The Suez Canal as a link and a barrier in the transmigration process of planktonic organisms between the two big seas: Red Sea and Mediterranean

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Abstract: Suez Canal is the main connecting link between the Red Sea in the south and Mediterranean in the north. It crosses many lakes, which in its turn represent different habitats. 87 zooplankton taxa and species were collected for complete year from 10 selected stations on the canal. Most zooplankton species seem to be immigrant plankters to the Suez Canal, and much interest was focused on determining from which end of the canal these organisms were invading the opposite sea. Plankton appears to enter the Suez Canal from the south via water currents; to do so it needs to be carried over a distance of 20 km along the canal from the Gulf of Suez into the Bitter Lakes, then pass across the Bitter Lakes before being carried a further 12 km along the canal into Lake Timsah. Transport of zooplankton southward along the canal from the Mediterranean is unlikely to take place during most seasons of the year because it would require transport against the dominant-water flow; it is possible only during a brief period (July-September) of reversed flow. Moreover, conditions (barriers, obstacles and/or links) along the migratory route of the Suez Canal, in either direction, are likely to determine the success of passive transport of zooplankton species. However, the canal itself, along with its lakes, should also be considered as a substantial permanent habitat in its own right for 15 zooplankton species. Thus, the canal cannot be considered only as a funnel or corridor through which animals (53 zooplankton species) pass like ships from one sea to the other.
[El-Serehy HA, Abdel-Rahman NS, Al-Misned FA, Bahgat MM, Shafik HM, Al-Rasheid KA. **The Suez Canal as a link and a barrier in the transmigration process of planktonic organisms between the two big seas: Red Sea and Mediterranean.**. *Life Sci J* 2013;10(4):2099-2104] (ISSN:1097-8135). http://www.lifesciencesite.com. 279

Keywords: Zooplankton; Migration activity; Atlanto-Mediterranean; Indo-Pacific-Red Sea; Suez Canal.

1. Introduction

The Suez Canal is a transitional zone that links two different basins: the Indo-Pacific Red Sea basin and the Atlanto-Mediterranean basin, and, in so doing, reconnects two biogeographical provinces, the Mediterranean and the Red Sea, that had been partially separated since the early Miocene (ca 20 Ma) and completely separated since the late Miocene (Messinian), ca 5 Ma ago (Robba, 1987). This, in its turn, has influenced the fauna and flora of the canal.

The canal crosses three different lakes: Lake Timsah, the Great Bitter Lake and the Little Bitter Lake, on its route from Port Said on the Mediterranean Sea to Port Suez on the Red Sea. The original length of the canal was 163 km, only 70 km of which were cut from dry land. In the early years after its opening the canal had a navigational depth of 8 m and a surface width of 59-98m but successive projects to widen and deepen the canal have brought its depth to 30 m and its width to 350 m. There are no locks on the main canal; although for most of the year the main sea level at Suez is slightly above that at Port Said (Lisitzin, 1974) and a north-bound current flows through the central parts of the canal, while south-bound currents occur from July-September when the Mediterranean at Port Said is a little higher than the Red Sea at Suez (Morcos and Gerges, 1974). When the Suez Canal was opened, the differing faunas and floras of the tropical Red Sea and the subtropical Eastern Mediterranean were connected. It was therefore, reasonable to expect that the canal might bring about an exchange of species between the two areas, a phenomenon that has indeed been observed by a number of biologists (e.g. Aron and Smith, 1974; Steinitz, 1982, Por, 1971; Por, 1978; Halim, 1990; El-Serehy, 1992; Galil, 2006; Zenetos et al., 2010; El-Serehy and Al-Rasheid, 2011; El-Serehy et al., 2012).

The present study is an attempt to consider the role of the Suez Canal as a habitat, as a connecting link and/or a barrier in the process of transmigration of planktonic organisms between the two big seas: Red Sea and Mediterranean.

2. Material and Methods

During the present study, monthly zooplankton samples were collected from ten different stations along the Suez Canal (Figure 1). These stations were chosen to represent different conditions as possible from north to south of the canal. Stations I, II and III were chosen at the northern part of the canal (Port Said). Station IV, V, VI, and VII were approximately at the middle part of the canal, where the former (station IV) lies at El-Qantra, while the last three stations (V, VI,VII) were chosen to reflect the stress of the environmental conditions as well as the impact of the pollution of the Lake Timsah on the zooplankton community. Stations VIII, IX, X were located at the southern part of the canal (Great Bitter Lake, Little Bitter Lake and Suez Bay, respectively).

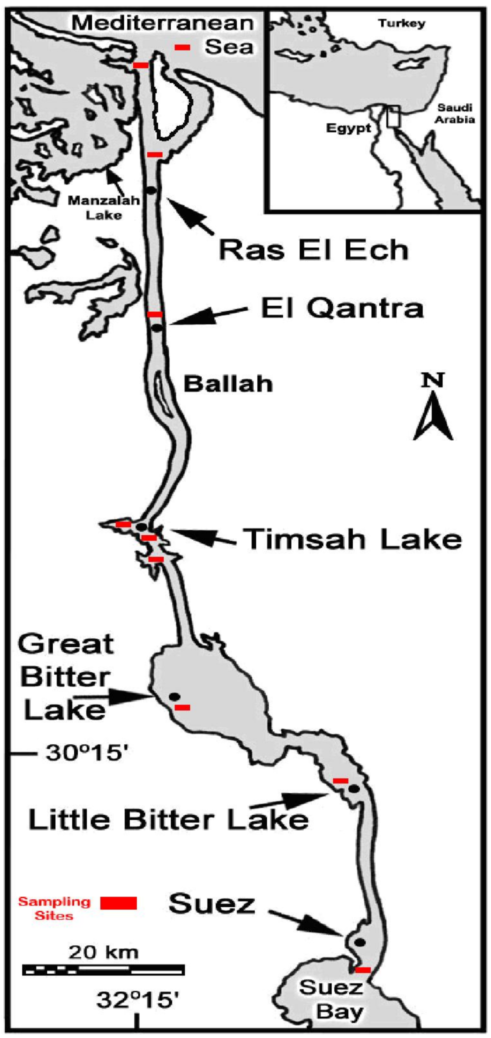

Figure 1. Map of the Suez Canal showing the position of zooplankton sampling stations (in red colour) during the present study.

Conical standard plankton net of 55 µm mesh size, with an opening diameter of 50 cm and 1 m length was used to collect plankton samples from the previously mentioned 10 stations. In each station, the net was towed horizontally just beneath the water surface for 5 minutes. A flow meter was fitted onto the opening of the net to calculate the filtration rate. Collections were made during day-time high tide. British Admiralty tide table predictions for the Gulf of Suez and Suez Canal area were checked before each visit. The samples collected were placed in suitable plastic bottles and immediately preserved in 4 % buffered formalin for later analysis and enumeration.

Surface water temperature, salinity, water transparency, dissolved oxygen, pH, alkalinity and chlorophyll *a* were measured in the water of each station monthly for a complete year, from June 2007 until May 2008.

In the laboratory, zooplankton species were identified and taxon abundance (ind. / $m^{3)}$ was estimated. Species identification was performed according to Jorgensen (1924), Wimenny (1966), Dussart (1967 & 1969), Newell and Newell (1967), and Boltovskoy (1999).

3. Results

a-Physico-chemical conditions of the Suez Canal

Table (1) summarizes the physico-chemical properties controlling the distribution of the zooplankton in the 10 stations of Suez Canal during the present study. There was a general trend of increasing temperature and salinity at the southern part of the canal (station VIII, IX, X). Fluctuations in pH around slightly alkaline values were generally limited. Sechi disc depth ranged from 0.67 to 5.98 m giving an estimated depth of euphotic zone of 0.84 and 7.5 m. The highest values of dissolved oxygen were 7.0 mg/l while the lowest values were 4.2 mg/l (Table 1). Generally, the polluted stations (III, and VII) achieved lowest oxygen values. Alkalinity was high in general and ranged between 172.6 mg/l at station X and 291.2 mg/l at station VII. Station II sustained highest values of chlorophyll *a* concentration (0.77 µg/l) while station IX recorded the lowest values (0.07 µg/l).

b- Zooplankton community composition in the Suez Canal

The zooplankton populations recorded in the Suez Canal comprised 87 species included in 64 genera within 19 taxa. The Copepoda appeared as the most important group forming about 52.27 % of the total number of zooplankton (annual average 33250 ind. / m^3).

Table 1. Average annual values of environmental variables in the Suez Canal sampling sites and the impact of human activities during the present study. St = station; T. = Temperature; S = Salinity; pH = Hydrogen ion concentration; S.D = Secchi disk depth; E. D = Euphotic zone depth; W. D = Water depth; D. O = Dissolved oxygen; O_2 % = oxygen percentage saturation, Alk = Alkalinity; Chl *a* = Chlorophyll a concentration; I.H.A =Impact of human activities; F.I = Freshwater Intrusion; D. W =Domestic Waste; - = absent and + = present.

Environmental variables												
Station	T.°c	S‰	PH	S.D m.	E.D m.	W.D m.	D.O. Mg/l	O_2 %	Alk Mg/l	Chl. a µg/l	I.H.A	F.I
St. I	20.1	37.2	8.25	1.3	3.9	20	7	139.7	211.1	0.33	-	-
St. II	19	36.4	8.22	1.75	2.9	20	6.8	136.5	208.9	0.77	-	-
St. III	22	27.2	8.29	0.67	7.5	13	4.2	88.7	256.2	0.16	D.W	+
St. IV	22.4	40	8.21	2.83	1.8	20	6.5	135.6	203.5	0.27	-	-
St. V	22.5	34.5	8.21	2.0	2.5	20	5.8	142.2	220.6	0.31	-	-
St. VI	22.6	29.3	8.21	1.58	3.2	6	6.5	127.4	245.4	0.41	D.W	+
St. VII	23	22.3	8.14	1.04	4.8	6	4.6	87	291.2	0.40	D.W	+
St. VIII	23.5	46.3	8.18	2.98	1.7	13	6.8	147	204.2	0.23	-	-
St. IX	23.7	41.8	8.2	2.39	2.1	13	6.6	141	192.4	0.07	-	-
St. X	24.3	41.9	8.17	5.98	0.8	26	6.2	133	172.6	0.46	-	-

The protozoa (Foraminifera and Tintinnida) occupied the second position (42.48 %) of the total zooplankton (average 27021 ind./m^3). The meroplanktonic group (larvae of benthic fauna) represented the third important group and amounted for 2.67 % of the total zooplankton population density (average 1248 ind./m^3). Rotifera occupied the fourth position with a rate of 1.96 % of the total counts (average 1248 ind./m^3). Tunicata represented the fifth important group and amounted for 0.34 %, and with an average of 219 ind./m^3). Cladocera occupied the sixth position with a rate of 0.2 % of the total zooplankton count (average 129 ind./m^3). The other groups were rarely encountered. These comprised Hydrozoa, Nemertea, Ostracoda, Amphipoda and Cheatognatha. They contributed collectively 0.08 % of the total zooplankton (48 ind./m^3) (Figure 2).

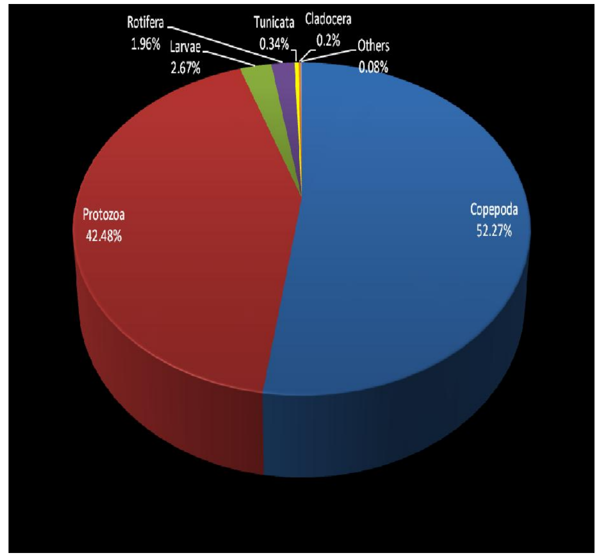

Figure 2. The percentage contribution of the different planktonic groups to the total zooplankton community in the Suez Canal during the present study.

c-Origin of zooplankton species that thrive in the Suez Canal

The 73 zooplankton species surviving in the canal can be classified into 5 different groups according to their origin as follows:

1- 16 species derived from the Red Sea: *Codonellopsis longa*, *C. Morchella*, *Eutintinnus fraknoi*, *Favella campanula*, *F. Panamensis*, *Metacylis jorgensenii*, *Tintinnopsis butschli*, *T. Tubulosa* (Tintinnida), *Acartia latisetosa*, *Acrocalanus gibber*, *Labidocera minuta*, *Tortanus gracilis* (Calanoida), *Corycaeus erythraeus*, *C. Medius* (Cyclopoida), *Fritillaria formica* and *Stegosoma magnum* (Urochordata).

2- 8 species derived from the Mditerranean Sea: *Favella ehrenbergii*, *Tintinnopsis nordiguisti* (Tintinnida), *Podocoryne areolata*, *Lensia conoidea* (Hydrozoa), *Evadne spinifera*, *Podon polyphemoides* (Cladocera), *Centropages ponticus* (Calanoida) and *Appendicularia sicula* (Urochordata).

3- 29 species common to both Red Sea and Mediterranean: *Helicostomella subulata*, *Tintinnopsis cylindrical*, *T. Campanula*, *T. Mortenseni*, *T. tocatinesis* (Tintinnida), *Zanclea sessilis* (Hydrozoa), *Evadne nordmanni*, *E.tergestina*, *Penilia avirostris* (Cladocera), *Acartia centrura*, *A. Fossae*, *A. negligens*, *Centropages furcatus*, *Clausocalanus vanus*, *Paracalanus parvus*, *Tempora stylifera* (Calanoida), *Clytemnestra scutellata*, *Euterpina acutifrons*, *Microsetella norvegica* (Harpacticoida), *Krohnitta subtilis*, *Sagitta enflata*, *S. neglecta* (Cheatognatha), *Oikopleura longicauda*, and *O. dioica* (Urochordata).

4- 15 species considered as a distinctive endemic local zooplankton fauna of the Suez Canal: *Globigerina glutinata*, *G. inflate* (Foraminifera), *Codonella aspera*, *Codonellopsis schabi*, *Proplectella claparedei*, *Stenosemella ventricosa* (Tintinnida), *Oceania coccinea*, *Podocoryne borealis*, *Sarsia gemnifera* (Hydrozoa), *Ascomorpha saltans*, *Brachionus calyciflorus*, *Keratella quadrata*, *Polyarthra vulgaris* (Rotifera), *Pontellopsis regalis* (Calanoida) and *Doliolum denticulatum* (Urochordata).

5- 5 species with uncertain origin: *Euphysa aurata* (Hydrozoa), *Cytheridea punctillata*, *Xestoleberis depressa* (Ostracoda), *Parathemisto abyssorum* (Amphipoda) and *Lucifer hanseni* (Decapoda).

d-Site and seasonal distribution of total zooplankton

The magnitude of the standing crop of zooplankton attained its highest densities at station II in the northern part of the canal, which sustained average annuals of 210435 ind. /m^3, and then gradual decrease in zooplankton population density was observed southwards along the canal (Figure 3). The seasonal dynamics in zooplankton population density (Figure 4) was characterized by remarkably high numbers during summer and early autumn (248689 ind. / m^3), however, these numbers gradually decreased until winter where they reached their lowest values (15349 ind. / m^3).

4. Discussions

During the present study, the magnitude of the zooplankton species composition gave rise a total of 87 taxa and species. A total of seventy three were identified to the species level, while two were identified to genus only, and twelve are larvae of different benthic fauna. From Figure (3), the magnitude of the standing crop of zooplankton has attained its highest densities at station II in the northern part of the canal, and then gradual decrease in zooplankton population density was observed southwards along the canal. This can be attributed to the fact that station II exhibited the most suitable average annual values of abiotic and biotic variables (Table 1). The population dynamics and distribution of zooplankton have been correlated with environmental factors (Weikert, 1982; Quiroga et al., 2013). Moreover, this station is supposed to be affected by the sewage pollution from the neghibouring station III through the northward current dominating the canal most of the year. Moraitou Postolopolou (1981), and Ahmad et al. (2011) reported that partial pollution by sewage produces more zooplankton abundance in the water body.

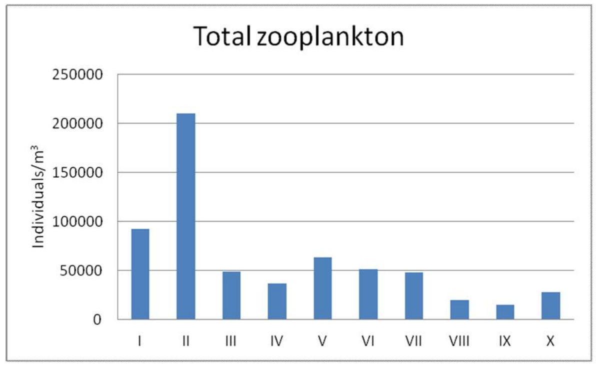

Figure 3. Site distribution of the total zooplankton in the Suez Canal 10 stations during the present study.

The seasonal dynamics in zooplankton population density was characterized by remarkably high numbers during summer and early autumn, however, these numbers gradually decreased until winter where they reached their lowest values. The higher increase in zooplankton numbers during summer was essentially due to the sharp increase in tintinnid populations during this season (152529 ind. / m^3 during July).

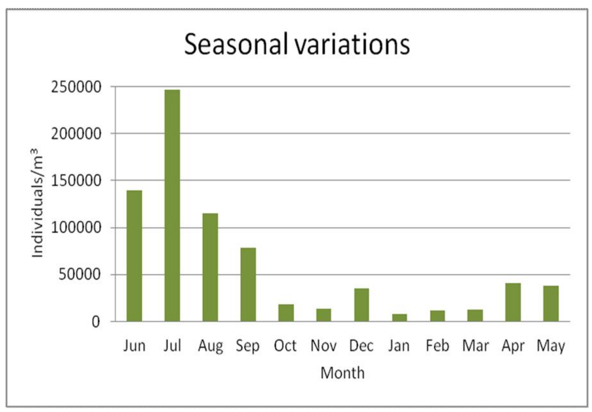

Figure 4. The monthly variations in the total zooplankton at the ten station in the Suez Canal during the present study.

In an attempt to throw light on the migration activity of these zooplankton species between the two big seas of Red Sea and Mediterranean, it is very important to know the origin of the zooplankton species first. In other words, whether the Suez Canal has a distinctive local zooplankton fauna or an immigrant fauna between the two seas?. The present study deals with 73 species of zooplankton of which 29 species are represented in the two seas (Jorgensen, 1924; Delalo, 1966; Halim, 1969; Lakkis, 1971; Weikert, 1982), 16 were derived from the Red Sea

(Delalo, 1966; Halim, 1969; Weikert, 1981), 8 were represented in the Mediterranean (Jorgensen , 1924; Lakkis, 1971), and 15 are considered a distinctive local endemic fauna of the canal and the remaining 5 species have been considered with uncertain origin. All of zooplankton species recorded occurs in the canal in one or more of the station sampled, and would appear to survive the summer in the canal in high numbers. But how did they originally come to the canal, and are they annually re-introduced at self-sustaining isolated populations?. Migration may take place by passive transport by currents (common for planktonic adults and planktonic larvae of benthic forms), by other animals or man; and by active migration (common for larger active animals). Zooplankters most likely enter the Suez Canal in water currents; to do so from the south they would need to be carried the 20 km or so along the canal from the Gulf of Suez into the Bitter Lakes (which formerly had a very high salinity that may have been lethal), then pass across the Bitter Lakes before being carried the further 12 km or so along the canal into Lake Timsah where dilution effects with freshwater and pollution impact would be a critical barrier for survival of the immigrant zooplankton. Transport of zooplankton southward along the canal from the Mediterranean is unlikely to take place during the winter against the water flow, but is possible during the brief period of summer reversal of flow (Oren, 1969; Morcos, 1975). Because the main part of the 80 km or so from the Red Sea is canalized, passive transport of plankton by water currents from the north could occur within a week even at the low speed of ½ km/hour.

Conditions on the route, in either direction, are likely to determine the success of passive transport; because zooplankton species seem to thrive better in summer than in autumn, winter and spring in the northern part of the canal (Port Said), thus they are likely to have been derived from the Mediterranean Sea during summer and from the Red Sea during the rest of the year. The difference between conditions in Lake Timsah, Bitter Lakes and those in the canal could determine the success of migration process of zooplankton organisms. Those species that are present both in the Suez Canal and in the Red Sea and Mediterranean may be the tolerant ones, and those species common in the canal, but not reported in the Red Sea or Mediterranean may be less tolerant of the more stringent conditions of the canal and its lakes. The existence of these latter forms suggests that the canal and its lakes contain at least some self-sustaining isolated populations of zooplanktonic species that may reflect the fact that the Suez Canal is a habitat in its own and should not be considered as a funnel or pathway through which zooplankton organisms pass like ships from one sea to the other.

In conclusion, zooplankton community can be passively transported to the Suez Canal either from Mediterranean or Red Sea. The water current dominating the canal at a given time should determine the direction of this migration trip. Zooplankton migration from Red Sea to Mediterranean through the Suez Canal is more likely to occur during most of the year. The canalized part of the Suez Canal facilitates the process of zooplankton transmigration process, however, the lakes of the canal are supposed to be barrier for migration activity of zooplankton between the two big seas. Suez Canal and its lakes contain at least some self-sustaining isolated populations of zooplankton species that may reflect the fact that the Suez Canal is a habitat in its own and should not be considered as a funnel or pipe through which zooplankton organisms pass like ships from Red Sea to Mediterranean and vies versa.

Acknowledgements:

The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group no RGP-VPP-242.

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11/10/2013