Aquatic entomofauna of a Dead Sea oasis

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Abstract

A survey of the aquatic and semi-aquatic insect fauna of a semi-tropical, arid zone oasis on the western Dead Sea coast, was conducted primarily in the summer and winter seasons of 1980/81. A table is given of the aquatic entomofauna, including their zoogeographical affinities, Israeli distribution and presence in En Gedi and in each of the two canyons there. Zoogeographical analysis reveals a predominance of tropical and arid African affinity (Ethiopian = 31%, Saharo-Arabian = 19%), with a major affinity also to the Mediterranean (21%). The entomofaunal community was divided among seven ecological biotopes: fast or slow flowing streams and pools; eddies; bedrock or deep pools; standing or stagnant pools. A community analysis table of the occurrence of the major faunal elements in each of seven biotopes is presented. Some rather stenotopic taxa were indicative of biotopes. A comparison is made of summer and winter seasonality including the effects of flash floods and the relation of these phenomena to emigration/imigration and life cycles of the entomofauna. The effects of agriculture and tourism are discussed and proposals made for conservation of the biotope communities. These biotopes and their entomofaunal communities are presumed to represent most of the habitats of Middle East arid zone springs.

Introduction

The study of aquatic insects in Israel and the Middle East in general has been greatly neglected relative to other aquatic animals and plants. Most of what is known is from a variety of scattered faunistic works in many kinds of limnological biotopes. Few studies have been made of single biotopes as a system or isolated systems of fresh water. In Israel, which has a large variety of arid and semi-arid fresh water habitats, such system-type limnological research has only recently been initiated, e.g. Nahal Dan Hydrobiological Survey, Lower Jordan River (Ortal & Por 1978), and a survey of temporary winter rain pools of the Coastal Plain. One of the most interesting local systems of fresh water habitats was almost completely eliminated by man without much serious limnological study other than faunistics and floristics – the Huleh Lake and Swamp (Furth 1977). Since fresh water systems are so important to arid land peoples this lack of research and understanding is unfortunate, especially because recent industrial and agricultural pollution many have ruined some of these ecosystems beyond repair or beyond the point of understanding their natural limnological qualities and capacities. Therefore, it is through these realizations that the few projects mentioned above, and this survey of aquatic and semi-aquatic insects of En Gedi, have been initiated in order to begin to understand the water quality of the relatively natural aquatic system in Israel and to attempt to discover water quality indicators. En Gedi, situated on the western coast of the Dead Sea, is a good aquatic system for such a study for many reasons. It is a rather unique locality (at -393 meters, the lowest point in the world) be-

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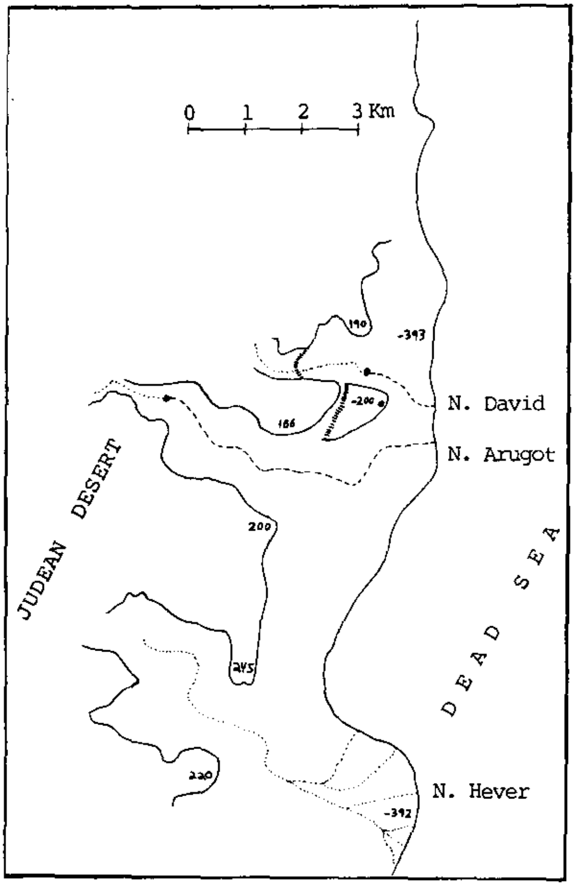

Fig. 1. En Gedi and environs (large dots = spring sources; dashes = path of canyon with perennial streams and pools; tiny dots = path of dry canyon, with water during floods only; cross-hatches = large vertical drop; numbers are elevations in meters).

cause of its tropical desert oasis environment and isolation it avoids many natural influences of nearby areas, and this makes it ideal for such a study. Also, the fresh water sources of En Gedi are mostly part of the Nature Preserves Authority so much of their natural state has been preserved in recent years.

In En Gedi there are three major fresh water sources: Nahal (= canyon in Hebrew or Wadi in Arabic) Arugot, Nahal David and En Gedi Springs (Fig. 1). The main emphasis of this survey is on the two largest, N. David and N. Arugot, although all aquatic insects in the En Gedi are considered. N. David and N. Arugot are very similar in their general geological and hydro-ecological (limnological) characteristics; both are fed from many small underground springs along their descent towards the Dead Sea, and consist of a long series of pools, waterfalls, and streams of varied sizes; sections of each canyon are shaded by vegetation. En Gedi Springs consists of a single large source pool, shaded by a very old *Sisyphis spina-christi* tree, with a few small effluent, shaded, canal-like streams flowing a short distance (ca. 20 m) through a vegetated region and over the side of a cliff.

The wet parts of N. David are divided by the Shulamit Waterfall (ca. 25 m) into two steps, each of which is relatively flat (low gradient), and its total length is approximately 1.5 km. Generally the water in N. David has a salinity of 70–75 ml Cl $\cdot$ l^{-1} (Dalinsky & Priesmant 1973) and a temperature 21 °C (Gasith & Botosaneanu 1971) to 25–26 °C. N. Arugot's springs extend considerably further (ca. 4–5 km), with several small waterfalls and an apparently steeper gradient towards the Dead Sea; thus, potentially a generally faster water flow in some parts. N. Arugot has more standing and stagnant pools at both ends of the flowing water than does N. David. N. Arugot also seems to have a greater relative abundance of pools with green filamentous algae (*Cladophora/Spirogyra*) as well as other submerged non-aquatic vegetation. In En Gedi Springs the salinity ranges from 50 to 70 ml Cl $\cdot$ l^{-1}. In N. Arugot salinity ranges from 87 to 120 ml Cl $\cdot$ l^{-1} and the water temperature from 18 to 21 °C at the origins to 27 °C in slow-moving, streams, pools, and eddies (Samocha 1974). N. Arugot seems to have a greater diversity and permanency of vegetation associated with a desert oasis. Generally the various types of aquatic communities are similarly represented in both canyons (see community analysis section below).

There are many other springs along the western and southern coasts of the Dead Sea. Some unpublished records exist for aquatic insects of these other Dead Sea springs, especially from a faunistic survey of the Dead Sea Area to the Sinai in 1968–1970 (Margalit & Avrahami 1973), and from isolated studies of single aquatic insect groups (Gasith 1969; Samocha 1974; Wewalka, *in litt.*; Dumont, *in litt.*; Mathis, *in litt.*; Braverman, *in litt.* and *et al.* 1981). However, the En Gedi system is by far the largest spring in the Dead Sea Area of Israel in water volume and for diversity of aquatic habitats or biotopes. Therefore, the present in-depth study of faunistics of all aquatic insects as well as the various aquatic community biotopes of En Gedi should be indicative of the complete range of an arid tropical stream ecosystem in this region. Hopefully this study will be the basis for a program of nature preservation of these aquatic communities as well as being a biological foundation or indicator for understanding any changes that occur in these habitats.

Methods and materials

This survey of aquatic and semi-aquatic insects was made initially while working for the Nature Preserves Authority of Israel in 1969 (August – November); the specimens (including those of N. Hever) are now in the En Gedi Field School. Additional collecting trips were made at the end of the summer season 1980 (October 24–25) and winter season 1981 (February 23–25), in order to supplement the 1969 collections and to add more detailed ecological information, especially relative to the different aquatic communities there. The different aquatic biotopes/communities existing in En Gedi were classified and sampled at several locations or stations in each canyon (8 stations in each canyon), and En Gedi Springs (1 station). In winter fewer biotopes were sampled due to the paucity of the less common habitats, e.g. deep pools and bedrock pools; most of the summer stations were sampled again as well as some additional ones. Field notes were made at each station relative to water speed, submerged vegetation, substrate, and preliminary determinations of the insect taxa present. The collections were made with triangular aquatic insect nets (212 and 475 micron mesh) and preserved in 70% Ethanol. The specimens of the 1980–1981 field collections are deposited in the collection of the IES. Identifications were made using the collections at Tel Aviv University (Department of Zoology) and at the IES as well as specialists in and outside of Israel.

All of the aquatic insect taxa known from En Gedi have been listed in Table 1. Table 1 gives the distribution in En Gedi and in Israel (to the best of my knowledge) as well as the general zoogeographical affinities of each taxon, when known. Table 2 lists the community biotopes from the various aquatic habitats of En Gedi with the taxa recorded or expected to be found in them.

Table 1. Aquatic and semi-aquatic insects of En Gedi.

Taxa	Zoogeography	Israel	En Gedi	N. David	N. Arugot
COLEOPTERA					
Dryopidae: (* = G. Wewalka, *in litt.*; ref. 10)					
Dryops sulcipennis Costa? (*)	Med	DS, ?	+	–	+
Dytiscidae:					
Aglymbus gestroi Sharp	Er	SS, DS	+	–	+
Guignotus major (Sharp)	Er	SS, CN, DS*, JD	+	–	+
Hyphydrus pictus Klug	Er	SS, CN, DS	+	+	+
Laccophilus hyalinus DeGeer	Med/ES	NS, DS, JD, SCP, S, YV, GH	+	–	+
Potamonectus lanceolatus (Wlk.)	Er	SS, NS, NN, DS, SCP	+	–	+
Prodacticus pictus Sharp	Er/IT	DS	–	+	–
Rhantus includens (Walker)	Er	SS, DS	+	+	+
Helodidae:					
Hydrocyphon deflexicollis (Mueller)?	ES	DS	–	–	+
Hydraenidae:					
Hydraena sp.	–	DS, ?		–	+
Octhebius sp.	–	DS*, ?	–	+	+

Table 1. (continued).

Taxa	Zoogeography	Israel	En Gedi	N. David	N. Arugot
Hydrophilidae:					
Coelostoma sp.	–	DS*, ?	+	–	+
Laccobius sp.	–	CN, DS*, ?	+	+	+
? sp. #1	–	DS, ?		–	+
? sp. #2	–	DS, ?		–	+
DIPTERA					
Ceratopogonidae: (* = Y. Braverman, *in litt., et al.* 1976, 1981; ref. 1)					
Bezzia sp.		DS, UG?	–	–	+
Culicoides agathensis Callot, Kremer, Rioux*	ES	NN, DS, SCP, CCP, JV, LG, GH	–	–	+
Culicoides circumscriptus Kfr.*	Pal.	NN, DS, JV, SCP, CCP, NCP, LG, GH	+		–
Culicoides firuzae Dzhafarov*	IT	SS, SN, CN, DS	–		+
Culicoides imicola Kieffer*	Eth	NN, DS, JV, SCP, CCP, NCP, JF, UG	+		+
Culicoides aff. *jumineri* Callot & Kremer*	Med	NS, CN, DS, GH	–	+	–
Culicoides kingi grp.*	Eth	NS, CN, DS	+	–	+
Culicoides pulicaris Linn.*	Pal	SN, CN, DS, SCP, CCP, JV, GH	+		–
Chironomidae: (* = J. Kugler, pers. comm., ref. 5)					
Ablabesmyia sp.*	–	DS, ?		+	–
Chironomus sp.	–	DS, ?	–	–	+
Cricotopus sp.*	–	DS, ?	–	+	–
Polypedilum tiberialis Kief.*	Med	DS, all areas N.		+	–
Chironomid spp.	–		–	+	+
Culicidae: (from Margalit & Avrahami 1973; ref. 7)					
Anopheles dthali Patton	Eth	SS, NS, DS		–	+
Anopheles rhodesiensis rupicolus Lew.	Eth	SS, DS	–	–	+
Anopheles sergenti (Theobd.)	Med/Er	SS, NS, DS, JM, JV, C, UG	–	+	+
Anopheles superpictus Grassi	Med	SS, NS, DS, JD, JV, JM, CCP	–	–	+
Culex laticinctus Edwards	Med/Er	SS, NS, CN, DS, JV, JM, JF, C	–	+	+
Culex mimeticus Noe	Med	NS, DS, JD, JM	–	+	+
Culex pipiens (L.) complex	Cosmop.	NS, all areas		–	+
Culex univittatus Theobald	Eth	DS & areas N.		–	+
Culiseta longiareolata (Macq.)	Med/Eth/IT	SS, NS, areas N.		+	+
Uranotaenia unguiculata Edw.	Med	NS, DS, areas N.		–	+
Dixidae:					
Dixa sp.		DS, ?	–	+	
Ephydridae: (* = W. Mathis, *in litt.*; ref. 8)					
Actocetor margaritatus (Wdmn.)*	Eth/Med	all areas	–		+
Allotrichoma sp.*	?	DS, ?		–	+
Athyroglossa sp. #4*	?	Negev, DS	–	–	+
Atissa pygmaea Haliday*	Pal.	DS, CP		–	+
Brachydeutera argentata (Wlk.)	Cosmop.	DS, areas N.		–	+
Chlorichaeta albipennis (Loew)*	Eth/Med	Negev, DS		–	+

Table 1. (continued).

Taxa	Zoogeography	Israel	En Gedi	N. David	N. Arugot
Elephantinosoma sp. #2*	Eth?	CN, DS	–	–	+
Ephydra flavipes (Macquart)*	Eth/Med	all areas	–	–	+
Halmopota mediterranea Loew*	Med	DS, MH	–	–	+
Homalometopus albiditinctus Bkr*	Er	SS, DS	–	–	+
Hyadina guttata (Fallen)*	Med	DS	–	–	+
Ochthera mantispa Loew*	Med	all areas	–	–	+
Psilopa sp.*	?	DS, ?	–	–	+
Scatella paludum (Meigen)*	Cosmop.	all areas	–	–	+
Scatella tenuicosta Collin*	Holarctic	all areas	–	–	+
Psychodidae:					
Psychoda sp.		DS, ?	–	–	+
Simuliidae: (Crosskey, 1967; ref. 11)					
Simulium ruficorne Macq.	Eth	SS, NN, DS	–	+	+
Stratiomyidae: (Freidberg, *in litt.*; Lindner 1974, 1975, 1979; ref. 12)					
Heraclina orientalis Lindner	Er	SS, DS, JV	+	–	–
Odontomyia hydroleon (Linn.)	Pal.	NN, DS, JF, C, UG	+	–	–
Oxycera trilineata (Fab.)	Pal.	DS, CCP	+	–	–
Syrphidae: (* = det. M. Kaplan)					
Eristalinus tabanoides (Jaenk.)*	Er	SS, SN, CN, DS	–	–	+
Eristalis tenax (L.)?	Cosmop.	all areas	+	–	–
Tabanidae:					
Tabanus sp.	–	DS, ?	–	+	+
EPHEMEROPTERA (* = Samocha 1974; ref. 9)					
Baetidae:					
Baetis sp. L6*	ES	DS, YU, UG, GH	–	–	+
Baetis sp. L56*	Eth	DS	–	–	+
Baetis sp.	–	DS, ?	–	+	+
Centroptilum sp.*	Eth/Er	SS, DS, JV, UG, GH	–	–	+
Cloeon dipterum (L.)?	Med/ES/Er	all areas	–	–	+
Cloeon sp. L51*	Eth/Er	SS, DS	–	–	+
Caenidae:					
Caenis macrura Stephens	Med/ES/Er	DS, YV, UG, GH	–	–	+
Leptophlebiidae:					
Eutrhaulus sp.*	Er/Eth	DS	–	–	+
HEMIPTERA: HETEROPTERA					
Corixidae:					
Corixa affinis Leach	Pal.	SN, CN, NN, DS, JM, CCP, C, LG, UG, MH	–	–	+
Sigara marginata (Fieber)	Eth	SS, DS*	+	–	+
Hebridae:					
Hebrus pusillus (Fallen)	Pal.	DS, JD, JV, UG	–	–	+

Table 1. (continued).

Taxa	Zoogeography	Israel	En Gedi	N. David	N. Arugot
Hydrometridae:					
Hydrometra stagnorum (L.)	ES	DS*JV, JM, CCP, UG	–		+
Leptopodidae: (Linnavuori 1960; ref. 6)					
Patapius spinosus (R.)?	Med	DS, JD, JV, JM, YV, LG	+		–
Mesoveliidae:					
Mesovelia vittigera Horvath	Eth/Med	DS*JV, CCP	–	+	+
Naucoridae:					
Heleocoris minusculus (Walker)	Er	SS, CN, DS*	+	+	+
Nepidae:					
Laccotrephes fabricii Stal	Eth/Or	SS, CN, DS*	–		+
Notonectidae:					
Anisops sardea H.-S.	Med/Eth/Or	CN, NN, DS*JV, CCP, C, UG		–	+
Anisops varia (Fieber)	Eth	SS, CN, DS*	+	+	+
Veliidae:					
Microvelia gracillima Rt.	Eth	CN, DS*UG	–	–	+
Rhagovelia nigricans (Burm.)	Eth	CN, DS*JD, JM, JV, CCP, NCP, UG	+	+	+
ODONATA (* = H. Dumont, collected from Dead Sea Area & *in litt.*; ref. 3)					
Anisoptera:					
Aeschnidae:					
Anax imperator Leach	Eth	CN, DS, ?	+	+	+
Anax parthenope Selys*	Eth	DS, ?	+	–	–
Libellulidae:					
Brachythemis leucosticta (Burmeister)*	Eth/Er/Med	DS, JV, UG	+	–	
Crocothemis erythraea (Brullé)	Eth/Med/IT	DS, CCP	+		–
Diplacodes lefebvrei (Ramb.)*	Eth	DS, ?	–	–	+
Orthetrum brunneum (Fonsclmb.)*	Med/ES	DS, ?	+	+	+
Orthetrum chrysostigma (Burm.) (*)	Eth	DS, JV	–	+	+
Orthetrum ramburi (Selys)*	Er	DS, ?	+	–	–
Orthetrum ransonneti (Braver)*	IT/ES	DS, SS	+		–
Sympetrum fonscolombei ? (Selys)	Eth/Med/IT	DS, ?	–	+	+
Trithemis annulata (Pal. Beauv.)	Eth	DS, JV, CCP	+	+	+
Trithemis arteriosa (Burm.)*	Eth	DS, ?	–		+
Zygonyx torrida (Kirby)	Eth	DS, JD	+	+	+
Zygoptera:					
Coenagrionidae:					
Ischnura sp.	-	DS, ?	+	+	–
TRICHOPTERA (* = A. Gasith 1969; ref. 4)					
Hydropsychidae:					
Hydropsyche sp.	Med?	DS, ?	–	+	+

Table 1. (continued).

Taxa	Zoogeography	Israel	En Gedi	N. David	N. Arugot
H. hirra Mosely	Er Eth	DS, JV, UG		–	+
Hydroptilidae: H. odona Mosely		DS		+	+
H. angustata Mosely	Er	DS			+
Hydroptila simulans Mosely*	ES/IT	DS, JV		+	
Ithytrichia ~~sp.~~ dovporiana Botosaneanu	Eth (?) end.	DS, ~~X~~	–	+	+
Philopotamidae:					
Chimarra ~~sp.~~ (*) lejea Mosely	Eth	DS, ~~X~~	-	+	+
Psychomyiidae: (* = Botosaneanu & Gasith 1971; ref. 2)					
Tinodes negeviana Bot. & Gasith*	Er	CN, DS	–	+	–

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(*) = only part of data from reference.
DS* = recorded from other eastern and/or southern Dead Sea springs and not mentioned in text (G. Herbst of IES, *in litt.*).
? = some question about identification or probable incomplete distribution.

Zoogeography:

Med	= Mediterranean	IT	= Irano-Turanian (Central Asia, etc.)
Eth	= Ethiopian Region (= Tropical Africa)	Pal	= Palearctic
Er	= Eremian (= Saharo-Arabian or Saharo-Sindian)	Cosmop.	= Cosmopolitan (= worldwide)
ES	= Euro-Siberian	Or	= Oriental

Israel Distribution:
The abbreviations are from the map of Israel and Sinai (= geographical areas) as used in Furth (1980) the only differences are: JM for the Judean Mountains; SS for all southern Sinai; NS for all northern Sinai; and SN includes the Arava Valley.

Results

Community analysis

The aquatic communities in En Gedi can be divided into two major categories – flowing water and standing water. These categories can be further subdivided based on: strength of the current; physical structure of the streams, including composition of the bottom; submerged vegetation; constancy of water sources and outlets; etc.

The following are the seven aquatic biotopes in En Gedi, according to my analysis:

1) The faster moving stream environments (Fig. 4) with shallow, pebbled bottoms, the water is better oxygenated; velocity is between 31.2 and 62.5 cm · s^{-1}. In this biotope one always finds the naucorid predator, *Heleocoris minusculus,* but few if

Table 2. Ecological biotopes of En Gedi aquatic entomofauna*.

Taxa	Fast	Bdrk.	Slow	Edd.	Deep	Stn.	Stg.
COLEOPTERA							
Dryopidae:							
Dryops sulcipennis?	+	–	–	(+)	–	–	–
Dytiscidae:							
Aglymbus gestroi	–	–	–	–	–	+	+
Guignotus major	–	–	(+)	–	(+)	+	+
Hyphydrus pictus	–	–	(+)	–	(+)	+	+
Laccophilus hyalinus	–	–	+	–	(+)	+	+
Potamonectus lanceolatus	–	–	(+)	–	(+)	+	+
Prodacticus pictus	–	–	–	–	–	+	+
Helodidae:							
Hydrocyphon deflexicollis?	–	–	+	(+)	–	–	–
Hydraenidae:							
Ochthebius sp.	–	–	+	+	–	+	–
Hydrophilidae:							
Coelostoma sp.	–	–	–	–	–	–	+
Laccobius sp.	+	–	+	+	–	(+)	+
? sp. #1	–	–	+	(+)	(+)	–	–
? sp. #2	–	–	+	(+)	(+)	–	–
DIPTERA							
Ceratopogonidae:							
Bezzia sp.	–	(+)	+	+	–	–	–
Chironomidae:							
Chironomus sp.	–	–	–	–	–	+	+
Chironomid spp.	+	(+)	+	(+)	+	+	+
Culicidae: (see Margalit & Avrahami, 1973, Margalit & Tahori, 1973, 1974)							
Culicid spp.	–	–	+	+	–	+	+
Dixidae:							
Dixa sp.	+	–	+	+	–	–	–
Ephydridae:							
Brachydeutera argentata	–	–	–	–	–	+	+
Psychodidae:							
Psychoda sp.	–	–	–	–	–	+	+
Simuliidae:							
Simulium ruficorne	+	+	+	–	–	–	–
Syrphidae:							
Eristalinus tabanoides	–	–	–	–	–	+	+
Eristalis tenax	–	–	–	–	–	–	+
Tabanidae:							
Tabanus sp.	+	–	(+)	+	–	–	–

Table 2. (continued).

Taxa	Fast	Bdrk.	Slow	Edd.	Deep	Stn.	Stg.
EPHEMEROPTERA (see Samocha 1974 for details)							
Baetidae:							
Baetis sp.	+	-	+	+	-	-	-
*Cloeon dipterum***	-	-	+	-	(+)	+	+
Caenidae:							
Caenis macrura	+	(+)	+	+	+	+	+
HEMIPTERA							
Corixidae:							
Corixa affinis	-	-	-	-	(+)	+	+
Sigara marginata	-	-	-	-	(+)	+	+
Hebridae:							
Hebrus pusillus	(+)	-	+	(+)	-	-	-
Hydrometridae:							
Hydrometra stagnorum	-	-	-	-	-	+	+
Mesoveliidae:							
Mesovelia vittigera	+	-	+	+	(+)	-	-
Naucoridae:							
Heleocoris minusculus	+	+	+	+	+	+	+
Nepidae:							
Laccotrephes fabricii	-	-	-	-	-	+	+
Notonectidae:							
Anisops varia	-	-	+	-	(+)	+	+
Veliidae:							
Microvelia gracillima	-	-	+	+	-	+	+
Rhagovelia nigricans	+	+	+	+	+	+	+
ODONATA							
Aeschnidae:							
Anax imperator	-	-	+	-	-	+	+
Libellulidae:							
? sp. #1	+	+	+	+	+	+	(+)
? sp. #2	+	+	+	+	+	+	(+)
Coenagrionidae:							
? spp.	(+)	-	+	(+)	+	-	-

Table 2. (continued).

Taxa	Fast	Bdrk.	Slow	Edd.	Deep	Stn.	Stg.
TRICHOPTERA							
Hydropsychidae:							
Hydropsyche sp.	+	-	-	-	-		
Hydroptilidae:							
Hydroptila simulans	(+)		+	-	-	-	-
Philopotamidae:							
Chimarra sp.	+		+	-	-	-	-

* Biotopes = Fast streams; Bedrock (Bdrk.) streams & pools; Slow streams & pools; Eddies (Edd.); Deep pools; Standing pools (Stn.); Stagnant pools (Stg.).

(+) = not yet recorded in the biotope, but predicted to be found there.

** *Cloëon dipterum sensu lato*, see text for explanation.

any other aquatic predatory Hemiptera or Coleoptera. In the truly aquatic orders of insects, one may expect to find nymphs of the Mayfly genus *Baetis* and the Caddisfly, *Hydropsyche* sp. Black Fly larvae and pupae (*Simulium ruficorne*) have been found in shallow, fast-moving, well-oxygenated parts of the streams, especially at small waterfalls. Libellulid dragonfly naiads of at least two species are often found attached to the rocks or other substrate in the swift water. The hydrophilid *Laccobius* sp. may be found in this habitat if there is some submerged vegetation. The dixid midges (*Dixa* sp.) are also characteristically found on debris in swift water.

2) In many places the fast-moving streams flow over bedrock substrate with little or no loose stones or debris on the bottom, only algal growth and *Melanopsis* snails. *Hydropsyche* sp. can be found in such a biotope as well as surface feeding *Rhagovelia nigricans*. *Simulium ruficorne* larvae are also found in this habitat sometimes and also potentially other insects mentioned above in fast-flowing streams.

3) In the categories of slow-moving water are the slow streams and small basins or pools with relatively a lot of vegetation and often some mud or silt-like deposits on the bottom. The velocity of the slow streams and pools is approximately 12.5–18.8 $cm \cdot s^{-1}$. These pools offer habitats richer in organic matter than most of the other biotopes; such vegetated, silt-bottomed pools are more common in N. Arugot than in N. David. In such pools one finds any or all of the Mayfly species, especially *Caenis macrura* and *Cloeon dipterum*.

Also, this habitat is a very likely one for the Odonata families Libellulidae, Coenagrionidae, and Calopterygidae, especially the Damselflies (Zygoptera). Of the predaceous bugs, *Heleocoris minusculus*, especially the smaller nymphs, is evidently the most common in slow-moving water as well as adults of *Rhagovelia nigricans* on the open water surface.

The Water Treader, *Mesovelia vittigera*, is likely to live in this habitat and Notonectidae, especially *Anisops varia*, can be found occasionally in this environment. In slow-moving water it is quite common, especially in N. Arugot, to find large mats of filamentous green algae (= *Cladophora* & *Spirogyra*) or often submerged terrestrial vegetation (Fig. 2). Such submerged or floating vegetation is the primary habitat of *Laccobius* sp., *Ochthebius* sp., *Hebrus pusillus*, libellulid naiads, mayfly nymphs especially *Caenis macrura*.

Even larvae of various species of chironomids are associated with either the silt bottom or the vegetation in such slow-moving streams or pools.

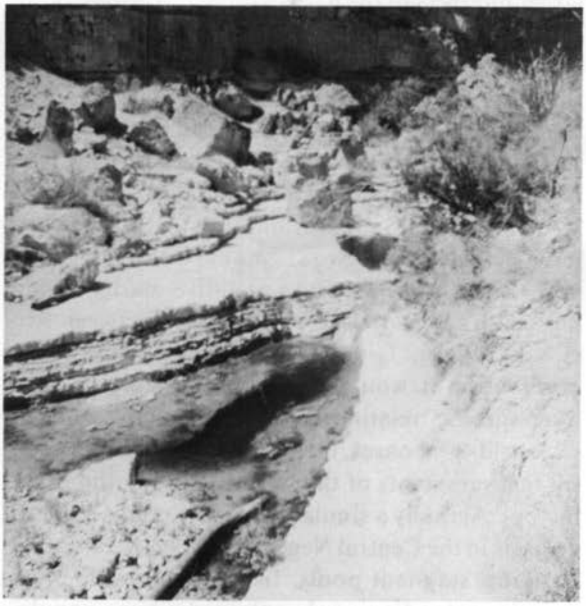

Fig. 2. Slow-flowing stream and pool biotope, with *Cladophora/Spirogyra* algal mats along the sides; Nahal Arugot.

Fig. 3. Slow-flowing stream with deep pool biotope, partly shaded by Willow trees; Nahal Arugot.

4) The eddies in the slow or fast-moving streams provide a habitat of relatively quiet water away from the main current (Fig. 2). This micro-habitat is usually different in its substrate (bottom), vegetation, temperature from the main stream because of its more gentle current. The most characteristic inhabitant of this biotope in the En Gedi fauna is *Rhagovelia nigricans* and to a lesser extent *Mesovelia vittigera*, both surface dwellers. Beneath the water surface, *Heleocoris minusculus* can also be found rather commonly. It is possible to find species of the Mayfly genus *Baetis* and potentially some Anisoptera (Odonata). Also living sometimes in exceptionally slow-moving eddies may be the larvae and pupae of mosquitoes, especially species of *Culex* and *Anopheles*.

5) Rather characteristic of the streams in En Gedi are relatively large, deep pools (1–3 m in depth and of various sizes) (Fig. 3). The upper layer of such pools may be different from the lower layers with respect to current, temperature, nutrients, etc. There is likely to be more organic matter on the bottom due to sedimentation and silting effects. Therefore, such a habitat may provide the necessary environment for a variety of insects, including a few of those more often found in standing water. Some of the dytiscid and hydrophilid beetles as well as the corixid and notonectid bugs are potential inhabitants of these deep pools, but not in large numbers. Also, some mayflies such as *Caenis macrura* and *Cloeon dipterum* and some Odonata naiads, especially the dragonflies (Anisoptera) can be found in deep pools. *Heleocoris minusculus* is also

Fig. 4. Fast-flowing stream biotope; Nahal David.

found in smaller numbers here. When roots or other parts of vegetation penetrate the water at the edges, this adds the potential for those insects associated with vegetation to be found in these deep pools.

6) Standing water pools with any input and/or outlet can probably be grouped faunistically and ecologically with the stagnant pools; however, there are some subtle differences that are worthy of note and separation. The relative amount of algal growth, organic matter, temperature, oxygen content, and salinity are probably somewhat different in the standing versus the stagnant pools; however, this study did not attempt to measure these variables. These factors may affect the relative abundance of particular species of the aquatic insect populations. Standing water (in the broad sense, including stagnant water) in En Gedi is the primary habitat for: Dytiscidae; some Hydrophilidae; Corixidae; Notonectidae; Nepidae; Hydrometridae; some Veliidae; Culicidae; some Chironomidae (e.g. *Chironomus*) and some Ephydridae. In addition, some Mayflies (e.g. *Cloeon* and *Caenis*) and various Diptera are also components of this habitat. On the surface of standing water one often finds *Rhagovelia* and *Microvelia*, usually winged adults. It is interesting to note that most of the above-mentioned insects are predators. Standing pools, however, are often very productive in vegetation, i.e. algae, and various organisms that are phytophagous or scavengers. Mosquito larvae and pupae presumably provide a good source of food for the many predators of the standing water system.

7) Stagnant pools of various sizes are primarily found at the entrance (= downstream) and at the inland-most (= upstream) sources of N. Arugot and in N. David's dry canyon; in most cases these are remnant pools from the winter flood water; they are less oxygenated and support heavy algal growth. They are quite similar in their entomofauna to the above-mentioned standing pool habitat. *Heleocoris minusculus* nymphs were perhaps the most common aquatic summer insects in most biotopes of En Gedi; however, in stagnant pools at the source of N. Arugot only adults were found. An interesting phenomenon was noticed in two adjacent stagnant pools near the upstream-most sources of N. Arugot. The most stagnant of these two pools contained large numbers of the water boatman, *Sigara marginata*, and the other pool contained even larger numbers of the backswimmer, *Anisops varia*. Neither pool had a mixture of these two predatory bugs (*Sigara* may be phytophagous also) even though the quantity of mosquito larvae as well as other ostensible factors seemed approximately the same in the two pools. Possibly there was some type of inter-specific competition and/or exclusion, or some very fine ecological limiting factors that differed between these two stagnant pools. The subtle differences in submerged vegetative matter would not cause such a dramatic separation between two closely adjacent faunas. Since this was only a single observation it would be worthwhile to study the inter-specific relationships in stagnant pools of such arid-land oases, including detailed limnological measurements of the water qualities and other factors. Actually a similar observation was made at an oasis in the Central Negev Desert in two adjacent standing/stagnant pools. In this case a large and very deep standing pool contained a huge population of *Corixa affinis* and a closely adjacent, shallower, stagnant pool contained *Notonecta maculata* and *Anisops varia*, each occupying a separate niche in the stagnant pool. However neither pool contained any combination of the two families of water bugs. A few insects are more typical of stagnant water: the water measurer appropriately named *Hydrometra stagnorum;* the large water scorpion, *Laccotrephes fabricii;* the diving beetles, *Prodacticus pictus;* and *Aglymbus gestroi;* rat-tailed maggots, *Eristalinus tabanoides, Eristalus tenax;* the shore fly, *Brachydeutera argentata;* and various mosquitoes, such as species of *Culex, Culiseta, Anopheles.*

The following were in the stagnant pools of N. Hever in 1969: *S. marginata; A. varia; Rhagovelia nigricans; P. pictus; Hyphydrus pictus; Rhantus includens; Guignotus major;* and *Potomonectus lanceolatus.*

Aspects of the En Gedi aquatic entomofauna

COLEOPTERA

Dryopidae: Long-toed Water Beetles
Dryops sulcipennis? was found on the stones in the fast-running streams of N. David where some vegetation, especially roots of *Phragmites*, penetrate the stream edges and is probably the site of larval activ-

ity. *Dryops sulcipennis* has also been found in slow-moving streams of N. Arugot (G. Wewalka, *in litt.*).

Dytiscidae: Predaceous Diving Beetles

In desert areas like En Gedi, most dytiscids can be found in both slow-moving water as well as the standing and stagnant pools. Certain species such as *Prodacticus pictus* are only found in stagnant pools, while others like *Aglymbus gestroi* and *Guignotus major* are found in standing pools or slow-moving pools with vegetation. The larvae and adults are major predators of other aquatic insects probably including mosquito larvae and pupae. Several other species of dytiscids recorded in the Dead Sea area (G. Wewalka, *in litt.*) may be eventually found in En Gedi: *Eretes stictius* (Linn.); *Guignotus signatellus* (Klug); *Hydroporus mariannae* Wewalka; *Potomonectus crotschi* (Preud.); and *P. cerisyi* (Aubé).

Helodidae: Marsh Beetles

Adults of *Hydrocyphon deflexicollis?* have been found in the slow-moving, algal-matted streams of N. Arugot. Probably both larvae and adults are associated with the *Cladophora/Spirogyra* algal mats there.

Hydraenidae: Minute Moss Beetles

Ochthebius sp. larvae and especially adults were found quite commonly in the algal mats (*Cladophora/Spirogyra*) in the slow-moving streams of N. Arugot and are probably scavengers. *Hydraena* sp. (1 specimen) was apparently found in the algal mats of standing water. *Ochthebius muelleri* Ganglbauer, *O. ragusae* Kuwert, and *Hydraena arabica* Balfour-Browne have recently all been found in the Dead Sea Area (G. Wewalka, *in litt.*, determined by M. Jäch) and may eventually be found in En Gedi.

Hydrophilidae: Water Scavenger Beetles

In the aquatic habitats of En Gedi, hydrophilids were less diverse than the dytiscids but were often found in larger numbers near the shore where the movement of the water was less and the vegetation was denser. They apparently get some protective shelter from such dense littoral vegetation. *Laccobius* sp. was most commonly found in slow-moving streams or pools, especially amongst the green filametous algae. They may be also found in the faster streams or deep pools, but only rarely. *Coelostoma* sp. was found in the wet gravel next to standing or stagnant pools, especially in narrow parts of the canyons where pigeon guano was abundant. They apparently feed on decomposing pigeon guano. Two other, as yet undetermined, hydrophilids were found in slow water of N. Arugot. *Berosus* sp. was found in the Dead Sea Area (G. Wewalka, *in litt.*, determined by M. Jäch).

DIPTERA

Ceratopogonidae: Biting Midges or Punkies

Blood feeding adults of seven species of *Culicoides* have been found in En Gedi primarily through light trapping (Braverman *et al.* 1981); their aquatic larvae are probably scavengers along the shores or in the algal mats. The larvae of another genus, *Bezzia* sp., was found amongst the floating mats of filamentous green algae (*Cladophora/Spirogyra*) in slow-moving streams. The larvae of *Bezzia* are very similar to *Palpomyia:* both are known to be predatory and to breed in a variety of habitats, including algal mats; the adults are of the predaceous type.

Chironomidae: Midges

In En Gedi chironomid larvae (presumably several species) were found in virtually all aquatic habitats; however, they seemed to be most common in slow-moving water with silted bottoms; most are scavengers but some, e.g. *Ablabesmyia* sp., are predatory. *Chironomus* sp. was found in abundance in a stagnant pool near the inland-most sources of N. Arugot. Because they have haemoglobin in their blood, giving them a red appearance, they are able to live in relatively anaerobic conditions such as those that probably exist in the stagnant pools of En Gedi. This nearly anaerobic state would also limit greatly the numbers of truly aquatic insects in some stagnant pool habitats, especially those without vegetation. Many species of chironomids are restricted to specific habitats and thus, when studied more thoroughly, will be very useful as ecological indicators.

Culicidae: Mosquitoes

In En Gedi the five species of *Culex* are probably the most commonly encountered, but four species of *Anopheles* are also present as well as one each of *Culiseta* and *Uranotaenia*. In the flowing streams of N. David and N. Arugot one does not usually encounter mosquito larvae, except possibly at the sides or eddies of the slowly moving pools, but rather in the standing water near the inland-most sources of the canyons and those near to the Dead Sea. The mosquito larvae feed on algae and organic debris. *Anopheles* may also be found where irrigation water has accumulated because of broken pipes, etc. (Furth 1970, unpublished report to the Nature Preserves Authority – Mosquito Project of En Gedi, 1969). In the fall of 1969, many Culicinae egg rafts, possibly *Culex pipiens* or *C. sinaiticus*, in the standing pools at the entrance of N. Arugot. During the same survey in 1969, many *Anopheles* (presumably *sergenti*) were found at sites of broken irrigation pipes near the Youth Hostel in the flat alluvial plain between N. David and N. Arugot. This was the main source of *Anopheles* in En Gedi at that time; very close to human hosts. The Dead Sea Area was only declared Malaria-free by the World Health Organization in 1968. Further details of distribution and associations of the mosqitoes of En Gedi can be found in Margalit & Avrahami (1973) and Margalit & Tahori (1974).

Dixidae: Dixid Midges

The larvae of these midges live in swift-flowing water attached to the downstream side of rocks or floating objects. *Dixa* sp. has been found in fast-moving streams in En Gedi. The larvae were found in a typical U-shaped position near or at the surface. They crawl effectively on the substrate in a characteristic push-pull motion on a film of water. Larval food is believed to consist of microscopic organisms on the surface film or algae.

Ephydridae: Shore Flies

Brachydeutera argentata larvae and pupae have been found in the standing and stagnant pools near the inland-most sources of N. Arugot. The larvae of this species feed as scavengers on old plant material as well as eating green filamentous algae present in such habitats. The pupae float on the water surface and were often found on the shore. The other Ephydridae listed in Table 1 were adults collected by aerial net at En Gedi in 1980 (W. Mathis, *in litt.*), but have larvae associated with aquatic habitats.

Psychodidae: Moth Flies

The larvae and pupae of *Psychoda* sp. have been found only in standing water containing some filamentous green algae and submerged non-aquatic vegetation.

Simuliidae: Black Flies

The filter-feeding larvae and pupae of *Simulium ruficorne* was commonly found attached to the substrate, sometimes bedrock, in the fastest flowing parts of streams often at various small waterfalls or just above such waterfalls, sometimes in large numbers. Larvae of *S. ruficorne* can exist in slow-flowing habitats; adults are ornithophilic (Crosskey 1967).

Stratiomyidae: Soldier Flies

Stratiomys longicornis (Scopoli) was recently reported in En Gedi from the very saline water of the Dead Sea (Freidberg 1981), but it can certainly be expected in the standing or slow-moving pools of fresh water there. Adults of other stratiomyids (with aquatic larvae) have been recorded in En Gedi (see Table 1) as well as four species of *Nemotelus* from other Dead Sea Area localities (Lindner 1974, 1975; Lindner & Friedberg 1979).

Syrphidae: Hoover Flies

The larvae of the Rat-tailed Maggot, *Eristalis tenax?*, was found scavenging in the sewage ponds of Kibbutz En Gedi in 1969. Freshly emerged adults of *Eristalinus tabanoides* were found at a stagnant pool near the inland-most sources of N. Arugot.

Tabanidae: Horse Flies

The predatory larvae of *Tabanus* sp. were found under stones in fast-flowing streams in En Gedi.

Tipulidae: Crane Flies

In En Gedi Crane Fly larvae evidently live in or along fast-flowing streams feeding on decaying vegetable matter.

EPHEMEROPTERA

Baetidae

Species of *Baetis* were quite commonly found in moving water, especially in the faster flowing, well-oxygenated streams, but also in slower moving vegetated pools and streams; they do not exist in standing water. By contrast, *Cloeon dipterum* evidently prefers the standing or even stagnant aquatic habitiats in En Gedi. It is able to maintain full respiratory capacity at low oxygen concentration by producing a water current with its gills. It is known to feed primarily by collecting sedimented algae and detritus, and it can also feed on *Spirogyra* (Cianciara 1980).

Cloeon dipterum has been found to be a complex of at least three species in Europe, including *C. cognatum* Stephans and *C. inscriptum* Bengtsson (Sowa 1975). This may explain its diversity of habitats in Israel; however, in the present study it will be considered as a single taxon.

Caenidae

Caenis macrura nymphs were commonly found in slow-moving pools with mud or silt bottoms and with some vegetation; however, it has also been found in faster flowing streams, especially at the sides (eddies), as well as in standing water. The nymphs of these mayflies probably feed primarily as scavengers of organic (plant) matter.

HEMIPTERA: HETEROPTERA

Corixidae: Water Boatman

Apparently the biotopes of En Gedi are not adequately suitable for a diversity of corixid species. They were more a part of the standing pool community than the flowing streams. The standing or stagnant pools provide a habitat only for *Sigara marginata* (not previously recorded in Israel) commonly and *Corixa affinis* more rarely. It is questionable if they complete their entire life cycle in the En Gedi pools. Many corixids, unlike the other aquatic Heteroptera, are apparently herbivorous although reports of predatory behavior are common. *Sigara lateralis* (Leach) and *S. nigrolineata* (Fieber) can be expected in En Gedi because they are recorded from Wadi Kelt (near Jericho) (Hoberlandt 1951) and especially the former species since it has such a widespread Palearctic, including North Africa and the Middle East, and Oriental range (Brown 1951).

Hebridae: Velvet Water Bugs

Hebrus pusillus was found in considerable numbers in the thicker floating mats of filamentous green algae, primarily in slow-flowing streams and pools, ocassionally in faster water. They were apparently in the submerged parts of the algal mats and on their surface.

Hydrometridae: Water Measurers

Hydrometra stagnorum was collected in 1969 at the inland-most sources of N. Arugot in a standing pool filled with vegetation, especially green filamentous algae: it is also known from En Naka (Dead Sea Area). The biology of this species in Israel has been studied by Salternik (1935; unpublished M.S. thesis, The Hebrew University of Jerusalem).

Leptopodidae: Spiny Shore Bugs

Patapius sinosus has been recorded on the wet gravelly shore of a small waterfall at En Gedi (Linnavuori 1959); however, Linnavuori (1964) later refers to this species as *P. sentus* (Drake & Hoberlandt).

Mesoveliidae: Water Treaders

Mesovelia vittigera was primarily found in slow-flowing streams and pools, in eddies of these habitats, or less commonly in faster streams where vegetation or emergent rocks were common. This species was less common than the other surface dwelling bugs in En Gedi.

Naucoridae: Creeping Water Bugs

Heleocoris minusculus was found in all habitats and is probably the most common aquatic insect there. The nymphs were most common in well-oxygenated fast or slow streams and pools with vegetation. They swim rapidly amongst the vegetation or stones on the bottom, in search of prey and are, at the same time, well camouflaged. They were often the dominant insects in such habitats. Adults were only found in standing water where presumably they could fly either from outside En Gedi or from the nearby flowing streams and pools in En Gedi. The adults were not found in the flowing habitats in the summer season but in the winter. Thus, presumably the adults fly into the flowing waters in the winter season after the floods, mate, lay eggs, and die. In late summer the newly matured adults apparently begin to leave their breeding streams in search of large, permanent or semi-permanent bodies of standing water, some of which were close (within En Gedi), but most of which were probably outside En Gedi in other parts of the Judean Desert or Dead Sea Area.

Nepidae: Water Scorpions

In En Gedi *Laccotrephes fabricii* has been found only in N. Arugot in stagnant pools closest to the Dead Sea. These pools were apparently left from winter flooding with some spring water possibly seeping in from nearby or underground sources. There were usually very few in each pools, possibly due to competition, and they are found near the edges in algal growth or other vegetation. Adults presumably fly, though rarely, to disperse to and from other pools. It is also known from En Nemer (Dead Sea Area).

Notonectidae: Back Swimmers

Both *Anisops* species present in Israel have been found in En Gedi, possibly because of their especially good dispersal ability, most commonly in the standing water habitats.

Anisops varia is probably a breeding resident in En Gedi or nearby, whereas *A. sardea* found once there (G. Herbst, pers. comm.) and *Notonecta maculata* (found in the Dead Sea Area and may be expected in En Gedi) possibly migrate there from areas to the west and north.

Anisops varia is by far more common and may be occasionally found in slow-moving pools or deep pools where there is some amount of vegetation; however, the largest numbers of adults were found in standing water with much aquatic life, often including mosquito larvae.

Veliidae: Riffle Bugs

Rhagovelia nigricans was another of the most commonly encountered aquatic insects in En Gedi. It was found in all habitats, however, most commonly in the eddies of fast flowing streams and in the slower moving streams and pools. Adults and older nymphs were found on the open surface of pools whereas the young nymphs were found near the more protected edges of the pools. Adults could also be found in standing pools. *Microvelia gracillima?* has been found in very large numbers on the surface of large standing and stagnant pools near the inland-most sources of N. Arugot. Both of these veliid species are fully winged in En Gedi.

Other aquatic or semi-aquatic bugs may eventually be found in En Gedi because they have been recorded in the general vicinity (Linnavuori 1960): *Naboandelus popovi* Brown (Gerridae) recorded from Jericho; *Plea automaria* (Pal.) (= ? *pullula* (Stål)) (Pleidae) near Jericho; and the tiny corixid *Micronecta parvula* Lundblad from Jericho.

ODONATA

Anisoptera: Dragonflies

Aeschnidae: Darners

Anax imperator may migrate to En Gedi from considerable distances and breed in the larger pools of the slow-moving streams, deep pools, or in the larger standing pools that also contain vegetation. They are probably the best potential dispersers of all the aquatic insect community in En Gedi.

Libellulidae: Common Skimmers

In En Gedi, Libellulidae were commonly seen along the streams, especially in sunny places. The largest of the common species is *Zygonyx torrida,* which is a strong flier usually seen high above the streams, seldom perching. The other common species which often rest on vegetation or rocks near the water to sun themselves were more commonly observed. The small *Trithemis annulata* was very commonly seen. Also common are: *Brachythemis leucosticta, Orthetrum chrysostigma, Crocothemis erythraea.* The naiads were most commonly found in swift streams, attached to rocks and vegetation, as well as in slow-moving pools with much vegetation. Occasionally they might be found in standing pools, if there is sufficient vegetation in the water.

Paragomphus genei (Gomphidae) has been recorded in the Dead Sea Area (Jericho) and may eventually be found in En Gedi (Dumont, *in litt.*). *Crocothemis sanguinolenta* Burm. has also been recorded in the Dead Sea Area by Morton (1924).

Zygoptera: Damselflies

Coenagrionidae: Narrow-Winged Damselflies

In En Gedi *Ischnura* sp., possibly *I. evansi* Morton or *I. fountainei* Morton, is presumably the most common damselfly; both are known from the Dead Sea Area (Dumont, *in litt.*).

Morton (1924) has also recorded *Epallage fatime* Charp. from the Dead Sea Area. Adult damselflies in general were seen near the edges of streams and pools rather than at standing water. The naiads of Zygoptera were most commonly found in swift-moving, well-oxygenated water and sometimes in slow-moving pools with vegetation. *Pseudagrion syriacum* (Selys) (Coenagrionidae) and *Calopteryx syriaca* Ramb. (Calopterygidae) have been recorded by Dumont (*in litt.*) from the Dead Sea Area of Jordan, and may eventually be found in En Gedi.

TRICHOPTERA: Caddisflies

Hydropsychidae

Hydropsyche sp. larvae were the most common and the largest caddisfly in En Gedi found in the fast-flowing streams and near small water falls in both canyons. Its tube-like retreat, behind the food-catching net by which it scavenges, was usually attached to debris or stones on the stream bottom.

Hydroptilidae: Micro-Caddisflies

Hydroptila simulans has early instars that feed on filamentous algae (they have been reared on *Cladophora*), and they have also been reared in brackish water (Gasith 1969). This species was found in flowing water in En Gedi.

Ithytrichia sp. was found in En Gedi by G. Herbst (pers. comm.).

Philopotamidae

Larvae of this family are found in fast-flowing streams where they build long silken nets from which they scavenge. *Chimarra* sp. has been found in En Gedi only as an adult.

Psychomyiidae

Tinodes negeviana adults have been recorded in N. David. The larvae of this species are not known, but another species in the north builds tube-like structures on the surface of the rocks in swift-flowing streams (Gasith, pers. comm.).

Winter survey

The floods in both N. David and N. Arugot presumably carried away much of the aquatic insect life that was not able to escape by flight as well as much of the vegetation, including the *Cladophora/Spirogyra* algal mats. The last flooding of the two canyons was on December 26–27, 1980, approximately two months before the winter survey. Even though insufficient detail of phenology and life cycles is known, the biological evidence at the time of the winter survey, i.e. algal mat development and life cycle progress of aquatic insect species, suggests that renewal of plant and insect life in the canyons (post-flooding) began more than one month ago. Several significant differences between the winter and summer aquatic insect faunas were evident relative to the types (= species), abundance, and developmental stages in the various aquatic biotopes. At least two new taxa were found, probably due to the difference in season, and other species were either more or less common than they were in the summer survey.

The following are remarks about some of the significant differences between the winter season survey and the summer season survey.

The most common aquatic insect in the summer was *Heleocoris minusculus*, found in the immature (nymph) stage in all biotopes throughout En Gedi; adults were only found in stagnant/standing pools near the sources of N. Arugot. However, the winter survey showed this bug to be relatively less common, not found in standing water, and adults more common than nymphs. Again they were found in most biotopes of both canyons, especially in N. Arugot, but both adults and nymphs were often found together. The nymphs found in the winter were usually tiny or small; thus the development of *H. minusculus* had apparently only begun shortly before this survey (approximately 2–3 weeks). This could be a rough indicator of the time that had elapsed since the last floods; however, not enough is known about the phenology and development of this bug in order to know the exact amount of time required for young nymphs to develop. Another major indicator was the extensive development (especially in N. Arugot) of green filamentous algal mats (*Cladophora/Spirogyra*).

These mats were usually floating or partially submerged in slow-moving pools and streams, but also in standing water and to some degree at the still sides of faster streams. These algal mats evidently provide food and shelter for an interesting complex of aquatic and semi-aquatic insects and this is an important feature of the aquatic habitats in arid zone springs like En Gedi. As in the summer season, adults of the hydrophilid, *Laccobius* sp., were abundant in these algal mats, but also could be found elsewhere, i.e. in bottom debris near shore.

However, during the winter, hydrophilid larvae, presumably of the same *Laccobius* sp., were found imbedded in the submerged parts of the algal mats and apparently feeding on the algae. The apparent larva/adult association for this hydrophilid is a significant discovery; it should be followed up by attempted rearing of the larvae. In the winter, Ceratopogonidae (*Bezzia* sp.) represented a family new to the survey. It is a long, thin, midgelike larva that was also living deep in the algal mats at several stations in N. Arugot, The Mayfly, *Caenis macrura?*, was also found in abundance in the algal mats; however, it was also commonly found in slow pools and streams, standing water, and fast streams (it was much more abundant in the winter than in summer). Several adults of a hydraenid beetle (*Ochthebius* sp.) were also found in the algal mats. Another newly represented group found during the winter is the beetle family Helodidae; adults were found at two stations in N. Arugot associated with algal mats. Mosquito development appeared to be especially more widespread and abundant during the winter season. *Culiseta* sp. was the most common mosquito, found even in the eddies or at the sides of very slow-moving water. In some standing pools the larvae and pupae of *Culiseta* were found by the thousands, e.g. a bedrock pool in upper N. David. This particular pool should have been drained or treated with *Bacillus thuringiensis israeliensis*, because it was not far from the En Gedi Field School. *Anopheles* sp. (larvae) were also found in small numbers at more widespread stations than in the summer, especially at the still sides of streams. The Black Fly larvae of *Simulium ruficorne* were more abundant than in summer on the bottoms and submerged debris in fast and even some slower flowing streams. Larvae of the dixid midges (*Dixa* sp.) were found on submerged plants in slow-moving streams, especially N. David. There was a distinct recent emergence of at least two species of Mayflies (probably *Caenis macrura* and *Cloeon dipterum*); this was especially evident in N. Arugot and sub-images or their cast skins could be seen floating on the water. A significant discovery was both larvae and pupae of the Caddisfly *Hydropsyche* sp., and it was more abundant than in the summer. At one station in N. Arugot the larvae, pupae, and adults of *Hydroptila simulans* were found; an important phenological fact. In addition to these two Caddisflies, a series of adults of another species, *Chimarra* sp., were collected on the rocks near a slow-moving stream with a small (20 cm) waterfall; larvae of this species are unknown.

As expected, most of the Heteroptera found during the winter survey, e.g. *Heleocoris, Rhagovelia, Microvelia, Hebrus,* were in the adult stage, apparently having dispersed (flown) there from another (non-flooding) permanent spring. Two different dytiscid larvae were found in the last stagnant pool of N. Arugot, where the adults of *Guignotus major* and *Aglymbus gestroi* were found in the summer. There is a possibility that the larvae found were of these two species, but more frequent and careful collections should be made at this pool as well as attempted rearing of these larvae in order to be certain.

Discussion

The aquatic insect community structure of En Gedi can be generally constructed from the taxa in Table 2. This certainly represents at least the major components, although probably a few other minor elements of it are as yet undiscovered. The details of the food chain and exact interactions of these elements in the En Gedi system are not known; however, the general niche of each is apparrent, i.e. predator, herbivore, scavenger, as mentioned in the text above. A few other species of Coleoptera and Hemiptera not listed in Table 1 as well as other records for those species listed (from other Dead Sea springs) will be published in a paper dealing with a broad spectrum biotic study of the entire Dead Sea Region (J. Margalit and C. Dimentman, pers. comm.). It is believed, however, that the present survey was comprehensive enough so that most species not found are probably uncommon and often non-breeding, sporadic immigrants to the En Gedi aquatic ecosystem. Some other Dead Sea or Middle East springs may have certain features that cause differences in the components of the aquatic entomofauna from those in the various biotopes of En Gedi, i.e. brackish or mineral springs, permanent standing pools (wells), springs never disturbed by flooding, little or no human influence, non-dispersing endemics, etc.

The detailed limnological parameters for the various faunal elements or for each type of biotope have not yet been measured but a distinctive pattern of the aquatic entomofauna for each biotope in En Gedi is evident and is a useful indicator for analyzing potential change from unnatural causes.

The seasonal succession of species in the En Gedi aquatic communities is interesting because it consists of quite local immigration, long distance immigration, as well as local breeding generations and their subsequent emigration at the end of the season. Consequently, there is an element of chance and irregularity for some of the less common members of the aquatic biota, yet the primary fauna is generally seasonally and perennially constant. The summer and winter surveys of this study reflect some of the seasonal changes and dynamic aspects of the aquatic ecosystem with its various biota. There is however, need for more continuous sampling at all seasons in order to realize transitions of entire community succession in En Gedi. The aquatic ecosystem of En Gedi is presumed to represent most biotopes and their communities in the arid or semi-arid climates of the Middle East and, thus, it can serve as a model for further studies there.

A major factor in the general ecology of desert springs is that of the winter floods that occur when rain water drains into the catchment areas above (= upstream) the canyons in which a spring is located. These floods often occur suddenly and very forcefully (flash-flooding) and can very quickly change the physical as well as biological aspects of a canyon. These flash floods move large boulders, small stones, debris, and often remove large stands of vegetation (algal mats, large Willow and *Tamarix* trees, areas of *Phragmites*). After each flood new pools are created and old ones eliminated (relative to the previous season) by deposition and elimination of large amounts of small stones and pebbles. Therefore, the various aquatic biotopes change after each flood. Some canyons flood every winter, while others may have a flood once in 10–20 years. These floods also bring an additional source of water into the canyons, which certainly affects the water quality (temporarily) and the aquatic biota. Flooding also eliminates a certain number of the aquatic organisms that are present and these must be replenished by migration or subsequent development and reproduction of the dormant stages and/or those stages that are able to survive the floods in algal mats and other vegetation, fissures in the rocks, etc. Such floods are presumed to be the reason why none of the Dead Sea canyons contain populations of any fishes. In the case of aquatic insects, however, at some stage of their life they are able to fly and so emigration to and immigration from other temporary or permanent bodies of water, is an important factor to the ecology of an oasis like En Gedi.

Flooding in the two canyons of En Gedi is quite common, but N. Arugot floods more often than N. David. This is because the catchment area of N. Arugot is 210 km^2 (an area that receives 384 $mm \cdot y^{-1}$ of precipitation); whereas, N. David's catchment area is only 18 km^2 and receives only 60–70 $mm \cdot y^{-1}$ precipitation. The potential flow of N. Arugot is from 0.5 million $m^3 \cdot y^{-1}$ (= MCM) to 8.0 MCM. The average annual discharge for the three sources in En Gedi: N. David = 1.0 MCM; N. Arugot = 1.26 MCM; and En Gedi Springs = 0.43 MCM (Dalinsky & Priesmant 1973).

En Gedi essentially has a tropical or subtropical arid climate and serves as an isolated tropical environment for Ethiopian (tropical African) and Saharo-Arabian (eremian or desertic) elements of the fauna and flora. Some of these elements are relictual, having been separated from their original African populations (often for a very long time) with no chance of expansion to other such tropical habitats because of various ecological limiting factors. Others of these tropical elements do have exchange (via dispersal to and from) with other populations in the Rift Valley of the Middle East or with African populations. In the case of the aquatic insects in En Gedi, most species evidently have a constant input from other local populations through flight dispersal. Such immigration is especially characteristic for some aquatic Hemiptera and Coleoptera as well as larger dragonflies.

Considering the 79 species the zoogeographical affinities are fairly well known (see Table 1). An analysis reveals the following percentages of zoogeographical affinity: Ethiopian = 31.2; Saharo-Arabian (eremian) = 19.0; Mediterranean = 20.7; Irano-Turanian = 4.4; Euro-Siberian = 8.4; Oriental = 1.0; Palearctic = 8.9; Holarctic = 1.3; Cosmopolitan = 5.1.

The zoogeographical affinities are even more meaningful if the widespread species (Cosmopolitan, Palearctic, Holarctic) are eliminated. Since there is no good method for quantifying biogeographical affinities for species found in two or more regions or subregions, a modification of the method used in Furth (1979, 1980) has been followed. This involves assigning each species a value of 1.0 and dividing it according to its present-day zoogeographical affinities/distribution in the two or more areas (regions or subregions of the Palearctic), i.e. two areas = 0.5 each, three areas = 0.33 each; the percentages are subsequently figured.

The dominant Ethiopian affinity, with a strong influence of Saharo-Arabian affinity, is to be expected in En Gedi. A strong Mediterranean affinity is also no surprise since that element dominates most of the fauna in the areas to the west of the Dead Sea Area. Bytinski-Salz (1961) indicates that throughout Israel insects that are associated with fresh water have an especially strong affinity to the Ethiopian Region. The tropical and arid African influence is especially strong for many animals and plants all along the Rift Valley from the Red Sea coast north to the Sea of Galilee area (Bodenheimer 1935a, 1935b; Zohary 1962; Furth 1975). In the springs, streams and pools in the north of Israel Mediterranean, Irano-Turanian, and Euro-Siberian species of aquatic insects are more dominant, although some of the Ethiopian and Saharo-Arabian species do penetrate those areas, more than terrestrial insect species. It should be remembered that many of the aquatic insects are known to be excellent long-distance dispersers/migrators and, because humidity and often temperature are drastically fluctuating factors, their penetration and survival in non-tropical areas is not necessarily unusual. Therefore, this study provides further evidence for the dominance of African (tropical and eremic) biogeographic elements in the Rift Valley of the Middle East and especially the Dead Sea Area.

In view of the tropical climate and predominance of Ethiopian elements, the aquatic insect fauna of En Gedi is, nevertheless, somewhat depauperate. There seems to be a paucity of many Coleoptera and Hemiptera groups: no Pleidae, Belostomatidae, or Gerridae; few corixids; no haliplidae, Gyrinidae, Elmidae; and few Hydrophilidae. Most of these families have been recorded in the Dead Sea Area and may be eventually expected in En Gedi, but rarely. The reason for this paucity is not clear although it may be somewhat related to the absence of true aquatic vegetation in the canyons of En Gedi. Such vegetation usually supplies nutrients and shelter for a large number of aquatic insect species. This lack of aquatic vegetation may also be due, at least partially, to the intense annual flash flooding. Some of this phenomenon may be caused by the fact that generally desert regions are more depauperate of fauna and flora and, thus, possibly a variety of factors have isolated this semi-tropical oasis from many aquatic insects that do not disperse well and/or have not been able to colonize it from great distances.

It is difficult to separate any one or two biotopes of the seven mentioned below as the most important or endangered in En Gedi. All biotopes are part of the semi-tropical, desert oasis aquatic ecosystem and are necessarily parts of a continuous system. Basically they are all inter-connected and intermittently dispersed in an irregular manner and the pattern of pools and streams changes after each flood. Only the standing and stagnant pools are often somewhat disjunct from the other biotopes in that they have no (or little) flow of water connecting them to the slow and fast-moving streams and pools. In fact, in these two biotopes one finds the greatest diversity of aquatic insects, including many of the larger predatory species. It is often these biotopes of standing water that are in danger of being drained or drastically altered (usually with insecticides) by man. Therefore, ironically, it is these standing water biotopes that must be initially preserved. As mentioned above, any decrease in the natural flow, usually because of increased human useage of water ('hydraulic pollution'), will change the other biotopes and will probably create more (too many) standing pools. In the situation of En Gedi, the standing and stagnant biotopes can probably be restricted to those parts of the canyons above the sources of the springs and, thus, not frequented by tourists and furthest from the resident populations of En Gedi. Therefore, there will be less need for altering them to control pestiferous mosquitoes.

Historically En Gedi has been an agricultural settlement since ancient times; however, only recently (1953) Kibbutz En Gedi was founded and modern agricultural practices have been developed there. No attempt has been made to evaluate the effect of modern agriculture on the aquatic insect fauna of En Gedi in detail. However, one effect has been the increasing use of water for irrigation and drinking which is taken out of conduits from N. David and N. Arugot. This has considerably decreased the extent of aquatic habitats in these two canyons, which at one time presumably flowed into the Dead Sea. Also, this water is extracted periodically according to need and therefore, there is an irregular fluctuation in the amount of water available to flow through the canyons. Thus, the aquatic environments in N. David and N. Arugot go through periodic fluctuations to which the insects, vegetation, and other inhabitants have to adjust.

However, probably the greatest effect on the aquatic fauna of En Gedi was because of the Ministry of Health's mosquito control program in the 1960s (mainly against malaria bearing *Anopheles*) for which they sprayed DDT into the water of N. David, N. Arugot, and En Gedi Springs (near their sources). Besides being rather ineffective at controlling the mosquito problem, especially *Anopheles*, in En Gedi, this procedure eliminated or endangered much of the aquatic fauna of En Gedi's fresh water systems during its use. Some details of this DDT useage in En Gedi and its effects were mentioned in an unpublished report submitted by the author to the Nature Preserves Authority, the En Gedi Field School, and the Tel Aviv University in 1970. Shortly after this use of DDT was stopped in En Gedi and since that time the aquatic fauna there has flourished and extended its range within the fresh water habitats of En Gedi. This change was most easily seen in the expanded distribution of the frogs (*Rana ridibunda* Pall.) and the fresh water crabs (*Potamon potamios* (Ol.), especially in the canyons. Details of aquatic insect distribution were not adequately known for a comparison. Fortunately resevoirs of En Gedi's aquatic fauna existed outside of the DDT-sprayed areas and were able to repopulate the canyons of En Gedi after the cessation of DDT application.

Almost all of En Gedi's fresh water springs are part of the Nature Reserve there and are, therefore, protected areas. However, steps must still be taken to assure proper protection and management of the ecological balance of the various aquatic niches. The recent tendency of decreasing or changing types of agriculture and the increasing populations of people living in or visiting En Gedi, may create an increased demand for water and, thus, there is a danger of 'drying up' many aquatic habitats in the canyons. Increased tourism in the canyons also poses threats to certain habitats through pollution, physical damage, or careless management by changing the preserve to accommodate more tourists. Certain more remote parts of both canyons and En Gedi Springs should be designated 'off limits' to tourists to protect these areas. This has been done to some extent but perhaps it would be wise to expand or better enforce these protected sections.

The winter season seems to be the best (most active) time for monitoring and potentially controlling of the mosquito populations in En Gedi, at least *Culiseta* and *Anopheles*. However, it is suggested that any control measures use *Bacillus thuringiensis israeliensis* and that even this should not be used in the distant parts of N. Arugot that are not visited by hikers. This will allow the truly natural aquatic ecosystems and food chains of this oasis to function without disturbance.

It would be extremely useful to rear some of the aquatic insects of the En Gedi ecosystem. Some of these may be reared with a rather simplified system of aquariums and an aerated inflow or circulation of water. This would give valuable phenological and ecological information that could be used as precise indicators in predicting and estimating seasonal changes and the ecological influences of the En Gedi ecosystem. For example, very little at all is known about the Odonata immatures, especially the nymph/adult associations. This order contains major aquatic predators and the two or three common species of Libellulidae and one or two species of Coenagrionidae could probably be reared easily. Other species that would be useful to rear are: *Laccobius* sp.; various dytiscid species from the standing pools; Ceratopogonidae (*Bezzia* sp.).

Of course, it would also be very informative to continue regular general collections/surveys of the aquatic insects of the En Gedi aquatic biotopes, recording the various ecological/limnological data, i.e. dissolved oxygen, salinity/conductivity, water volume and velocity, and temperature. All this information can be used to better understand and preserve the water quality of Middle East arid zone ecosystems of which En Gedi is one of the most diverse and unique.

Summary

Summer and winter surveys of the aquatic entomofauna were made at the Dead Sea oasis of En Gedi, Israel. Table 1 gives an entomofaunal list of taxa recorded in En Gedi and in each of the two canyons there, including their zoogeographical af-

finity and Israeli distribution. There is a dominant zoogeographical affinity to the African (tropical and arid) with 31% Ethiopian, 19% Saharo-Arabian and also strong affinity to the Mediterranean (21%).

The aquatic habitats were divided as follows into seven biotopes according to their physical and some biological criteria: fast- or slow-flowing streams and pools; eddies; bedrock or deep pools; standing or stagnant pools. A community analysis of each biotope was given in Table 2 for the primary taxa. Some taxa are restricted to certain biotopes (stenotopic): *Simulium ruficorne* (Diptera) and the Trichoptera, to fast-flowing waters; Coleoptera (*Laccobius, Ochthebius*) and surface Hemiptera (*Hebrus, Microvelia*), to slow-moving water and usually associated with *Cladophora/Spirogyra* algal mats; and predatory Dytiscidae, Notonectidae (*Anisops*), Nepidae (*Laccotrephes*), as well as scavengers like mosquito larvae (*Anopheles, Culiseta*) and Corixidae (*Sigara*), found mainly in standing/stagnant water. The commonest (eurytopic) species were *Heleocoris minusculus* and *Rhagovelia nigricans*, both predatory Hemiptera.

Bio-ecological and local distributional information about most of the En Gedi species in Table 1 and predictions of other taxa recorded in the Dead Sea Area are provided. A comparison of the summer and winter fauna indicates life cycle differences that involve emigration at the end of their summer development and immigration in the winter from permanent external sources (= dispersal and re-population), because much of the fauna is evidently eliminated annually by winter flooding. It is suggested that parts of En Gedi be especially set aside to preserve all seven biotopes and their aquatic communities which are in danger because of increased agriculture and tourism. The taxa in Table 1 presumably contain almost all of the significant aquatic entomofaunal components of the En Gedi ecosystem so that the analyses made herein are assumed to be indicative of En Gedi and are probably applicable to most Dead Sea springs as well as many springs in the arid zones of the Middle East.

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