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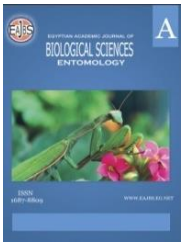

Behavioural Studies of *Enallagma vansomereni* (Odonata: Zygoptera, Coenagrionidae) in Qena Governorate (Egypt)

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ABSTRACT

The behavior of *Enallagma vansomereni* was investigated using mark-recapture techniques across a network of six stations. This study was conducted extensively in Qena Governorate, focusing on the ecology and evolution of this species. While mark-release-recapture methods are feasible for some animals, they present significant challenges for small, fast-moving species like insects. These challenges include low recapture rates, which can introduce biases in estimates of demographic parameters and hinder effective analysis and management of wild populations. In this study, the author utilized mark-recapture methods to examine the daily movement and survival probability of *Enallagma vansomereni*. A total of 2635 individuals (1770 males and 865 females) were marked and measured during the study. Of these, 1476 individuals (56.00%, comprising 1202 males and 274 females) were successfully recaptured. The daily movements of *Enallagma vansomereni* indicated that 1160 individuals were marked, with 1050 individuals observed moving either within or among the stations.

INTRODUCTION

Several studies have explored the behavior, movement, and dispersal patterns of Odonata (zygopteran dragonflies). Obtaining a comprehensive understanding of individual behavior and movements often requires extensive tracking over multiple days. Adult Odonata, in particular, are well-suited for ecological and dispersal studies due to their relatively large size, abundance, diurnal activity, ease of capture, and habitat preference for open areas where they are easily observable (Moore, 1957). Mark-recapture techniques have proven invaluable in these studies, allowing for the identification and subsequent observation or recapture of individuals. Corbet, Longfield, and Moore (1960) reviewed various mark-recapture methods, highlighting cellulose paint as a commonly used and effective tool. Odonata, including damselflies (Zygoptera), have been identified as excellent model organisms for mark-recapture studies (Mollet *et al*., 2015). In many damselfly species, mobility is limited (Ueda, 1976; Garrison, 1978; Parr & Parr, 1979; Utzeri et al., 1984; Banks & Thompson, 1985; Eberhard, 1986). By marking wild individuals, researchers can estimate population densities and key demographic parameters such as survival rates, longevity, and emigration rates.

Odonates have served as valuable model organisms for developing mark-recapture methods due to the ease of obtaining large datasets. One such method for analyzing mark-recapture data was tailored to assess survival rates among age classes in *Enallagma vansomereni*. Furthermore, Van Noordwijk (1978) conducted an extensive study on an odonate community, devising a regression-based approach for analyzing mark-recapture data. More recently, Rassim Khelifa *et al*. (2021) explored the integration of high-speed videos in mark-recapture studies of insects.

Den Boer (1990) defined dispersal as the undirected movement away from the original habitat, contrasting it with migration, and emphasized its significant impact on population dynamics (Dieckmann et al., 1999). Corbet (1980) underscored dispersal as a crucial demographic process in population ecology. Among odonates, temporary emigration for maturation is common in females and teneral individuals (Templeton & Rothman, 1981). McPeek (1989) investigated the varying dispersal tendencies among *Enallagma* damselflies (Odonata) across different habitats in southwestern Michigan, USA, focusing on the mechanisms involved. Despite its importance, the study of damselfly dispersal has been limited by its infrequent documentation, which has hindered investigations into whether certain individuals are more predisposed to dispersal than others (Anholt, 1990).

Most empirical studies on behavior and dispersal of odonate have primarily examined movements within patches (Garrison & Hafernik, 1981; Conrad & Herman, 1990; Jenkins, 2001) or movements between adjacent water bodies (Van Noordwijk, 1978; Koenig & Albano, 1987; Thompson, 1991; Stettmer, 1996). Schutte *et al*. (1997) conducted observations and captures of *Calopteryx splendens* over 64 days between May 16th and August 30th, 1993. Individuals were captured upon initial observation and marked with points on their wings using fast-drying lacquer. However, expansions in distribution due to factors such as deforestation, agricultural and mining development, and global warming have been observed in odonates (Sternberg *et al*., 1999). This suggests that certain species are capable of moving across unsuitable habitats.

Odonata, particularly damselflies, are ideal candidates for detailed dispersal studies due to several factors. Firstly, they are large, conspicuous, and easily handled and observed. Secondly, most dispersal events are relatively straightforward to monitor, as the majority of movements occur between populations inhabiting water bodies less than 1 km apart (Moore, 1953; Stettmer, 1996; Conrad *et al*., 1999). Kelvin Conard *et al*. (2002) investigated the characteristics of distraction *Ischnura elegans* and *Coenagrion puella* (Odonata), including age, sex, size, morphological traits, and ectoparasitism. Male mobility, particularly for those observed infrequently, proved challenging to estimate. Some males exhibited strong site fidelity, while others were sighted at different locations during each observation. Males and several females were gently captured using nets and marked with unique combinations of white and/or red paint spots on the outer edges of their wings. Marked individuals were released back into their capture site after approximately one minute. Mohamed (2024) studied the survival, behavior and mark-recapture of *Ischnura elegans* in Dakahliya Governorate (Egypt).

MATERIALS AND METHODS

Study Sites:

The study directly investigates both within-patch and between-patch dispersal of *Enallagma vansomereni*, utilizing data obtained from mark-release-recapture techniques across six populations located in Nag'e Hamady city, Taramsa village, and Mazlaan in Qena Governorate, Egypt. Understanding movements between these stations is particularly relevant for this rare species, as it inhabits six fragmented habitats in Egypt. The research

aims to assess the variability in dispersal tendencies within the damselfly *Enallagma vansomereni* (Odonata: Zygoptera) populations and explore potential reasons for this variability.

To achieve such research, six stations were chosen in Nag'e Hamady city (4 stations), Taramsa village and Mazlaan in Qena Governorate (Egypt). To survey these above-mentioned insects we used the sweeping net. The field study was conducted from March to the end of August 2022.

Enallagma vansomereni individuals were collected at six stations in Qena Governorate, each station (200 meters) being divided into 20 sections of 10 meters, to determine. The author next examined if significant dispersal occurred between stations by following the *Enallagma vansomereni* composition through the flight season. Dispersal between stations with *Enallagma vansomereni* would be expressed as a change in adult species compositions at one or all of the stations through time.

Although fieldwork was carried out between 21st March and 29th August, covering most of the flight season of *Enallagma vansomereni*. The individuals of each station are distinguished by a different color from the individuals of other stations. Unmarked individuals were each given a number of points on the wings, this means that on the first visit, we made one point on the wing with an indelible pen and on the second time we made two points and so on, and the individual was released at the place of capture. After marking, the damselflies resumed their normal behaviour rapidly. When individuals were recaptured, their sex, the date of marking, the section in which they were recaptured and the number of points were noted.

To employ capture-recapture methods with a mobile animal population, it's essential to mark captured animals individually upon their initial capture, without marking them again subsequently. These individual marks must enable the identification of capture and recapture times for all individuals observed during the sampling period. Capture-recapture data were collected to investigate population structure changes throughout the flying season and to compare the survival rates of newly marked animals with those that had been marked previously but were still alive (Robinson *et al*., 1983).

Daily Movement:

Enallagma vansomereni was observed and captured on one day at six stations: They were captured with a net and marked with consecutive numbers of points on the wings by many colors and then immediately released in the same sector in which they had been captured. During each recapture, the recording involved counting the number of points and noting the wing color.

Size of Population:

The mark-recapture technique is employed to estimate the size of a population when it's not feasible to count every individual. The fundamental concept involves capturing a small sample of individuals, marking them harmlessly, and releasing them back into the population. Later on, another sample is captured, and the number of marked individuals in this second sample is recorded. In smaller populations, the likelihood of recapturing marked individuals is higher compared to larger populations. This relationship can be mathematically expressed using the following equation.

The formula used for estimating the number of individuals in a population using mark-recapture techniques is:

$N = (M.C) / R$

N is the estimated number of individuals in the population.

M is the number of individuals initially captured and marked.

C is the total number of individuals captured during the second sampling session (both marked and unmarked).

R is the number of individuals recaptured during the second sampling session, specifically those that were marked during the first capture.

RESULTS

The relative frequencies of *Enallagma vansomereni* at the six stations are documented in Tables (1 and 2). Movement of *Enallagma vansomereni* within each station section was observed, with some individuals also moving among all stations. A total of 2635 individuals (1770 males and 865 females) were marked and measured throughout the study period, out of which 1476 individuals (56%), comprising 1202 males and 274 females, were recaptured. The recapture rate and sex ratio showed higher proportions for males compared to females across all stations. Both males and females exhibited similar proportions of individuals moving during their lifetime across all stations. In several stations, a significant majority of individuals moved within suitable stream stretches, while a notable proportion remained stationary. A total of 161 *Enallagma vansomereni* individuals migrated, including 135 males (with migration distances of 190m, 200m, 170m, 140m, 200m, and 180m at stations 1, 2, 3, 4, 5, and 6, respectively) and 26 females (with migration distances of 30m, 20m, 30m, 40m, 50m, and 30m at stations 1, 2, 3, 4, 5, and 6, respectively). The distribution of marking dates for individuals who migrated between stations showed a bimodal pattern over the season for *Enallagma vansomereni*. This pattern was largely influenced by extended periods of inclement weather, resulting in fewer markings or recaptures of individuals. A greater proportion of *Enallagma vansomereni* that dispersed were marked early in the season, likely reflecting differences in the emergence patterns of *Enallagma vansomereni.*

Table 1: Total number of marking and re-capture individuals of *Enallagma vansomereni* at stations 1, 2, 3, 4, 5 and 6 in Qena Governorate.

statio	No. of mark	Total no. of marked		No. of recapt.	Total no. of recaptured and percentage				No. and dist. of migration individual					
		Male	Female		Male	%	Female	%	m	%	D	F	%	D
1	14	291	120	17	200	68.7	45	37.5	21	10.5	190	2	4.4	30
2	14	305	150	17	193	63.2	52	34.6	25	12.9	200	3	5.7	20
3	14	304	135	17	205	67.4	42	31.1	23	11.2	170	3	7.1	30
4	14	290	142	17	183	63.1	51	35.9	20	10.9	140	4	7.8	40
5	14	310	158	17	215	69.3	43	27.2	25	11.6	200	5	11.6	50
6	14	270	160	17	206	76.2	41	25.6	21	10.1	180	9	21.9	30

Table 2: Sex ratio of marking and re-capture individuals of *Enallagma vansomereni* at stations 1, 2, 3, 4, 5 and 6 in Qena Governorate.

Station	Total no. sex ratio of marked individuals				Total no. sex ratio of recaptured individuals			
	Male	s. r. %	Female	s. r. %	Male	s. r. %	Female	s. r. %
1	291	70.8	120	29.1	200	81.6	45	18.4
2	305	67	150	32.9	193	78.7	52	21.3
3	304	69.2	135	30.7	205	82.9	42	17.1
4	290	67.1	142	32.8	183	78.2	51	21.8
5	310	66.2	158	33.7	215	83.3	43	16.7
6	270	62.7	160	37.2	206	83.4	41	16.6

Daily Movement:

Table 3 and Figures 3, 4, 5, 6, 7, and 8 illustrate the daily movement patterns of *Enallagma vansomereni* across six stations. At stations 1, 2, 3, 4, 5, and 6, a total of 1160 individuals were marked, including 795 males and 365 females, with varying numbers

marked at each station: 210 (150 males, 60 females), 215 (150 males, 65 females), 180 (140 males, 40 females), 178 (140 males, 38 females), 195 (150 males, 45 females), and 182 (140 males, 42 females), respectively. Throughout the stations, 1050 individuals (720 males, and 330 females) were observed moving within sections or between stations. The specific counts of movers at each station were: 172 (140 males, 32 females), 192 (145 males, 47 females), 170 (130 males, 40 females), 169 (130 males, 39 females), 179 (138 males, 41 females), and 168 (135 males, 33 females). Mobility was measured as the maximum distance between observations of individual movements within stations. Notably, a significant portion of recaptured individuals—41 (23.83%) at station 1, 44 (22.91%) at station 2, 39 (22.94%) at station 3, 40 (23.66%) at station 4, 41 (22.90%) at station 5, and 39 (23.21%) at station 6—moved distances of up to 10 meters. However, a small number of individuals—3 (0.17%) at station 1, 2 (0.10%) at station 2, 3 (0.17%) at station 3, 3 (0.17%) at station 4, 3 (0.16%) at station 5, and 3 (0.17%) at station 6—were observed moving distances up to 360 meters.

Table 3: Daily movement of *Enallagma vansomereni* at stations 1, 2, 3, 4, 5 and 6 in Qena Governorate.

Stations/ distance(m.)	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
10	41	44	39	40	41	39
20	21	23	21	21	21	21
30	5	7	5	5	5	5
40	10	0	10	10	10	10
50	11	0	11	10	11	11
60	14	0	14	14	14	14
70	3	21	3	3	3	3
80	5	0	5	5	7	5
90	8	0	8	8	8	8
100	4	0	4	4	4	4
110	0	0	0	0	0	0
120	0	0	0	0	2	0
130	0	22	0	0	0	0
140	0	17	0	0	0	0
150	0	15	0	0	0	0
160	0	0	0	0	0	0
170	0	0	0	0	0	0
180	3	0	3	3	3	3
190	0	0	0	0	0	0
200	0	0	0	0	0	0
210	0	4	0	0	0	0
220	3	2	3	3	3	3
230	8	3	8	7	8	8
240	6	7	6	6	6	6
250	7	5	7	7	7	5
260	4	3	4	4	4	4
270	5	0	5	5	5	5
280	1	0	1	1	3	1
290	2	0	2	2	2	2
300	0	5	0	0	0	0
310	0	4	0	0	0	0
320	2	2	2	2	3	2
340	2	4	2	2	2	2
350	4	2	4	4	4	4
360	3	2	3	3	3	3
Total no. Of moved indi.	172	192	170	169	179	168
No. Of recaptures	8	8	8	8	8	8

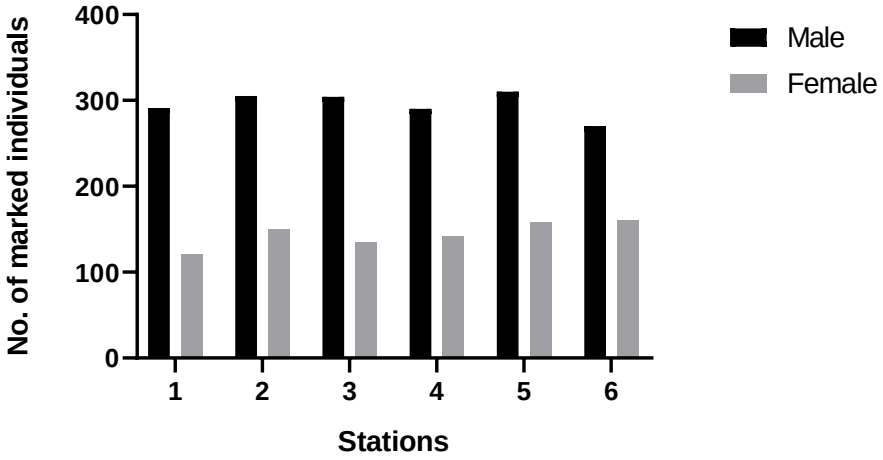

Fig 1: Number of marked *Enallagma vansomereni* at stations 1, 2, 3, 4, 5 and 6 in Qena Governorate.

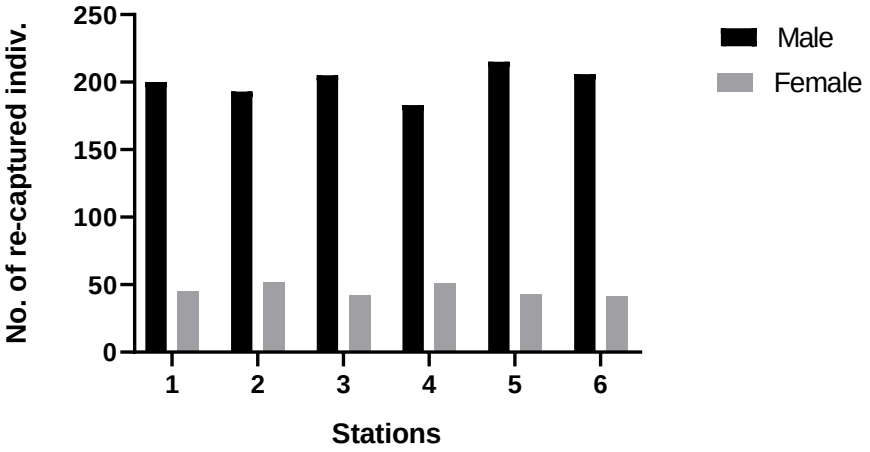

Fig. 2: Number of recaptured *Enallagma vansomereni* at stations 1, 2, 3, 4, 5 and 6 in Qena Governorate.

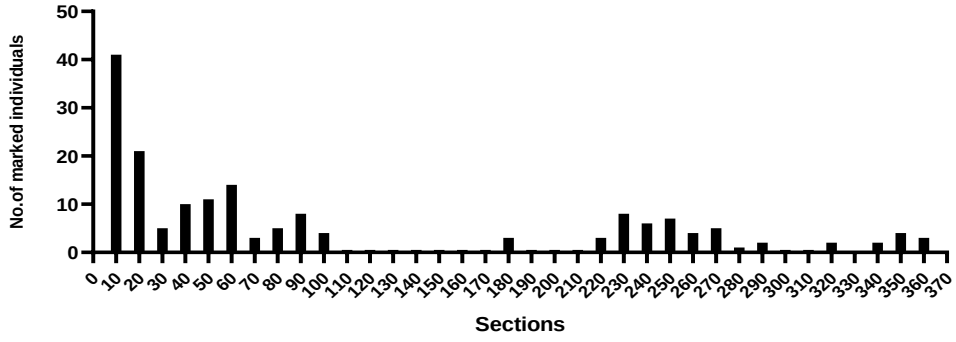

Fig.3: Daily movement of *Enallagma vansomereni* at station 1 in Qena Governorate.

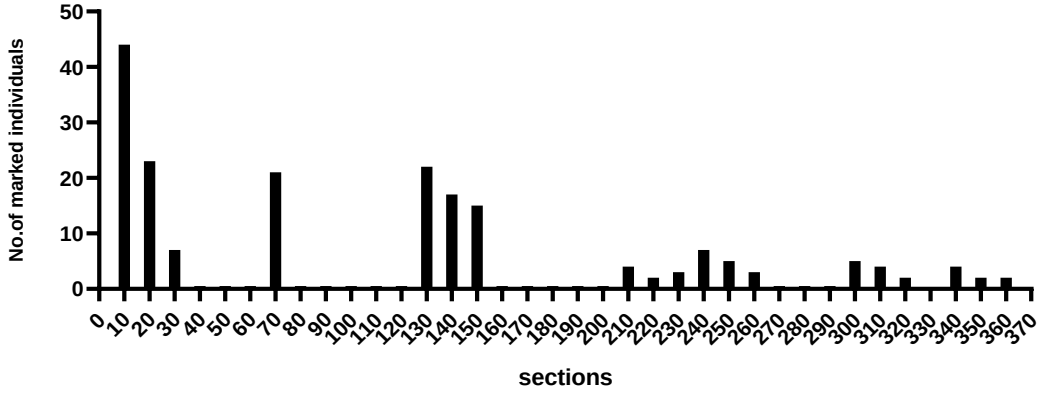

Fig. 4: Daily movement of *Enallagma vansomereni* at station 2 in Qena Governo

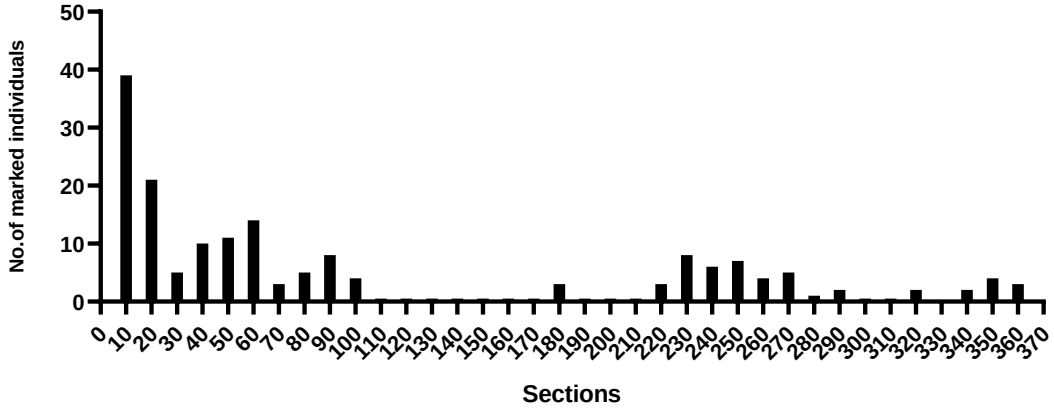

Fig. 5: Daily movement of *Enallagma vansomereni* at station 3 in Qena Governorate.

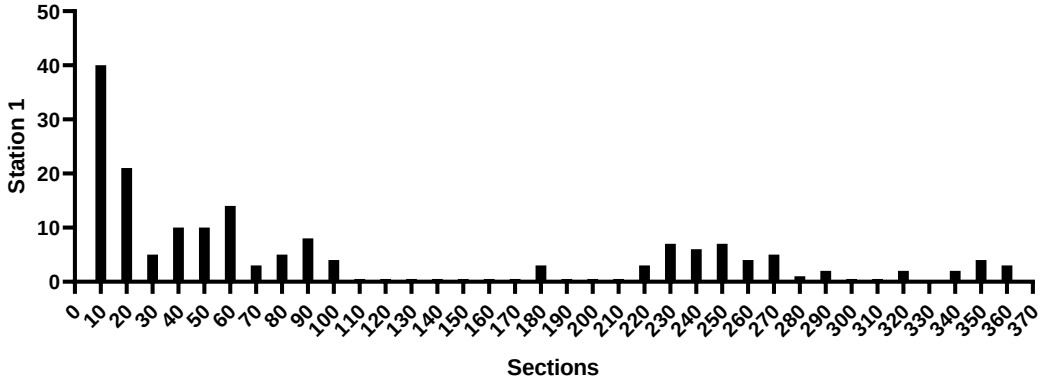

Fig. 6: Daily movement of *Enallagma vansomereni* at station 4 in Qena Governorate**.**

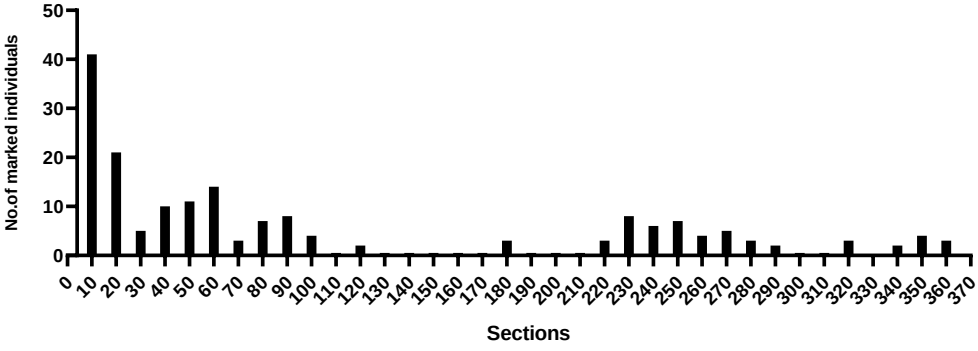

Fig. 7: Daily movement of *Enallagma vansomereni* at station 5 in Qena Governorate.

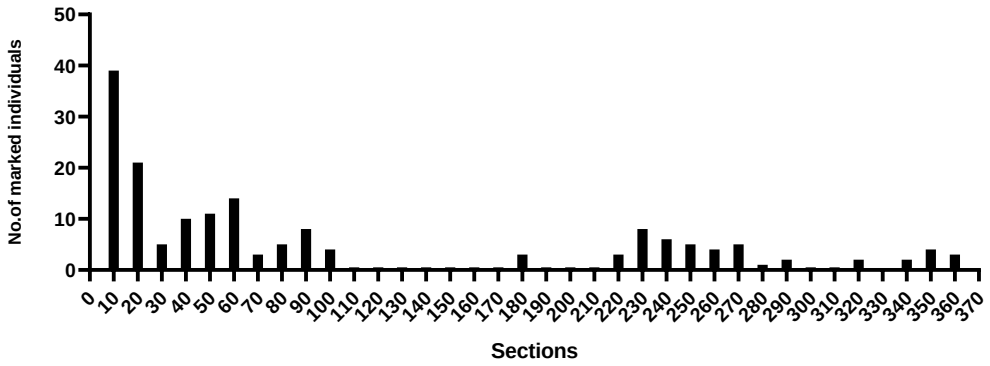

Fig. 8: Daily movement of *Enallagma vansomereni* at station 6 in Qena Governorate.

Survival:

The daily survival probability of *Enallagma vansomereni* was estimated at 86%, with variations observed between males (80%) and females (50%).

Size of Population:

Table 4 displays the count of *Enallagma vansomereni* captured, marked, and subsequently recaptured a week later after they had dispersed into the population. The size of the population in the six stations was 97, 128, 120, 75, 62 and 52.

DISCUSSION

Most of the marked individuals migrated distances of less than one hundred meters, aligning with findings by Schutte et al. (1997), Zohreh *et al*. (2023), and Mohamed, I. (2024). However, St. Quentin (1964) reported much smaller distances, suggesting that these distances may reflect individual home ranges rather than dispersal activities.

McPeek (1989) observed minimal movement between lakes in four *Enallagma* species. Michiels *et al*. (1991) noted that only about 20% of adults were likely to have emerged locally, indicating that the majority had immigrated over distances exceeding 1.75 km. Rainfall can impact survival, although substantial downpours are typically necessary (Cordoba-Aguilar, 1993).

Mark-recapture experiments are often conducted over months or years, resulting in relatively few encounter occasions. In contrast, daily monitoring in adult insect mark-recapture studies yields numerous encounter occasions. Insect studies involve larger numbers of individuals with lower recapture rates due to their small size and high mobility, resulting in sparse data. Consequently, large insect populations may not be suitable for combined analyses of recoveries and resightings, which are effective for unbiased estimations of survival and emigration in vertebrates (Frederiksen & Bregnballe, 2000).

The mobility of *Enallagma vansomereni* observed in this study surpassed previous findings in several aspects. Hunger & Röske (2001) reported that 96% of individuals in a population in southwestern Germany remained within 25 meters of their marking site. In contrast, in this study, a lower proportion (20-47%) of individuals remained within such close proximity, with the majority (46-80%) moving within their natal station. Maximum movements within stations and between stations were notably greater, reaching distances of 610 meters and 1060 meters, respectively, compared to 170 meters and 300 meters observed by Hunger & Röske (2001). *Enallagma vansomereni* exhibited movements of up to 360 meters between stations in the present study, consistent with findings by Hold (1997), Hopkins & Day (1997), Jenkins (1998), and Mohamed (2024). Jenkins (2001) noted a low rate of movements (1/1223 individuals) between adjacent streams (75-150 meters apart) in

the New Forest. In southwestern Germany, the maximum distance between sampled patches was approximately 600 meters (Hunger & Röske, 2001), whereas in Dakahliya, Egypt, it was approximately 230 meters (Mohamed, I. 2024).

Conrad et al. (1999) noted that 15% of recaptured individuals had dispersed to another pond. Den Boer (1990) suggested that weaker fliers might actually be better dispersers than stronger fliers, hypothesizing that they are less able to resist wind-driven movements if dispersal occurs passively.

It is noteworthy that adult *Enallagma vansomereni* were capable of moving significant distances within a single day, with observations of movements up to 360 meters. In contrast, larger zygopterans such as *Calopteryx splendens* and C. Virgo can cover distances of around 1 km within one or two days (Stettmer, 1996).

According to Zohreh et al. (2023), the survival rate of female *I. elegans* was notably lower than that of males. Mohamed (2024) reported a survival rate of 85.0% per day for *I. elegans*, with differences observed between males (81.0%) and females (50.4%). In our study, the daily probability of survival in *Enallagma vansomereni* was estimated at 83%, with variations noted between males (79%) and females (49%).

Declarations:

Ethical Approval: Ethical Approval is not applicable.

Authors Contributions: I hereby verify that the author mentioned on the title page have made substantial contributions to the conception and design of the study, have thoroughly reviewed the manuscript, confirm the accuracy and authenticity of the data and its interpretation, and consent to its submission.

Competing Interests: The authors declare that they have no competing interests.

Availability of Data and Materials: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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