In recent years, there have been reports of sharp increase in the global prevalence of diseases in the marine environment, a situation which has been linked with climate changes and numerous anthropogenic factors (Al-Hasawi 2019; Harvell et al. 1999; McVicar 1997). The fact that increased incidence of diseases and mortalities of fish populations often associated with pollution is not new (Lacerda et al. 2018; Overstreet 1997). However, the increase in sporadic mortality events associated with infective agents recently encountered in the marine environment at such a magnitude is definitely of concern.

The present study was carried out to investigate fish diseases and parasites along the coast of GoA during December 2017 to October 2018. Aim is to find out

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[*] Corresponding author. e-mail: zibdeh@ju.edu.jo.

potential infectious parasites in selected fish species collected from different coastal locations at depth range 0-40m. The phenomenon of declining fish populations from shallow coastal waters is evident along the entire coastline of Jordan's GoA (Al-Ma'ayta 2015; Al-Zibdah et al. 2018). GoA coastline most likely is one of the more extensively impacted shorelines probably due to occasional and sporadic spills, tourism, fishing and water-sports. Deterioration of environmental quality is known to affect the natural immunity of fish as well as stressful conditions are known to facilitate dispersal and transmission of infective stages of parasites and diseases (Al-Hasawi 2019; Diamant et al. 2010, 2001; Lafferty and Kuris 1999). In this study, we conducted a monitoring program for examining different fish species fished at various sites along the coast of GoA. Purpose is to understand the extent of stress-related infectious diseases occur in indigenous fish populations of GoA. Investigation was focused on parasitic infections in fish captured from 0-40m depth coastal areas. In addition, rabbit fish, *Siganus rivulatus*, was selected as an indicator fish for evaluating the ecosystem health and stability.

2. Materials and methods

During 10 months of sampling period, specimens belonging to 60 species were collected and identified from the seven sampling sites that represented different urban activities along the coast of GoA (Figure 1, Table 1).

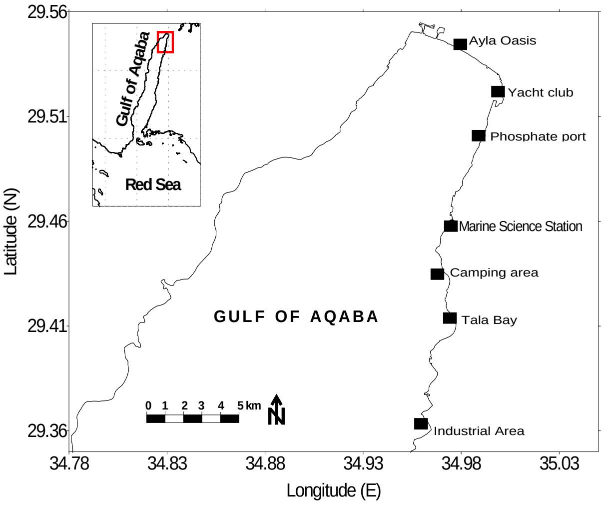

Figure 1. Sites selected for the collection of different fish species during a 10 months' period (Dec 2017-October 2018)

The sampling stations were chosen to represent a range of anthropogenic-impacted and reference habitats on various coastal locations along GoA. The following 7 sites were selected (clockwise): Ayla Oasis sea front, Yacht Club beach, Phosphate Loading Berth (PLB), Marine Science Station (MSS), Tourist Camp, Tala Bay and Jordan Fertilizer Industry (JFI) area.

Table 1. Description of sites selected for the fish sampling.

Name of site	Latitudes	Longitude	Description of existing activities
Ayla Oasis	29.539678°	34.979913°	Inlet outlet of artificial lagoons at north of Aqaba Gulf
Yacht club	29.529096°	34.997922°	Harbour of yachts at northern Gulf of Aqaba
Phosphate Loading Berth	29.498126°		Old Harbour to export crude phosphate
Marine science station (MSS)	29.458590°	34.975976°	Scientific marine environment studies
Tourist camp			Beach for public use (sea sports and camping)
Tala bay	29.405711°	34.975182°	Gated tourist resort
J. Fert. Indust. (JFI)			Fertilizers Industry

The sampling period was between December 2017 and October 2018. A total of 828 fish individuals belong to 60 species were collected and examined from all sites of GoA coastal areas. Fish were mostly obtained from fishermen operating baited mesh traps. Other fish were collected by MSS staff using a similar trap technique and gill nets. Baits used were selective in order to catch as many varieties as possible on a monthly basis. Fish samples were sorted to species level following Khalaf and Disi, 1997. Similarly, fish parasite taxonomy and identification was in accordance to various sources including Atlas of Fish Histology, 2009; world register of marine species WoRMS and FishBase. This is in addition to some publications on fish parasites that were utilized for the current study.

Fish samples were kept frozen until further examination for parasitological/pathological inspections. In laboratory, fish samples of the different species were thawed and examined to search for ecto and indo parasites. Specimens were initially examined externally for skin and gill lesions and/or parasites, followed by a complete necropsy in which the alimentary tract, and suspect organs were examined for lesions or the presence of parasitic infections. An incision was made from the dorsal spine to caudal fin to visually inspect and count the parasites, if present. The organs inspected were skin, internal tissue, gills, hepato pancreas, spleen, and gut. Any visible white pseudo cysts encountered in the tissue were counted (Codex guidelines for sensory evaluation of fish and shellfish in laboratories, CAC-GL 31-1999). In most cases, gills, liver, spleen, kidney and intestine were fixed in 4% buffered neutral formalin (BNF) for further processing of paraffin histology. Freshly prepared skin, gill, spleen, intestinal mucosa and digestive tract imprints were studied microscopically and in some cases, smears were air dried, fixed and stained with Giemsa or Z-N. Further, in the second part of work (unpublished) organs and suspected tissues were fixed with buffered neutral formalin to be processed with paraffin histology.

Moreover, the approach of Gelnar et al. (1997) and D'Amelio and Gerasi (1997) considering using an asymptotic curve to estimate species richness of a given population of parasites in a selective indicator fish species and here the rabbit fish (*Siganus sp.*) was taken into account. The fish were collected from three different sites in 2021 and proved suitable fish as far as heteroxenous species are concerned since they accumulate but cannot proliferate on the host. Results on parasitological models were backed by data analyses employing species diversity and richness indices (Soberon and Llorente, 1993; Walther et al., 1995) using one way ANOVA statistics.

3. Results and discussion

All fish species examined during this study period were sorted by family and categorized according to the trophic level, namely C: carnivore, H: herbivore, O: omnivore, and P: planktivore (Table 2).

Fish samples were somewhat biased towards Aqaba's southern coast, with 828 specimen fish examined. Fish are obviously more abundant toward the south of Jordanian GoA shoreline. This is certainly true as these areas are dominated by coral reef (Al-Zibdah et al. 2008; Al-Horani et al. 2006; Khalaf 2004). Fish populations were found in all sites with coral reef along the coast of GoA (Al-Zibdah and Odat 2007; Khalaf 2004). However, the majority of fish species as well as the number of individuals examined were collected from sites located in southern GoA (Figures 2 and 3).

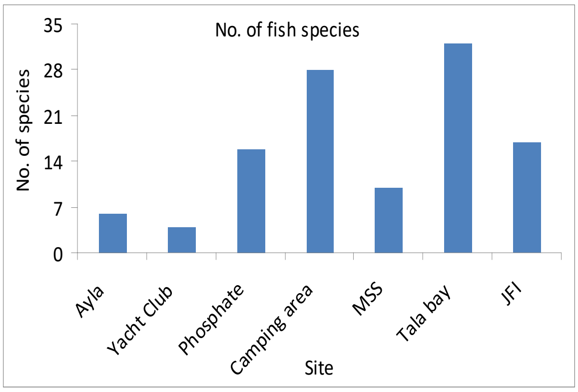

Figure 2. Number of fish species collected and examined from each sampling site (fish were found belong to 58 species and 21 families).

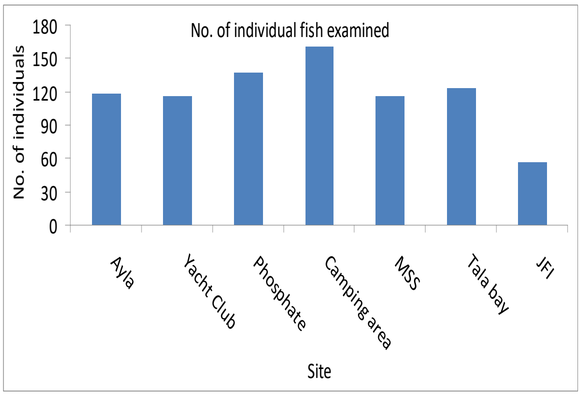

Figure 3. Number of individual fish inspected for pathological and parasitological infections from all sites along the coast of GoA

The infectious agents or parasites recovered from each species are given in the right-hand column in Table 2. Natural infections with Monogenea, Copepods, Isopoda, Nematode, and Helminthes were recorded, and some were identified to species level. For further histological examinations, specimens were fixed and preserved whole for paraffin sections of tissue and/or parasites from the examined fish. The infection prevalence of 8 disease agents that were pooled from all sampling sites is shown in Figure 4. These disease agents were *Psuedodactylogyrus sp.*, *Dactylogyrus sp.*, Copepod (*Gnathia sp.*), *Ergasilus sp.*, Maxillopoda, Nematodes (*Anisakis* sp.), Isopods and Helminthes (Jerônimo et al. 2022; Hoai 2020; Diamant et al. 2001). The highest prevalence of infection observed was with the gill racks, which were Flukes (helminthes), Isopods and monogeneans and were recorded in nearly 88% of the examined fish. However, the highest in infection % was for the two copepod species, *Ergasilus sp.* and *Psuedodactylogyrus sp.*, while the lowest % of infection was for the helminthes (fish flukes). The infection prevalence details according to each sampling site are also shown in Figure 5.

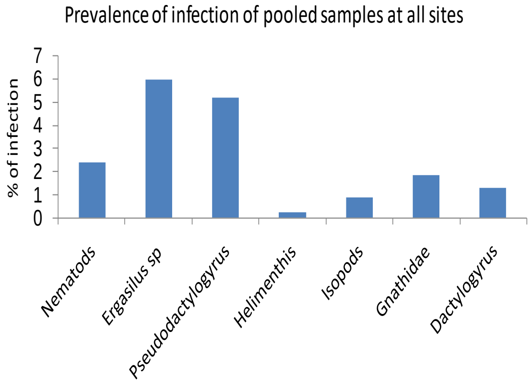

Figure 4. Prevalence of infection by different parasites of fish samples pooled from all sites

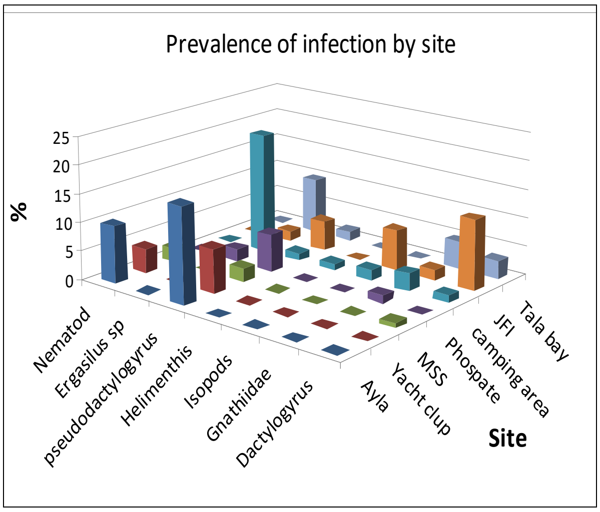

Figure 5. Prevalence of infectious parasites observed in examined fish species from the investigated sites along the coast of GoA

Table 2. Collected and examined fish species showing incidents of parasitic infections, fish trophic level and number of individual fishes in the present study.

Fish family	Species	Trophic level	No. fish examined	Parasitological findings
Acanthuridae	*Acanthurus nigrofuscus*	(H) Herbevore	7	
	Ctenochaetus striatus	H	12	*pseudodactylogyrus, Helminths*
	Zebrasoma xanthurum	H	14	*pseudodactylogyrus, Gnathiids*
Apogonidae	*Cheilodipterus macrodon*	(P) Plankitivore	1	
Baslistidae	*Balistapus undulates*	(C) Carnivore	7	
	Sufflamen albicaudatus	(O) Ominvore	3	
Bothidae	*Bothus pantherinus*	C	1	*Ganthiids*
Chaetodontidae	*Chaetodon Auriga*	O	1	*Ergasilus sp*
	Chaetodon austriacus	C	3	*Dactylogyrus*
	Chaetodon fasciatus	O	4	*Ergasilus sp*
	Chaetodon paucifasciatus	O	22	*Trichodina sp., Ergasilus sp*
	Heninochus diphreutes	P	76	*Ergasilus sp, Helminths, Isopodes*
Echeneidae	*Remora remora*	C	1	
Fistulariidae	*Fistularia petimba*	C	1	
Holocentridae	*Myripristis chryseres*	C	8	*Ergasilus sp, Ganthiids*
	Myripristis murdjan	C	42	*pseudodactylogyrus, Ergasilus sp, Dactylogyrus, Isopodes*
labridae	*Bodianus anthoides*	C	1	
	Cheilinus mentalis	C	4	
	Cheilinus abudjubbe	C	1	
	Cheilio inermis	C	1	
	Coris caudimacula	C	20	
Lethrinidae	*Lethrinus borbonicus*	C	5	*Isopods, Ergasilus sp*
	Lethrinus variegatus	C	37	*Monogenenean*
Monacanthidae	*Amanses scopas*	C	2	
	Cantherhines pardalis	O	11	
Mullidae	*Parupeneus forsskali*	C	2	
	Parupeneus rubescens	C	1	
	Pempherisvanicolensis	C	40	*Ganthiidae*
Ostraciidae	*Ostracioncubicus*	O	1	1
Pomacanthidae	*Apolemichthysxanthotis*	H	5	
	Genicanthuscaudovittatus	P	7	
	Abudefduf vaigiensis	P	2	
	Chromis pembae	P	5	
	Dascyllustrimaculatus	P	17	*Trichodina sp., pseudodactylogyrus*
	Pomacentrustrichourus	P	23	*Isopods*
	Amblyglyphidodonleucogaster	P	5	
Scaridae	*Calatomusviridescens*	H	7	
	Scarus fuscopurpureus	H	9	*Ganthiida, Dactylogyrussp, Isopods, pseudodactylogyrus, Ergasilus sp*
	Scarus ghobban	H	3	*Dactylogyrussp*
	Scarus niger	H	97	*pseudodactylogyrus, Ganthiids, Dactylogyrus, Isopods, monogenenean*
	Scarus sordidus	H	2	
	Scarus ferrugineus	H	10	*monogenenean, Ganthiids*
	Scarus genazonatus	H	1	
Scombridae	*Scomber japonicas*	C	1	
	Rastrelligerkanagurta	C	1	
Scorpionidae	*Dendrochirusbrachypterus*	C	1	
	Petrois miles	C	14	*Trichodina sp., pseudodactylogyrussp*
	Petrois radiate	C	5	
	Scorpaenopsis barbatus	C	1	
Serranidae	*Epinephelus fasciatus*	C	9	*Trichodina sp., monogenenean*
	Cephalopholishemistiktos	C	1	
	Variola louti	C	2	
Siganidae	*Siganus argenteus*	H	16	
	Siganusluridus	H	1	
	Siganusrivulatus	H	114	*Nematods, monogenenean*
Sparidae	*Acanthopagrus bifasciatus*	C	2	
	Diplodus noct	H	136	*Monogenenean*
Synodontidae	*Synodus variegatus*		2	

At some sites, the prevalence of certain infections was considerably higher than the mean. Moreover, the two parasites, *pseudodactylogyrus sp.* and *dactelogyrus sp.* were mostly noticed in different fish species that were caught at sites from north to south. This could explain the natural existence of these parasites in fish gills known to have multiple hosts. This might indicate abundance of several hosts in habitats that reveal forms of anthropogenic interventions along the coastline GoA (Hoai 2020; Ojwala et al. 2018). The prevalence of infection per site showed also dominance of the above two parasites and another parasite, nematodes, with a high % prevalence. These parasites actually were detected at sites of increased urban activities which might suggest its diverse abundance in different fish species. Nevertheless, this study considers selective fish species as potential indicators for the quality of the different coastal habitats. The generated data have shown that the fish *S. rivulatus* (Diamant et al. 2001, 1999) could be a good example species to express the ecological status and quality of different habitats along the coast of GoA (Figure 6).

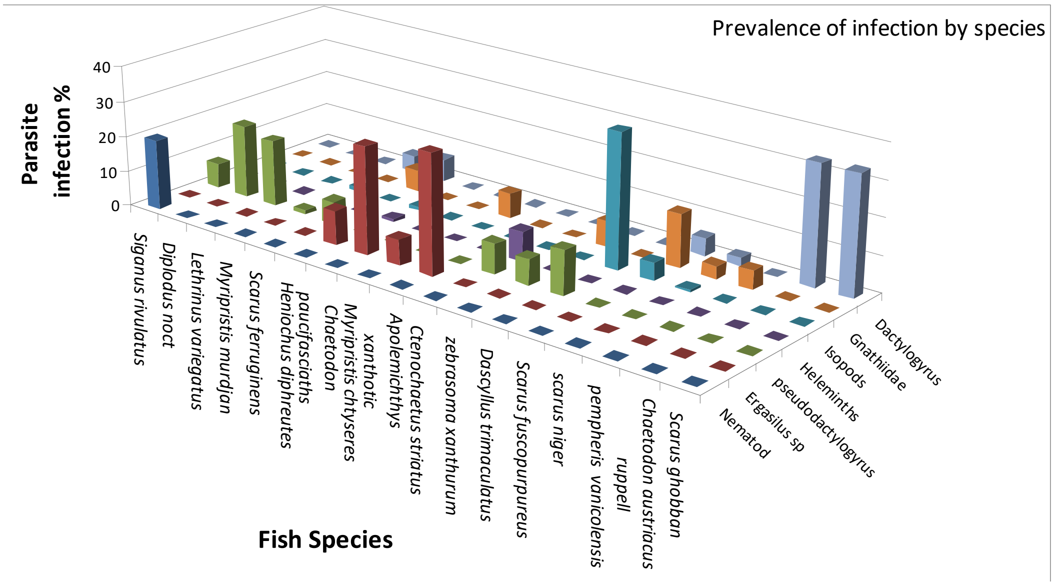

Figure 6. Prevalence of infection to each infectious agent by host species in the examined fish.

The GoA was a near-pristine area before 2-3 decades ago. However, there is now increasing evidence that coastal ecosystem in this area is experiencing environmental modifications (Ashmawy et al. 2018; Schumacher et al. 1995). Incidences of pollution from different sources were reported to result in forms of eutrophication most probably due to rapid urban development (Jerônimo et al. 2022; Silverman et al. 2004; Abelson et al. 1999). Such shifts from the pristine condition may lead to phytoplankton elevation above normal, which will result in an increase in zooplankton and/or benthic fauna of different taxa (copepods, polychaetes etc.), and these might represent potential hosts of fish parasites. In this study, we attempted to quantify some evidence on the above predictions. Indeed, the study showed some changes which were significant at certain points, shown here by the decline in the heteroxenous vs. monoxenous parasite species ratios. We noticed an increase in abundance of monoxenous parasites at certain sampling stations, while heteroxenous species remained plentiful, primarily at sites located away from those that showed sorts of anthropogenic impacts. This pattern was illustrated by a model that describes what is named "true" species richness of the habitat based on the sample size of a particular parasite population (Dzikowski et al. 2003; Walther et al. 1995) in selected indicator species, and here is the *S. rivulatus*. This fish is abundant in several habitats along the coast and easily caught at nearly all sites. Our main objective by this study was to provide some evidence that, in an environment of susceptible impacts, heteroxenous parasites refrain to complete their life cycles due to the depletion of their intermediate hosts in natural environment compared to monoxenous parasites that can proliferate with single host (Paperna 1997; Dzikowski et al. 2003; Al-Hasawi 2019). This relationship is particularly relevant as far as heteroxenous species are concerned (Digeneans, Acanthocephalan and many species of nematodes) since they accumulate but cannot thrive on the host. Hence, the generated data and results of this study were analyzed by employing species diversity and richness indices specifically for parasitological models (Al-Hasawi 2019; Dzikowski et al. 2003; Soberon and Llorente 1993; Walther et al. 1995). Such analysis was helpful to demonstrate distinct values of heteroxenous (H) vs. monoxenous (M) parasites between the different study sites in the indicator fish species (Figure 7).

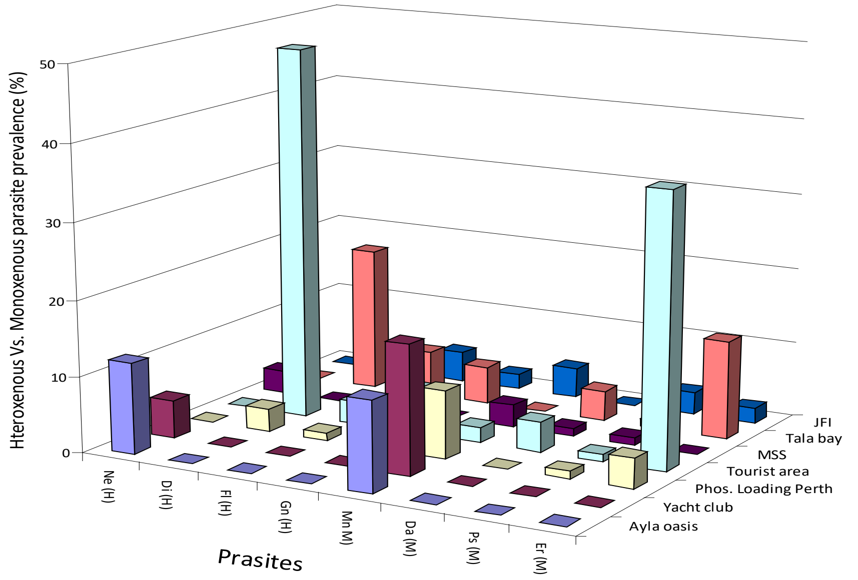

Figure 7. Cumulative number of encountered fish parasites in the different location and the prevalence (%) between heteroxenous vs. monoxenous. *Monogenean (Mo), Nematodes (Ne), Ergasillus sp. (Er), pseudodactylogyrus sp. (Ps), flukes (Fl), fish lice (Li), Gnathiids (Gn), dactylogyrus (Da), digenean sp.*

This study also used the cumulative species plot that extrapolates species abundance of a given habitat as a function of increasing sample size. The heteroxenous and monoxenous species were discretely considered for each site, and comparison of plots yielded comparable results when pooled samples were used. This method aided in approximating the abundance and diversity of parasite species within a particular habitat, allowing for the characterization of communities in potentially affected coastal marine ecosystems. However, findings suggest that there were variations in parasite abundance of the different sites along the coast. Despite the presence of various urban activities at these sites, the distribution of parasite communities did not show any clear pattern, except for what was observed at the Tourist camp site. A notable increase in visitor numbers was observed at this site, which might have anthropogenic implications, yet the ratio of heteroxenous to monoxenous parasites remains approximately 1:1.

Many case reports illustrate the negative effects of pollution on parasite communities, which are often reflected by a decline in species abundance and diversity, especially in those with multiple hosts during their life cycles (Lafferty and Kuris 2009; Dzikowski et al. 2003; MacKenzie et al. 1995). The current study was implemented to use such an approach as a practical tool for distinguishing between habitats subjected to differing degrees of adverse anthropogenic impact on Jordan's GoA coast.

As mentioned above, the higher ratio of heteroxenous vs. monoxenous parasites will explain greater stability in pristine habitats than in other sites that witness some forms of anthropogenic intrusions along the coast. Nevertheless, the results indicate that additional Red Sea and hence Gulf of Aqaba species are sensitive to several pathogens, and that an infection reservoir is now firmly established in the local feral fish communities. Consequently, any form of stress and/or pollution (e.g., ports and public beaches) may show increase prevalence of monoxenous parasites. Some host species were found to be particularly susceptible to some parasite agents. For example, the lion fish (*Pterios miles*) could be a potential indicator for the quality of habitats. The fish was collected from three different sites (Hotels area and Al-Ghandor beach at the northern most portion of Jordan's Gulf of Aqaba and old power station located just to the south of the Phosphate port) in 2021. Indeed, this fish and also the damselfish *Dascyllus trimaculatus* often carried heavy loads of *Trichodina sp.* on their gills. These findings warrant some explanation. *Pterois miles* samples were sufficiently large to allow a fairly detailed population study, and over 63.7% of the individuals examined supported gill infections with *Trichodina sp*. Infact, *Trichodina* ciliates have been shown to be an excellent bioindicator for sewage eutrophication in freshwater habitats (Yeomans et al. 1997; Lacerda et al. 2018). Almost all lionfish individuals examined in this study were from the north beaches and PLB area, the two sites which might be liable to the impacts of eutrophication. *Trichodina sp.* infections were also found on the gills in some other coral reef fishes (i.e. *Chaetodon paucifasciatus, Dascyllus trimaculatus* and *Epinephelus fasciatus*). However, it has yet to be determined whether these infections were with the same species known from impacted sites. In any case, trichodinids are often considered as ecto-commensal and probably have limited significance as pathogens (Diamant et al. 2001).

As stated earlier, the composition of natural fish parasite communities reflects the stability and evolutionary stage reached by the ecosystem in which the fish live because heteroxenous parasites (with complex, multiple-host life cycles) can persist only in habitats that include all host species, both intermediate and definite hosts required for completion of the natural parasite life cycles (Shehata et al. 2018). In environmentally susceptible environments, communities will display a reduced biodiversity, and here we expect mainly monoxenous (single-host) parasites to persist. Here, we compared the ecological indices of the parasite assemblages at each of the three distinctive sites, and employed the relation Sh/Sm, which is the ratio of heteroxenous vs. monoxenous parasites richness indices (Dzikowski et al. 2003; Walther et al. 1995).

A sufficient sample volume of the herbivore rabbit fish *S. rivulatus* was collected and employed because *S. rivulatus* was reported to support a rich parasite fauna of both heteroxenous and monoxenous species. Some of it is found to infect the gut helminthes (heteroxenous species) and gill monogeneans (monoxenous sp.) which are readily quantifiable. Table 3 shows a list of fish samples examined with some parasite species found in *S. rivulatus* that were utilized for the parasite richness and diversity analyses.

We employed 345 individual fish of *S. rivulatus* utilizing the approach of monoxenous-heteroxenous parasite analyses, some of which were collected during two interconnected seasons. The *S. rivulatus* parasite analysis was based on fish collected from three sites, namely Ayla Oasis, Yacht club and Marine Science Station (see Table 1).

Table 3. Number of rabbit fish (*S. rivulatus*) as indicator species, collected from two urban sites at north of GoA and in south (MSS) representing a marine conservatory.

Collection season	Ayla Oasis	Yacht club	MSS	Total
Summer-Fall	92	47	62	201
Winter-Spring	41	63	55	159
Total	133	95	117	345

In all fish of *S. rivulatus* samples, counts were conducted for parasitic metazoans (e.g. helminthes) belonging to heteroxenous (gut digeneans, nematodes and acanthocephalans) and monoxenous (gill monogeneans) as shown in Table 4.

Table 4. Major taxonomic groups of fish parasites reported in literature of both monoxenous (M) and heteroxenous (H) development at different target organs of the *S. rivulatus*.

Taxonomic group	Parasite Species	Development*	Target organ
Monogenea	*Pseudohaliotrematoides polymorphuseilaticus*	M	Gills
	Pseudohaliotrematoides polymorphussuezicus	M	Gills
	Pseudohaliotrematoides polymorphus indicus	M	Gills
	Pseudohaliotrematoides polymorphus "nagatyi"	M	Gills
	Pseudohaliotrema plectocirra	M	Gills
	Polylabris sigani	M	Gills
Digenean	*Hexangium sigani*	H	Gut
	Gyliauchen volubilis	H	Posterior gut
	Opisthogonoporoides hanumanthai	H	Gut
	Opisthogonoporoides spp.	H	Gut
Nematode	*Cucullanussigani*	H	Posterior gut
	Procamallanus elatensis	H	Anterior gut
Acanthocephalan	*Sclerocolum rubrimaris*	H	Anterior gut

*Diamant et. al. (1999)

Species richness and other diversity indices of *S. rivulatus* parasite assemblages during the present study period of host capture are shown in Table 5. Moreover, the parameters on species richness indices are presented in Figure 8.

Table 5. Diversity parameters employed on the *S. rivulatus* fish in this study.

	Ayla Oasis	Yacht club	MSS
N	92	47	62
Parasite species	13 *(7)*	15 *(8)*	17 *(5)*
Fish weight (g)	180.3±7.7^{a}	87±7.9^{c}	170.6±6.7^{ab}
Fish length (cm)	22.7±0.3^{a}	17.8±0.3^{b}	20.5±0.3^{b}
Condition factor (W/L^3)	14.8±0.4^{b}	14.7±0.4^{b}	17.1±0.3^{a}
Diversity indices:			
S (heteroxenous)	6.3±1.25^{b}	7.1±0.81^{b}	12.1±3.09^{a}
S (monoxenous)	7.3±2.21^{b}	8.1±1.53^{b}	5.1±1.51^{b}
Sh/Sm	0.86	0.88	2.4

Numbers that bear different superscript letters are significantly different *P*<0.05 (one way ANOVA); numbers in brackets is for heteroxenous parasite species. S: species richness, Y=a(1–e–bx)/b (Walter et al 1995).

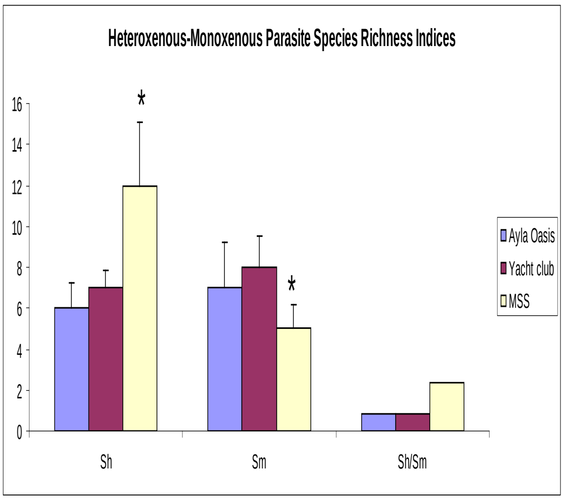

Figure 8. Species richness indices of the heteroxenous vs. monoxenous parasites as encountered in the indicator fish represented here by the *S. rivulatus*

Implementing the concept of Sh/Sm as a tool for evaluating the state of an ecosystem has been documented in several reports (D'Amelio and Gerasi 1997; Diamant et al. 1999, 2001). At some sites of increased urban activities along the coast, our results showed a noticeable increase in monoxenous species abundance associated with a decline in heteroxenous species, although still insignificant (Khan and Thulin 1991; Gelnar et al. 1997). In fact, the decline in heteroxenous species was found to be associated with habitats that witness some sorts of impacts along the coast. This was mainly noticed with the abundance of monogeneans being a monoxenous species. The impacts of pollution at the bottom sediment were reported also to develop monoxenous ciliate infections, mainly the trichodinids (Yeomans et al. 1997; Lacerda et al. 2018). The validation of such approaches as an indirect effect either physiological or immunosuppressive (Shehata et al. 2018) on the hosts under such conditions was a matter of additional investigation, and the data are still under processing (Al-Zibdah et. al., unpublished data). Fish examined from Aqaba's urban areas (public beach and phosphate port, both environmentally perturbed sites) show an increased incidence of elevated levels of certain infections, suggesting that resident fish populations could have been affected by anthropogenic stress which might be linked to habitat degradation. Moreover, the *S. rivulatus*, and based on previous reports, is an ideal species for the application of biochemical and histo-chemical biomarker tests (Diamant 2001, 2010; Martens and Moens 1995). These parameters were also part of the current study, but results are still under evaluation. Our results demonstrate that *S. rivulatus* in addition to other territorial fishes caught at different sites were observed to carry parasite communities that differ in their composition (heteroxenous or monoxenous development), all of which could be used as a measure for the degree of habitat integrity and stability along the coastline of GoA..

Acknowledgements

Authors wish to express their gratitude to the technical staff of Marine Science Station, Aqaba, especially to Mashallah Riyati and Raji Al-Khoja for their help in field and lab work. This research is part of the project #Agr/2/16/2016 supported by Science Research and Innovation Fund (SRIF)/Ministry of Higher Education to School of Basic and Marine Science, the University of Jordan/Aqaba.

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