doi:10.5697/oc.56-1.041
OCEANOLOGIA, 56 (1), 2014.
pp. 41–58.

Biometry and reproductive biology of *Pseudonereis anomala* Gravier 1901 (Polychaeta: Nereididae) on the Alexandria coast, Egypt

KEYWORDS
Polychaete reproduction
Pseudonereis anomala
Fecundity
Biometry
Length-weight relationship

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Received 13 June 2013, revised 14 November 2013, accepted 31 December 2013.

Abstract

The biometric characteristics and reproductive biology of the nereid polychaete *Pseudonereis anomala* were studied monthly from August 2009 to July 2010 at two ecologically different sites (Abu-Qir and El-Mex) on the Alexandria coast, south-eastern Mediterranean Sea. The maximum body length and weight showed different values at the two sites: 9.8 and 11.9 cm, and 0.77 and 1.3 g respectively. The formula of the length-weight relationship indicated allometric growth, whereas the regression equation between length to the 6th segment and weight reflected isometric growth. Immature individuals were the major component of the worm population at the two sites, making up 69.1% at Abu Qir and 66.9% at El Mex; the respective percentages of males and females at these sites were 5.8–8.1% and 22.8–27.3%. Spawning was observed all the year round with female fecundity conspicuously lower at Abu-Qir (annual average: $26\,556 \pm 999$ eggs per female) than at El-Mex (annual average: $47\,955 \pm 2916$ eggs per female). However, oocyte

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size was greater at Abu Qir (diameter: up to 250 μm) than at El Mex (diameter: up to 220 μm).

1. Introduction

The great diversity of reproductive forms in Polychaetes (Schroeder & Hermans 1975) may be due to the variation in life history traits with environmental changes, the presence or absence of epitoky, and the reduction or disappearance of the dispersal phase (Olive 1985, Prevedelli & Cassai 2001). Biometry, growth, survivorship, reproduction and productivity have been studied in many different polychaetes in different seas, for example, in *Pectinaria koreni* (Nicolaidou 1983), *Eupolymnia crescentis*, *Neoamphitrite robusta*, *Thelepus crispus* and *Ramex californiensis* (McHugh 1993), *Eunice fucata*, *E. insularis*, *E.* cf. *ornata*, *E. rubra*, and *Eunice* sp. (Costa-Paiva & Paiva 2007), *Namanereis littoralis* (Ezhova 2011) and *Marphysa sanguinea* (El Barhoumi et al. 2013). Furthermore, laboratory biological studies have been carried out on cultures of *Neanthes arenaceodentata*, *Platynereis dumerilii* and *Nereis virens* (Reish 1985, Jha et al. 1996, Olive 1999), while field studies were done on the cryopreservation of polychaete larvae (Olive & Wang 1997), growth and reproduction in captivity (Fidalgo e Costa 1999, Reish et al. 2009), spawning (Watson et al. 2003, 2005), sex pheromones (Bartels-Hardege et al. 1996), breeding and optimisation of the growth process (cf. Olive 1999), and biometry and population structure (Ménard et al. 1989, Omena & Amaral 2000, Dağli et al. 2005).

Nereids are important prey for many crustaceans and fish (Arias & Drake 1995), and many of them are widely used as fishing bait in the sea angling sport and leisure industry in different countries (Luis & Passos 1995, Olive 1999, Fidalgo e Costa 1999, Dağli et al. 2005, Cunha et al. 2005, Younsi et al. 2010). Although numerous studies have been done on the identification, abundance and distribution of polychaetes off the Egyptian Mediterranean coast (Dorgham et al. 2013), very little attention has been drawn to their biometry and reproductive biology.

Pseudonereis anomala Gravier 1901 is a commercially important nereid polychaete in Egypt, where it is usually collected by bait diggers and sold as live bait to fishermen and sea anglers. It is a lessepsian species that has acclimated well to the eastern Mediterranean (Çinar & Ergen 2005) and has become one of the most important invasive polychaetes in the shallow-water benthic communities of the eastern Mediterranean in general (Çinar & Altun 2007) and along the Alexandria coast (Egypt) in particular (Hamdy 2008). The biometry and reproductive biology of *P. anomala* have never been studied in marine habitats anywhere in the world, except for the investigations into its reproduction and feeding behaviour off the coast of

Turkey (Çinar & Ergen 2005, Çinar & Altun 2007). In Egyptian waters, one study was carried out on the spermatogenesis of *Halla parthenopeia* (Abd-Elnaby 2009) and another one on the gametogenesis and spawning of *Spirobranchus tetraceros* (Selim et al. 2005).

The present study is the first one dealing with the biometric measurements and reproductive biology of *P. anomala* and may be treated as a plea for more future studies on the life cycle and other biological characteristics of this species, which would enable its mass production for aquaculture. This study aims to follow up the monthly variation of the biometric measurements of the nereid in question, as well as the sex ratio, fecundity, egg ripeness and spawning season in relation to the environmental conditions along the Alexandria coast.

2. Material and methods

2.1. Sampling sites

Two sites characterised by abundant *P. anomala* were selected along the Alexandria coast, namely, Abu-Qir and El-Mex (Figure 1). Abu Qir is an exposed site on the western edge of Abu-Qir Bay east of Alexandria City, with a bottom containing a chain of natural rocks covered by a rich algal flora. El Mex is also an exposed rocky area on the western part of the Alexandria coast; it is directly affected by industrial, agricultural and sewage discharges.

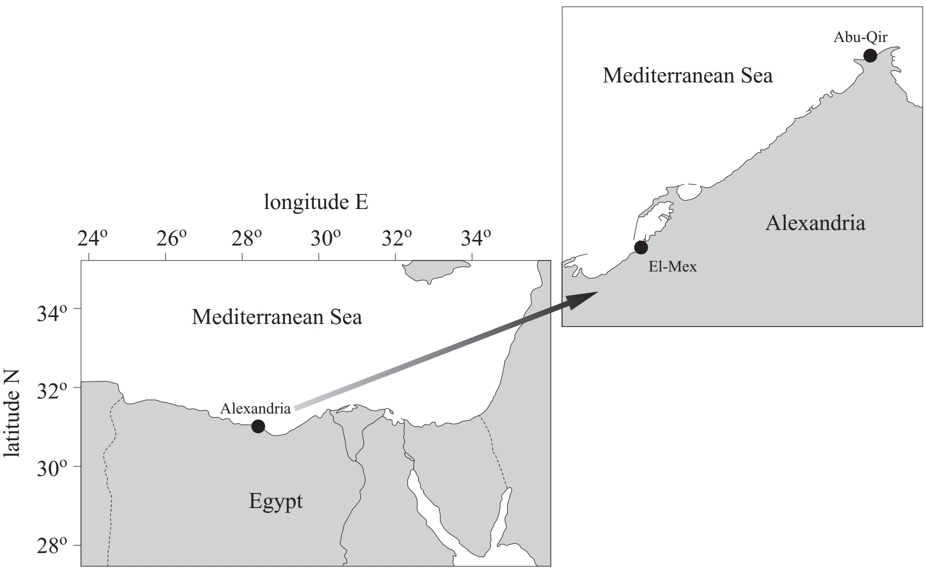

Figure 1. Locations of the sampling sites

2.2. Physicochemical parameters

Salinity, temperature, pH, dissolved oxygen (DO) and biochemical oxygen demand (BOD) were measured concurrently with polychaete collection. Both water temperature and pH were measured in the field using a digital portable pH–°C meter (HANNA 10pH). Salinity was determined with a calibrated salinometer (Beckman, Model RS-7C). DO and BOD were determined according to the Winkler method (Strickland & Parsons 1972).

2.3. Sample collection

The *P. anomala* worms were collected monthly by scraping the benthos from rocky substrates; the samples were placed in 5 litre plastic jars. The worms were sorted, counted and preserved in 4% buffered formalin for the biological observations and finally preserved in 70% ethanol.

2.4. Biometry

Several biometric parameters were measured for each monthly number of worms, namely the total length (TL), length to the 6th segment (L6S), body width at the 6th segment (W6S), prostomium length (PL) and prostomium width (PW). In order to minimise the formalin effect, the biometric measurements were done directly after sorting. The relationships between the biometric parameters were assessed by using regression and Pearson moment correlation analyses. The length-weight relationship was determined according to the allometric equation $W = aL^b$ (Hile 1936, Beckman 1948), where 'W' – total body wet weight [g], 'L' – body length [cm], 'a' – a constant and 'b' – the growth coefficient.

2.5. Reproductive biology

Numerous worms were dissected partially to define the sex and to collect eggs from females. The diameters of about 40 oocytes were measured monthly using an eye-piece micrometer; the mean diameter was calculated. Fecundity expressed as the number of eggs per female was found by counting all the ripe oocytes in the coelom of fully mature, intact, i.e. uninjured, females. Males were identified by the presence of sperm plates or sperm aggregates in the coelomic fluid, while worms without sexual products were considered immature.

2.6. Statistical analyses

The correlations between the environmental conditions and the biological parameters were calculated, and two-way ANOVA analysis was applied to determine whether there were significant differences between the two sampling sites.

3. Results

3.1. Environmental conditions

The water temperature at the two sites demonstrated a clear seasonal variation between the winter minimum (18.1°C) in February and the summer maximum (29.1°C) in July (Figure 2). The pH ranged from 7.85 to 8.60 at Abu-Qir and from 8.10 to 9.00 at El-Mex. Salinity displayed a narrow variation (38.4–39.9‰) at Abu-Qir, in contrast to the wide variation (24.4–39.8%) at El-Mex (Figure 3), which receives a large volume of waste water from El-Umoum Drain. DO was high (7.1–10 mg l^{-1}) at Abu-Qir but varied widely at El-Mex, between 4.4 and 14.6 mg l^{-1}. BOD was lower at the stressed site (El-Mex) (1.1–5.7 mg l^{-1}) than at Abu-Qir (3.3–7.4 mg l^{-1}).

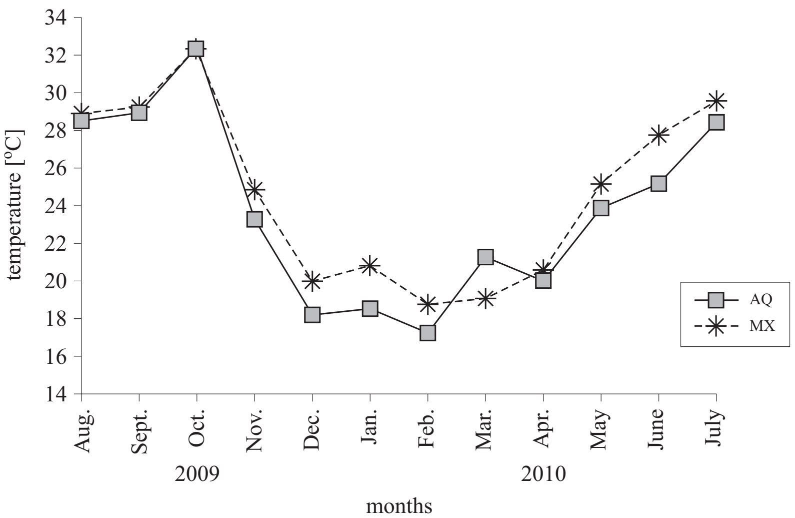

Figure 2. Monthly variation of water temperature at the sampling sites on the Alexandria coast

3.2. Biometric measurements

During the study period the biometric measurements and reproductive examination were carried out on a total of 447 and 822 specimens of *Pseudonereis anomala* from Abu Qir and El Mex respectively. The monthly number of worms examined depended upon their monthly abundance at each site and is given in Figure 4.

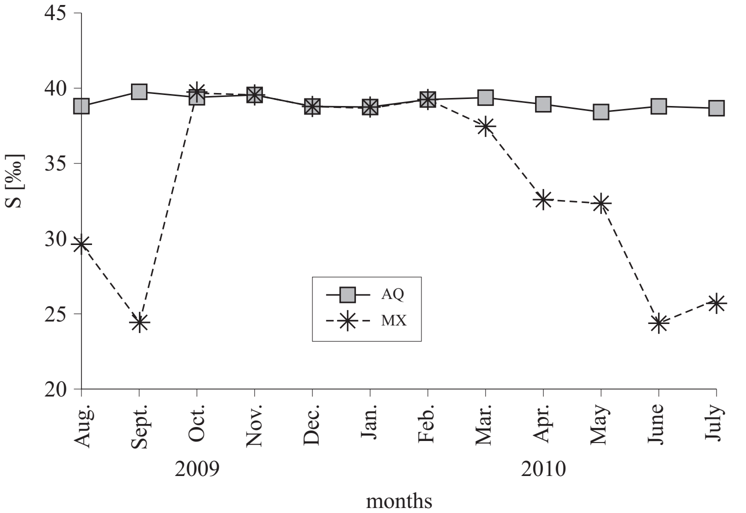

Figure 3. Monthly variation of water salinity at the sampling sites on the Alexandria coast

A high percentage of the worms from Abu Qir (46.2%) were from > 2 to 4 cm long, and a significant proportion (35%) were between > 4 and 6 cm long. Both length ranges were dominant at El Mex but in the reverse order: 31.7% were > 2–4 cm long and 42.9% had a length of > 4–6 cm. On the other hand, shorter individuals (< 2 cm) made a greater contribution to the Abu Qir population (5.9%) than to the El Mex population (1.9%), while longer ones (> 6–12 cm) were less prevalent (13.5%) at Abu Qir than at El Mex (23.5%). The respective lengths of the shortest worms were very similar (1.1 and 1 cm) in both areas, occurring during autumn (September and October respectively). Meanwhile, the longest individuals in the two areas were females, attaining a greater length (11.9 cm) at El Mex in February, against 9.8 cm at Abu Qir in both June and July.

On a monthly scale, the length range of > 2–4 cm prevailed over the > 4–6 cm length range during a significant part of the year at Abu Qir, whereas both ranges made similar contributions during the rest of the year (Figure 4). At El Mex, the range of > 4–6 cm prevailed for most of the year, whereas higher percentages of the > 2–4 cm range were recorded during only 4 months (Figure 5).

The minimum biomass (0.004 g) was the same at both sites in September, but the maximum biomass (0.768 g) at Abu Qir was recorded in both June and July and was markedly smaller than that (1.303 g) at El Mex in February. The majority of the Abu Qir worms (79%) weighted ≤ 0.2 g against 65% at El Mex, but the proportions of the greater weight classes (> 0.2–0.4 g and > 0.4–0.8 g) were lower at Abu Qir (17% and 4%

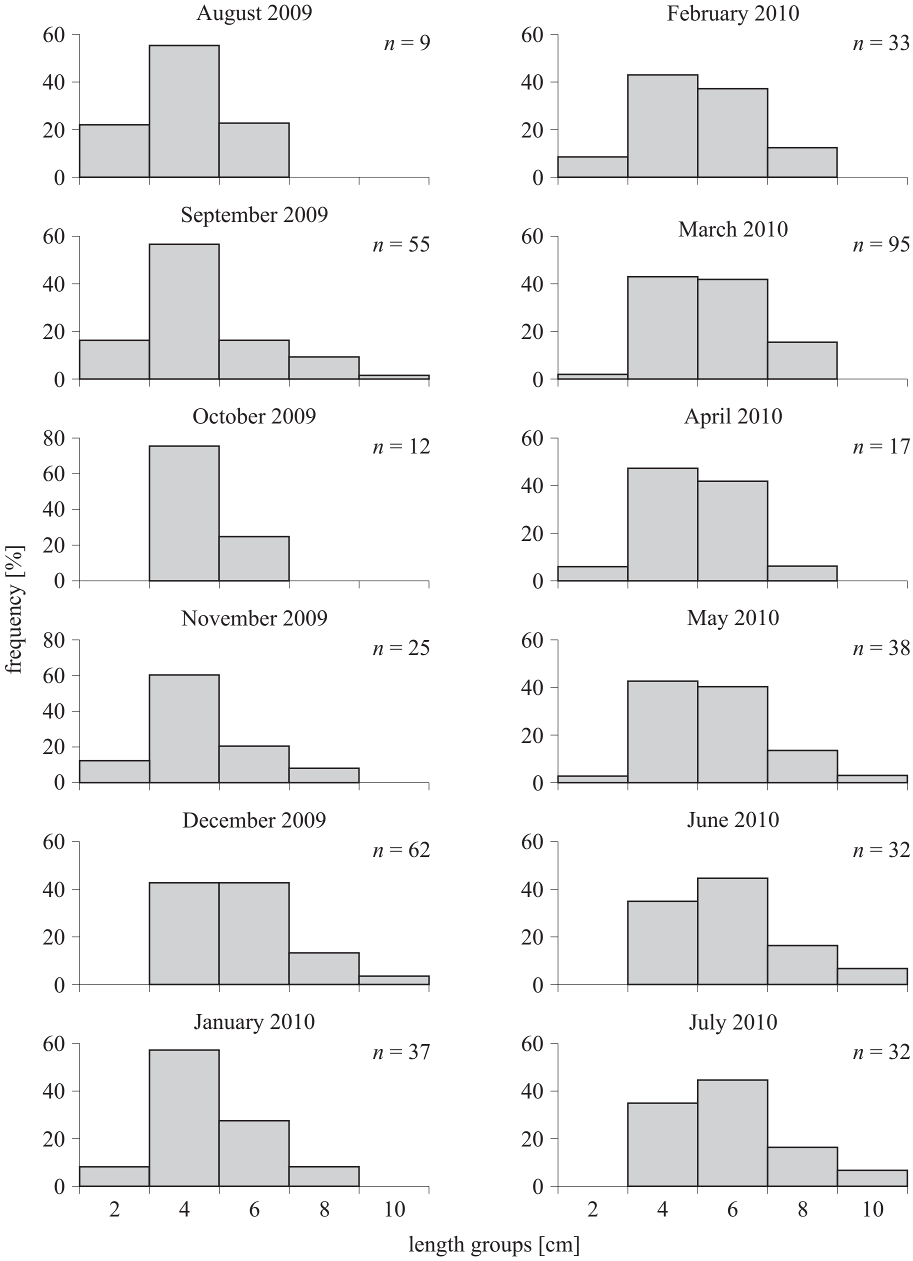

Figure 4. Monthly distribution of length frequency of *Pseudonereis anomala* individuals at Abu Qir (n – number of specimens measured)

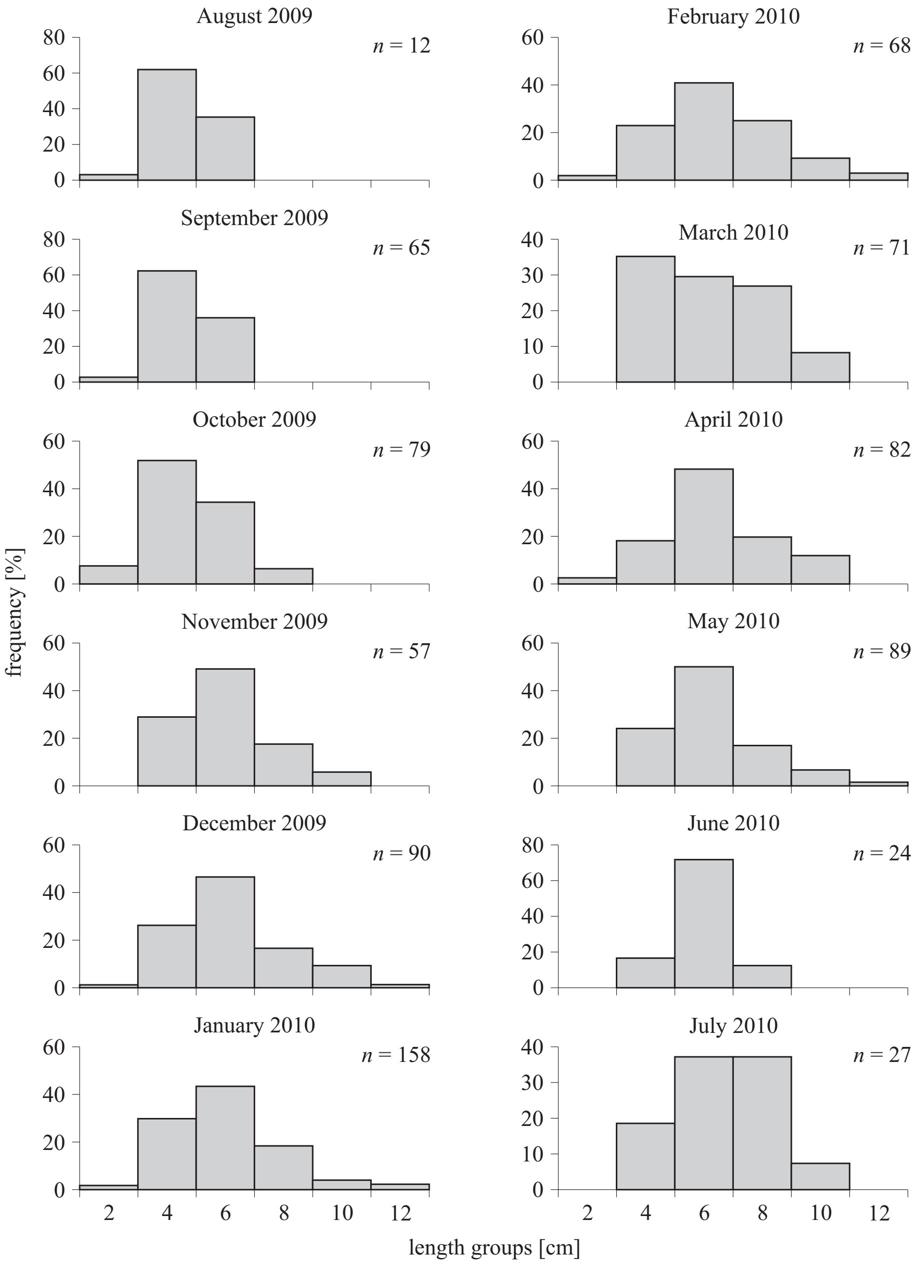

Figure 5. Monthly distribution of length frequency of *Pseudonereis anomala* individuals at El Mex (n – number of specimens measured)

respectively) than at El Mex (22.3% and 10.6% respectively). Meanwhile, worms weighing > 0.8 g made up 2.1% of the El Mex population, but were wholly lacking at Abu Qir.

The formulas of the length-weight relationship of *P. anomala* at the two sites were very similar: $W = 0.002 \times L^{2.541}$ ($r = 0.95$, SE = 0.06) at Abu Qir, and $W = 0.002 \times L^{2.572}$ ($r = 0.954$, SE = 0.09) at El Mex. The growth coefficient (b) at both sites being < 3 indicated allometric growth (Figures 6 and 7). The regression relationship between the length to the 6th segment and weight at Abu Qir and El Mex respectively yielded a value of 'b' (2.98 and 3.05) close to 3 (Figures 8 and 9), suggesting isometric growth.

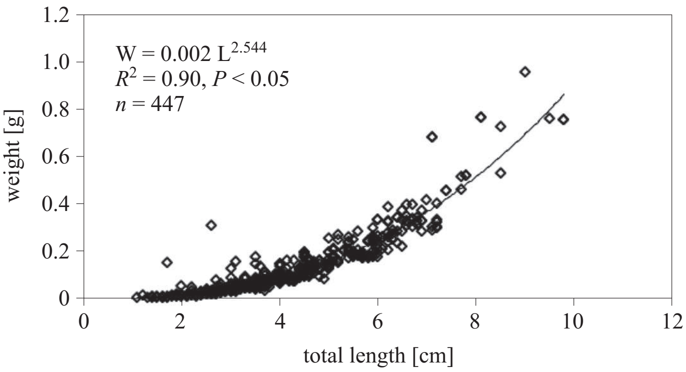

Figure 6. Length-weight relationship of *Pseudonereis anomala* at Abu Qir

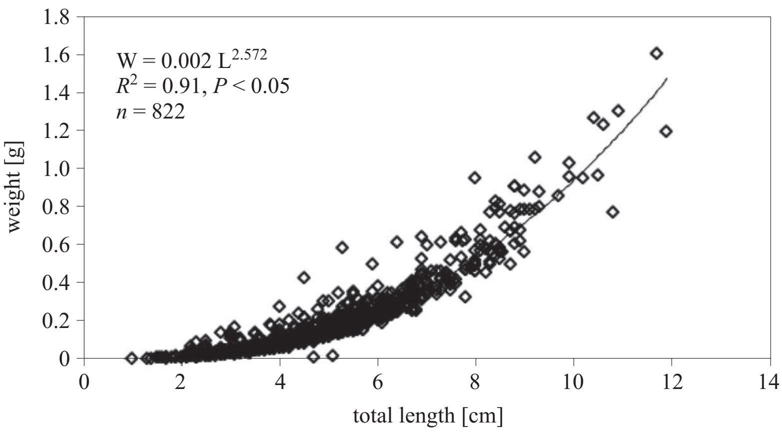

Figure 7. Length-weight relationship of *Pseudonereis anomala* at El Mex

Both body weight and length at the two sites demonstrated a strong and significant relationship with the other biometric parameters. But the

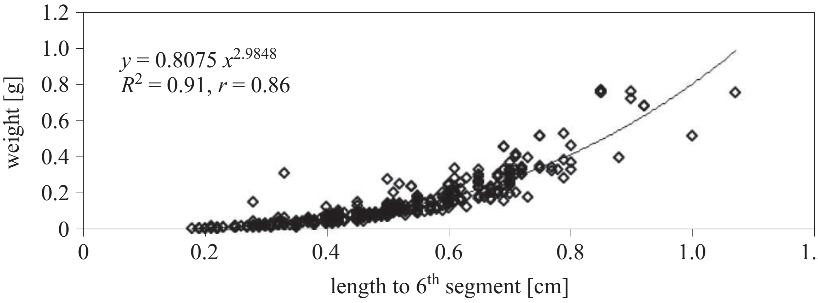

Figure 8. Regression analysis of weight [g] with length to 6th segment of *Pseudonereis anomala* at Abu Qir ($P < 0.05$, $n = 447$)

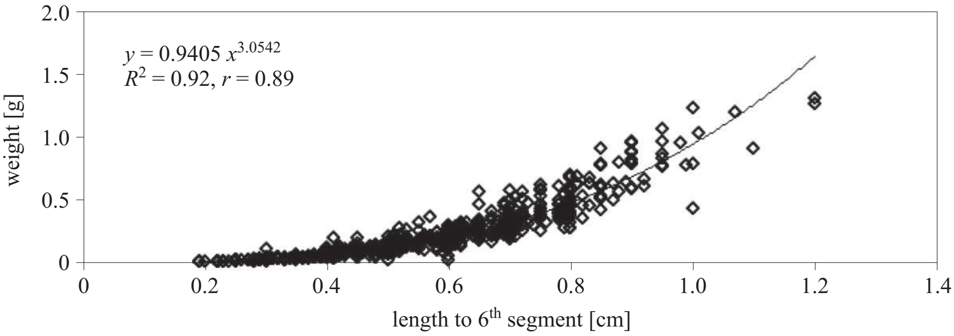

Figure 9. Regression analysis of weight [g] with length to 6th segment of *Pseudonereis anomala* at El Mex ($P < 0.05$, $n = 822$)

Table 1. Regression correlation between length and weight and other biometric parameters of *Pseudonereis anomala* at Abu Qir (AQ) and El Mex (MX), W = weight, TL = total length, R = correlation coefficient, Eq = regression equation

			Prostomium width	Prostomium length	Length to 6th segment	Width of 6th segment
W	AQ	R	0.922	0.922	0.9539	0.8944
		Eq	$7.2949x^{2.2}$	$27.586x^{2.6}$	$0.8075x^{2.98}$	$1.9476x^{1.9}$
	MX	R	0.922	0.9165	0.959	0.8888
		Eq	$10.321x^{2.3606}$	$30.299x^{6509}$	$0.9405x^{3.0542}$	$2.2188x^{1.9246}$
TL	AQ	R	0.866	0.8718	0.9165	0.8718
		eq.	$0.0324x{+}0.0073$	$0.0223x{+}0.0218$	$0.0905x{+}0.113$	$0.0503x{+}0.0077$
	MX	R	0.8775	0.8602	0.90	0.8485
		Eq	$0.0292x{+}0.0234$	$0.0217x{+}0.0281$	$0.0856x{+}0.1248$	$0.0472x{+}0.0174$

relationship of these parameters with weight appeared to be more significant than with length, as indicated by the higher values of the correlation coefficient (Table 1).

3.3. Reproductive biology

Sexual differentiation in *P. anomala* was identifiable only at maturation, when females changed colour from brownish to greenish, and males became darker brownish, owing to the colour of the gametes in the coelomic cavity.

The population of *P. anomala* comprised 8.1% males at Abu Qir against 5.8% at El Mex, whereas females made up 22.8% and 27.3% at the two sites respectively. The monthly maturity (males and females) varied between 16–40% at Abu Qir and mostly between 23–46% at El Mex, but a high level of maturity (50–75%) occurred from June to August at El Mex. There were more females than males at both sites over the year, except in September when 13 males were found against 9 females at Abu Qir and 10 males against 5 females at El Mex.

The fecundity of the El Mex worms (average: $47\,955 \pm 2\,916$ eggs/female) was markedly higher than at Abu Qir (average: $26\,556 \pm 999$ eggs/female). But the maximum oocyte diameter (250 μm) at Abu Qir was found in November and was greater than that at El Mex (220 μm) found in March. However, the oocyte diameter showed a similar pattern of monthly variation at both sites for most of the year, except from May to July when there were three peaks at each site (Figures 10 and 11). Nurse cells 20 μm in diameter were observed during winter (December and January) at both sites.

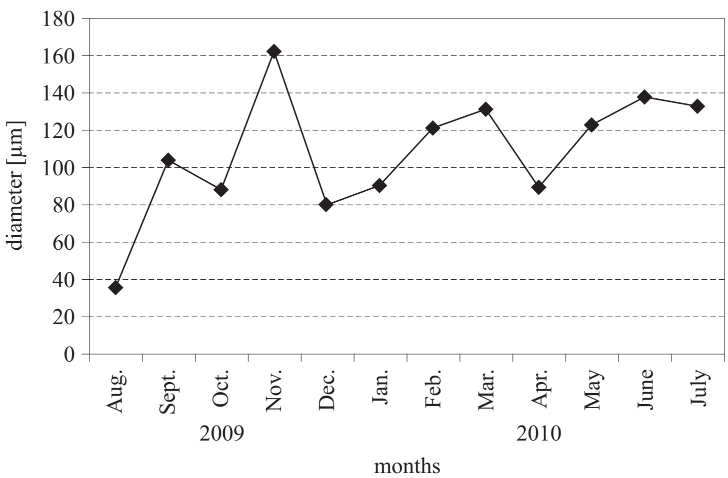

Figure 10. Monthly mean diameter of *Pseudonereis anomala* oocytes at Abu Qir

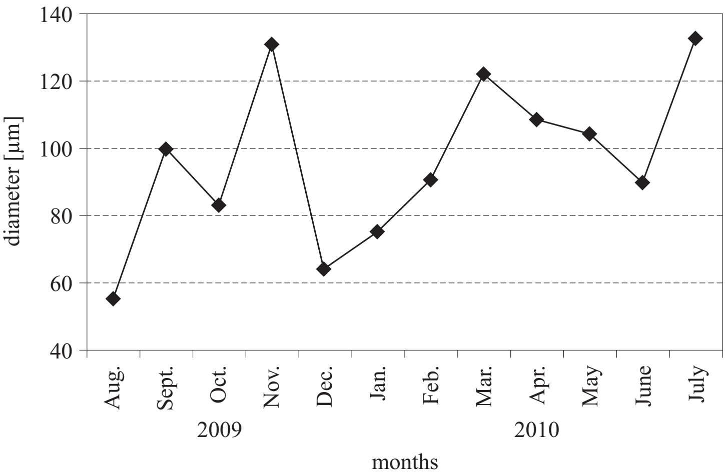

Figure 11. Monthly mean diameter of *Pseudonereis anomala* oocytes at El Mex

Epitokous reproduction was recorded for *P. anomala* during the present study, whereas at sexual maturation both sexes retained enlarged eyes and flattened posterior parapodia with natatory setae for swimming. Epitokous modifications started from the posterior segments and in females reached as far as segment 16 at Abu-Qir and segment 15 at El Mex, while in males they reached segment 13 at both sites (Table 2). Heteronereis worms of both sexes were larger at El-Mex than at Abu-Qir.

Table 2. Biometric measurements of *Pseudonereis anomala* in the swarming (heteronereis) stage at Abu Qir and El Mex

Site	Sex	Total length [cm]			Length of epitokous part [cm]	Epitoky starts at segment No.
		max length	min length	mean		
AQ	♀	9.8	2.8	6.0	1.8–1.9	16
	♂	6.0	2	4.1	0.6–1.3	14–13
Mx	♀	11.9	2.5	6.6	1.2–4	44–15
	♂	6.6	2.5	4.4	0.9–1.6	22–13

Two-way ANOVA analysis indicates significant differences in the majority of the measured parameters, but the differences between the two areas were not significant (Table 3).

Table 3. Two-way ANOVA for the different parameters measured at the two sites

Parameter	Source	df	MS	F ratio	*P*
	area	1	620.167	13.048	0.004
male	date	11	80.076	1.685	0.200
	date/area	11	47.530	0.380	0.940
	area	1	43.390	44.590	0.000
female	date	11	3.537	3.635	0.021
	date/area	11			
	area	1	6.000	1.941	0.191
immature	date	11	15.818	5.118	0.006
	date/area	11	3.091	0.206	0.993
	area	1	2501.042	5.253	0.043
TL	date	11	844.830	1.774	0.178
	date/area	11	476.133	0.484	0.880
	area	1	3.961	27.074	0.000
TW	date	11	0.894	6.112	0.003
	date/area	11	0.146	0.127	0.999
	area	1	0.027	18.182	0.001
Pros L	date	11	0.005	3.173	0.034
	date/area	11	0.001	0.226	0.990
	area	1	0.002	24.877	0.000
Pros W	date	11	0.000	4.118	0.014
	date/area	11	0.000	0.171	0.997
	area	1	0.004	24.935	0.000
L 6seg	date	11	0.002	12.235	0.000
	date/area	11	0.000	0.075	1.000
	area	1	0.023	19.634	0.001
W 6seg	date	11	0.006	5.005	0.006
	date/area	11	0.001	0.161	0.998
	area	1	0.000	2.500	0.072
Oocyte D	date	11	0.000	5.500	0.039
	date/area	11	0.000	0.364	0.948
	area	1	5.042	6.003	0.032
PH	date	11	46.247	55.066	0.000
	date/area	11	0.840	0.020	1.000

Table 3. (*continued*)

Parameter	Source	df	MS	F ratio	*P*
	area	1	0.024	1.100	0.317
salinity	date	11	0.090	4.094	0.014
	date/area	11	0.022	0.260	0.983
	area	1	180.402	9.540	0.010
DO	date	11	19.428	1.027	0.483
	date/area	11	18.910	0.576	0.815
	area	1	3.263	0.878	0.369
BOD	date	11	3.235	0.870	0.589
	date/area	11	3.717	1.148	0.406

4. Discussion

The present study revealed that *Pseudonereis anomala* on the Alexandria coast attained a maximum body length (11.9 cm) greater than that found in the Indian Ocean (6.5 cm – Day 1967), the Red Sea (4.5 cm – Fishelson & Rullier 1969) or in Turkish waters (5.1 cm – Çinar & Ergen 2005, 2.7 cm – Çinar & Altun 2007). The maximum weight of our specimens (1.3 g) was about four times that (0.35 g) in Iskenderun Bay, Turkey (Çinar & Altun 2007). But the Turkish worms were collected at the end of the spawning season, by which time the large worms had already died. The small size of the Red Sea and Indian Ocean worms can be attributed to the higher temperature and other environmental conditions. Temperature on the Alexandria coast was significantly correlated with total length only at El-Mex, whereas pH, DO and salinity were significantly correlated with the biometric parameters at either or both sites (Table 4). The greater size of the El Mex worms than those at Abu-Qir may be due to the greater availability of organic matter as a food source at El Mex.

The length-weight relationship in our study is indicative of allometric growth in *P. anomala*. Such a growth pattern was observed in Turkish worms, as indicated by the proportional increase of the body weight with increasing width (Çinar & Altun 2007). The observations of the latter authors do not reflect the actual structure of the polychaete population, because this consisted largely of juvenile worms. Isometric growth was also observed among the *P. anomala* worms on the Alexandria coast, according to the regression relationship between the length to 6th segment and body weight. Isometric growth may reflect the importance of the anterior part of the worm in the growth of this species.

Table 4. Significant correlations between environmental conditions and biometric parameters of *Pseudonereis anomala* (values in bold significant at $P = 0.1$, other values significant at $P = 0.05$)

	AQ		MX			
	S [‰]	pH	Temp.	S [‰]	pH	DO
immature				**0.563129**		
female			−0.6215			
male	0.610802					
TL	**−0.53034**	0.755128	−0.63043			**0.548384**
TW	**−0.57445**	0.606662	**−0.55085**			**0.548437**
P L	**−0.50155**	0.607051			0.628799	0.601368
P W	**−0.65259**	0.6872			0.758289	0.782951
L 6 seg	**−0.58126**	0.67338	**−0.50178**			0.7566
W 6 seg	**−0.52374**	0.714416	0.632815		**0.568357**	0.650666
oocyte D		**0.575409**				

Epitoky is a common reproductive pattern in many nereid species (Omena & Amaral 2000) and was recorded in *P. anomala* (Fischer 1999, Chatelain et al. 2008). These observations endorse our findings for this species along the Alexandria coast.

The life cycle and reproductive activity in many polychaetes depend on photoperiod, lunar cycles (Fischer 1999) and changes in water temperature (Fischer 1999, Omena & Amaral 2000). Our study showed that reproduction of *P. anomala* appeared to take place all the year round, but was more intensive at temperatures from 20 to 29°C. This stands in partial agreement with Çinar & Altun (2007), who suggested that the reproductive period of *P. anomala* on the Turkish coast took place in mid- or late summer. Unfortunately, the observations of the latter authors are not reliable, since they measured one immature specimen with a markedly smaller oocyte (diameter 50–85 μm) than ours. Furthermore, the ripe oocytes during the present study (diameter: 220–250 μm) were distinctly larger than those (195 μm) found in Izmir Bay (Çinar & Ergen 2005).

5. Conclusions

Pseudonereis anomala worms were characterised by a comparatively large size, which varied depending on the ecological conditions along the Alexandria coast. Individuals living in the water with a high organic matter content at El Mex were larger than those in the low-organic waters at Abu Qir, but the fecundity and oocyte diameter at El Mex were distinctly lower. This species undergoes allometric as well as isometric growth, with continuous spawning all the year round and intensive spawning in the 20–29°C temperature range.

Acknowledgements

The authors are deeply indebted to Dr H. Mitwally, associate professor of marine biology, Oceanography Department, Faculty of Science, Alexandria University, for help in the ANOVA analysis.

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