Egypt. J. Plant Prot. Res. Inst. (2018), 1(1): 32-42

Egyptian Journal of Plant Protection Research Institute

www.ejppri.eg.net

Seasonal activity of fresh water crayfish, *Procambarus clarkii* (Decapoda: Cambaridae) in irrigation canal of Abou-Kabir, Sharkia Governorate, Egypt

Samah M. Abdel-Kader

Agricultural Animal Pests Research Department, Plant Protection Research Institute, Agricultural Research Center, Egypt

ARTICLE INFO

Article History

Received: 10/3/2018

Accepted: 15/6/2018

Keywords

Procambarus clarkii, crayfish, seasonal activity and water temperature.

Abstract:

The red swamp crayfish, *Procambarus clarkii* (Girard) (Decapoda: Cambaridae) which was introduced into the Egyptian fresh water system, became widely distributed all over the country. The seasonal activity of *P. clarkii*, was conducted using baited trap in irrigation canal of Abou-Kabir (Gynabeit Bahr Fakous), Sharkia Governorate during the year 2016, through direct counts of active animals caught throughout 24 hours period. The results revealed that the number of caught crayfish fluctuated during the year, the highest catchability (activity) synchronized with high temperature prevailing in summer seasons as compared with those prevailing in spring and autumn seasons. Large crayfish (> 60 mm TL) were the most dominant in catches during the whole search period, whereas medium size (35-60mm TL) were more common in summer than spring and autumn, both sizes were mostly active at night. Small size crayfish (<35mmTL) were more abundant in spring, autumn but absent in summer and were mostly active at daylight. Females were dominant over males during spring, while males were dominant over females during summer and autumn.

Introduction

The red swamp crayfish, *Procambarus clarkii* (Girard) (Decapoda: Cambaridae), native to the south central United States (Louisiana) and north-eastern Mexico. But now, due to introductions by human (Machino *et al*., 2004), it has been transplanted world-wide (Torres and Álvarez, 2012). *P. clarkii* is considered one of the 100 worst alien invasive species (Savini *et al*., 2010), as consequence of deleterious impacts where introduced on native ecosystems (Reynolds and Souty-Grosset, 2012). After the introduction of *P. clarkii* to Egypt in the early 1980,s for aquaculture (Ibrahim *et al*., 1995), the crayfish populations have rapidly increased without control, invading the whole area of freshwater ecosystem, i.e., streams, marshes, ponds of fish farms, irrigation canals and ditches, causing complex changes on aquatic communities and the whole ecosystem function (Cruz *et al*., 2008). Its invasive potential being related to its high adaptability to the new habitats (burrow environments), early maturity, rapid growth rate, high fecundity, aerial exposure, disease resistance, plastic life history traits, polytrophism, and active dispersal capability (Gherardi *et al*., 2011), features that favor its establishment in new available habitats, when other environmental conditions are favorable (Correia, 2002). Soil nature, location and permanence of the water table and food supply, enough cover vegetation, low predators, temperature and light are considered the most important factors for distribution and activity of crayfish within their habitat (Souty-Grosset *et al*., 2014). In natural conditions photoperiod, temperature and water are the most critical factors controlling the most vital activity of aquatic animals (Farhadi and Jensen, 2015). Knowledge of the activity of this invasive *P. clarkii* is of fundamental importance for successful control understanding their invasions and in attempt to mitigate their occurrence and detrimental impacts (Simberloff, 2003). The aim of this research is to study the seasonal activity of *P.clarkii* (size and sex activity) in irrigation canal of Abou-Kabir and to investigate the factors inducing its acclimatization and rapid spread as well as if this species is more active during night (nocturnal) or during daylight hours (diurnal).

Materials and Methods

1. Description of the study areas:

The field experiment was carried out in irrigation canal of Abou-Kabir (Gynabeit Bahr Fakous) district at Sharkia Governorate during 2016 year. Abou-Kabir canal is approximately about 4 Km in length, its width and depth range from 2 to 4 m and 2–3 m, respectively. The bottom is varied from sand and clayey to loam in sediment nature. Due to the permanence of the water table during the whole year (Genabiet Bahr Fakous), the studied canal is surrounded by an extensive bank cover vegetation includes, *Salix tetrasperma, Pulchea dioscroidis,* as well as, *Cynodon dactylon* and *Vossia cuspidate* which create suitable refuges for crayfish. For each sampling date, water temperature was recorded by mercury thermometer at a depth of 50cm (Tolba, 1981). The variances in the seasonal activity of *P. clarkii* during the year were analyzed in accordance with temperature values. Some physicochemical parameters of the water were measurement by spectro-photometric measurements of multi-lab. P5 (WTW) in the laboratory (Table, 1).

Table (1): Some physico-chemical parameters of water at Abou-Kabir district during seasons of 2016.

Chemical analysis	Seasons			
	Winter	Spring	Summer	Autumn
PH	7.1	7.7	7.8	7.6
Temperature (°C)	6	20	27	17
Salinity (ppm)	200	100	100	100
Iron (ml/l)	0.1	0.1	0.1	0.02
Copper (ml/l)	0.1	0.1	0.1	0.01
Nitrite (ml/l)	0.08	0.03	0.4	0.6
Phosphate (ml/l)	0.5	0.4	0.5	0.5
Ammonium (ml/l)	0.1	0.1	0.6	0.1
Dissolved 02 (ml/l)	0.4	0.9	1.4	1.4

2.Crayfish capture:

To determine the daily activity of *P.clarkii*, sampling of the crayfish population was done bimonthly from March to November 2016, using small-mesh (10 mm in diameter), cylindrical trap (Gobbia), that baited with dead fish were placed directly into the bottom at approximately 1.5−2.0 m intervals at sunrise (0600 hr) across the irrigation channel. This trap was emptied at sunset (1800 hr) and left again in the water overnight till sunrise (0600 hr) and the number of crayfish per-trap were separately and recorded through 24-hr period. Trap was placed on the same position during the whole research period. The crayfish were transferred alive to the laboratory where subsequent data were recorded for each specimen as following: a. the number of specimens for each trap and the total length as in all of the previous studies, (from the anterior tip of the rostrum to the posterior point of the telson) using Vernier caliper. As an index of size; the collected specimens were divided into three groups on the basis of total length (TL), small crayfish (juvenile) if TL < 35mm, medium; immature crayfish if TL 35-60mm and large mature crayfish if TL> 60 mm as reported in previous studies (Cheese *et al.*, 2006).

b. Wet weight was determined using an electronic balance (accuracy 10^{-4} g).

c. The specimens were sexed by the presence or absence of developed gonopodia

Results and Discussion

The seasonal variation in daily activity of *P. clarkii* expressed by the number of crayfish entering trap per 24 hours (daylights and night) in irrigation canal of Abou-Kabir from March to November 2016, was shown in Tables 2,3,4 and 5 and Figures 1,2 and 3. Water quality parameters in the irrigation canal of Abou-Kabir remained within an acceptable ranges throughout the experiment as recorded in Table (1). A total of 744 red swamp crayfish specimens were caught from irrigation canal of Abou-Kabir in one year 2016. All catches constitute as number of specimens, total length and weight, were obtained. During spring 241specimens were caught (daylights 97and night144), in summer 320 specimens (daylights 120 and night 200), whereas catches were relatively decreased in autumn being 183 specimens (daylights 68 and night 115) and no specimen was caught in the winter seasons (Tables, 2, 3 and 4 and Figures, 2 and3). Of the total crayfish counts made during this study: 45small, 108 medium and 591 large (Figure, 1).

In early spring (March) at the average water temperature was 12^{0}C, a few number of length classes was represented in the trap, with predominance of large individuals (90 to 120 mm TL) with an the body weight (BW) varied between 225 and 630 mg for both sexes.

As the water temperature gradually increased from 16 to 20 ^{0}C in the mid and late spring (April and May) some fairly activity of small size, greenish-gray juvenile (18n. in daylights and 8n. in night, ranged from16 to35mm in TL and BW from 10-34.8mg) and medium size, immature stage (15n. in daylights and 17n. in night, ranged from 40-55mm in TL with BW ranged from 34.8 to 52mg) were found along with the large size, mature (64n. in daylights and 119n. in night, ranged from 80-120mm TL and BW 74-120 mg) (Table, 2). The trap catches during spring months showed a predominance of females (113) compared to males (102) that remained this way until the end of season (Table, 5). Female were slightly more active (74) than males (62) during night while, both sex were similar in its activity at daylights (males 40 and females 39). Juveniles were more active at daylights (18) than nighttime (8) (Table, 5). It can be seen that when the averaged of water temperature was 20^{0}C in spring, the total catch of *P. clarkii* was consist of individuals with mean TL varying between 16-35, 40-55 and 80-120 mm and BW varying between 10-34.8,34.8-52 and74-120 mg for small, medium and large individuals, respectively (Table, 2).

Table (2): Seasonal variation in daily activity of *Procambarus clarkii* represented by catch per trap at 0600 hr and 1800 hr in irrigation canal of Abou-Kabir during Spring months of 2016 year.

Time of capture	Sex	Number of different size capture/ Gobbia			Total
		Small 16-35mm(TL) 10-34.8mg(BW)	Medium 40-55mm(TL) 34.8-52mg(BW)	Large 80-120mm(TL) 74-120mg(BW)	
Daylights	Juvenile	18	-	-	18
	Male	-	10	30	40
	Female	-	5	34	39
	Total	18	15	64	97
Night	Juvenile	8	-	-	8
	Male	-	8	54	62
	Female	-	9	65	74
	Total	8	17	119	144
Grand total		26	32	183	241

TL: Total length BW: Body weight N:Number of individuals

Table (3): Seasonal variation in daily activity of *Procambarus clarkii* represented by catch per trap at 0600 hr and 1800 hr in irrigation canal of Abou-Kabir during summer months of 2016 year.

Time of capture	Sex	Number of different size capture/ Gobbia			Total
		Small	Medium 40-55mm(TL) 40.6-56.2mg(BW)	Large 60-120mm(TL) 65.6-530mg(BW)	
Daylights	Juvenile	-	-	-	-
	Male	-	8	48	56
	Female	-	14	50	64
	Total	-	22	98	120
Night	Juvenile	-	-	-	-
	Male	-	17	90	107
	Female	-	11	82	93
	Total	-	28	172	200
Grand total		-	50	270	320

Table (4): Seasonal variation in daily activity of *Procambarus clarkii* represented by catch per trap at 0600 hr and 1800 hr in irrigation canal of Abou-Kabir during autumn months of 2016 year.

Time of capture	Sex	Number of different size capture/ Gobbia			Total
		Small 25-35mm 30-45mg	Medium 45-55mm 47.4-56.3mg	Large 60-120mm 75.4-630mg	
Daylights	Juvenile	17	-	-	17
	Male	-	4	28	32
	Female	-	1	18	19
	Total	17	5	46	68
Night	Juvenile	2	-	-	2
	Male	-	12	55	67
	Female	-	9	37	46
	Total	2	21	92	115
Grand total		19	26	138	183

Table (5): Activity of juveniles, males and females *Procambarus clarkii* in daylight and night throughout different seasons of 2016 year

Time of capture	Total catch numbers of active crayfish/Gobbia												Total
	Spring				Summer				Autumn				
	J.	♂	♀	Total	J.	♂	♀	Total	J.	♂	♀	Total	
Daylights	18	40	39	97	-	56	64	120	17	32	19	68	285
Night	8	62	74	144	-	107	93	200	2	67	46	115	459
Total	26	102	113	241	-	163	157	320	19	99	65	183	744

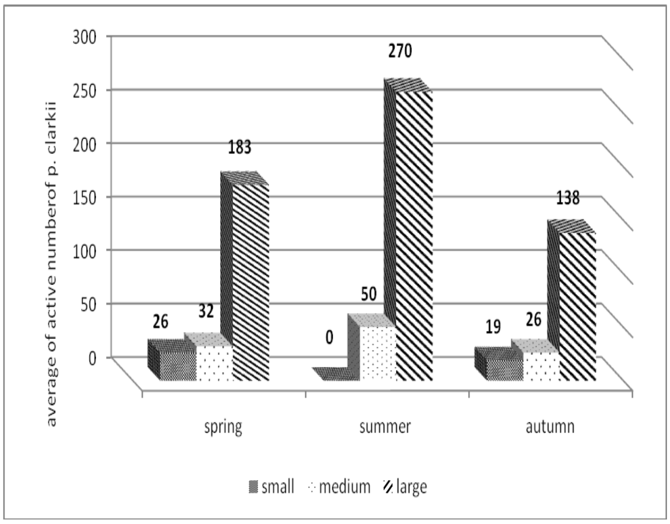

Figure (1): Catchability (activity) of small, medium and large Procambarus clarkii per seasonally during 2016 .

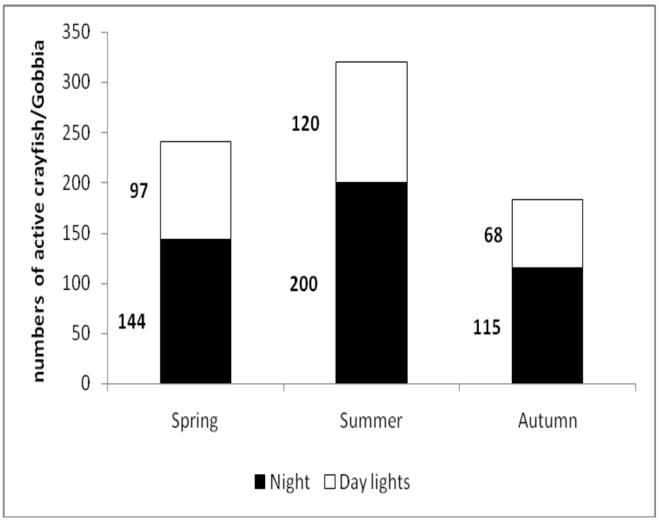

Figure (2): Daily activity of Procambarus clarkii individuals in night and daylights during seasons of 2016.

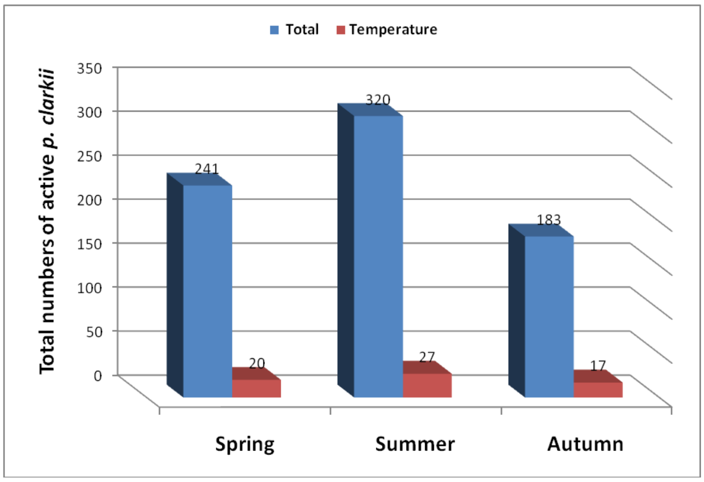

Figure (3): Total catch numbers of active *Procambarus clarkii* in relation to watertemperature°C

In summer, when the average water temperature was increased above 20°C, there was a higher activity for all crayfish individuals of medium and large sizes of both males and females, indicated by increased in the caught number of *P. clarkii* by the traps (n.320) through June to August at the average of water temperature 27°C. Whereas the caught number for medium sizes of males and females were 22 n. in daylights and 28 n. in night. Their TL ranged from 40-55mm and their BW ranged from 40.6 to 52.5 mg and from 41.3 to 56.2 mg in females and males, respectively. On the other hand, the caught number for large sizes of both males and females were 98n. in daylights and 172 n. in night, with TL measuring from 60 to 120mm in males, in females from 60 to 110mm with body weight varied between 69.4 and 530 mg and between 65.6 and 430 mg, for males and females, respectively Table (3). Furthermore, two sexes were more active in night (200n.) than daylights (120n.) as show in Tables (3and5). It can be seen that the trap catches during summer months showed a predominance of males (163n.) that remained this way until the end of autumn (99n.) (Table, 5).

It can be seen that when the averaged of water temperature was 27^{0}C in summer, total catches of *P. clarkii* was consist of individuals with mean TL varying between 40-55 and 60-120 mm and with BW ranges of 40.6-56.2 and 65.6-530mg for medium and large individuals, respectively (Table, 3).

After a high activity in summer months which extended to early autumn (September), a remarkable decrease in activity occurred when the averaged water temperature gradually decreased from 22 in September to 12 ^{0}C in November, indicated by decreased taken in the traps. At the water temperature 22^{0}C in mid September, green–gray colored of both juveniles (17n. in daylights and 2 n. in night with 25 -35 TL mm, BW 30-45mg) and medium (5n. in daylights and 21 n. in night with 45-55 TL mm, BW 47.4-56.3mg) were found with the majority were always large males and females,46n. in daylights and 92 n. in night with the total length varied from 60 to 120 mm and BW ranged from75.4-630mg in catches during this time (Table, 4). Adults males are dominant (99n.) over females (65n.) during autumn months (Table, 5). It can be seen that when the average of water temperature was 17^{0}C in autumn, total catches of *P. clarkii* was consist of individuals with mean TL varying between 25-35, 45-55 and 60-120 mm and BW varying between 30-45,47.4-56.3 and75.4-630 mg for small, medium and large individuals, respectively (Table, 4).

It can be seen that adults (large) dominated all trapping during the different seasons of 2016 year (spring n.183, summer, n.270 and autumn, n.138 individuals/Gobbia) followed by medium (spring n.32, summer, n.50 and autumn,n.26 individuals/ Gobbia), while the lowest small size recorded in spring n.26, autumn,n.19 (individuals/ Gobbia) and absent in summer) Figure (1). With the drop in temperatures of water during the winter months (December to February) no specimen was captured in theses months whereas the mean water temperature was 6°C (the coldest period in the year). During early morning hours in the early of winter (December) two males were observed with very sluggish weak movement over the substrate of irrigation canal around their burrow.

These results on *P. clarkii* activity in irrigation canal of Abou-Kabir were based on the number of captured crayfish, showed that all of crayfish individuals were active during the whole year except in the winter season and the changes in observed numbers represent changes in activity levels (Tables 2, 3, 4 and 5 and Figures 1, 2 and 3). Temperature has been recognized as one of the main environmental variable influencing the abundance and distribution of many aquatic ectothermal organisms (Lagerspetz and Vainio, 2006).

Data revealed that the increased or decreased of *P.clarkii* activity seem to be directly related with the change in water temperature of irrigation canal during the different seasons of the year, whereas the relatively high water temperature (12-27°C) in irrigation canal throughout most of the year was the suitable range for the activity of *P.clarkii* which has been previously reported to prefer warm water (Espina *et al.*, 1993). Our record for starting the activity of *P.clarkii* at the mean water temperature in spring (12-20°C) is similar to finding of Oluoch (1990) in Lake Naivasha, Kenya recording the mean monthly temperature range for Louisiana *P.clarkii* as being between 15.9 and 20.6°C. Similar results were presented by Gherardi *et al*. (2000) who showed that, at least in spring, more than 50% of *P. clarkii* collected by baited traps in an irrigation canal in Tuscany were active at daytime. The higher trapebility (activity) of *P. clarkii* in summer compared with other seasons is directly related to rising values of water temperature which ranged between 20-27^{0}C (Ackefors, 1999) and due to the fact that the summer is a period of food abundance (Noblitt *et al*., 1995). This finding is similar to what was found by other authors. Trimble and Gaude (1988) reported that the optimum temperature for growth, population structure and the abundance of harvestable crayfish in pond system ranges from 20 to 25°C. Provenzano and Handwerker (1995) reported that temperature should be kept below 30°C for survival of *P. clarkii*. Gherardi *et al.* (2000) in a laboratory reported that the rise of water temperature within the range 5-25°C was associated with the increase of *P. clarkii* locomotion activity. Furthermore, Payette and McGaw (2003) assured that *P. clarkii* were significantly more active at 22°C and avoided water temperature above 30°C and below 12°C. Aquiloni *et al*. (2005) reported that temperature (in some cases also water level) is the most influential factor in the movement pattern of *P.clarkii* and in determining the distribution of crayfish (Bohman *et al.*, 2013). Also similar to those reported for another crayfish species, Maguire (2002) found a positive effect between the water temperature and the number of animals caught for *Austropotamobius torrentium* as well as for *Astacus astacus* (Lucic, 2004). Kalder *et al. (*2016) recorded that the best temperature for culture of Marble crayfish (*Procambarus fallax*) was at 18-25°C, but could withstand temperature below 8°C and above 30°C for many weeks. The gradual reduction in capture of crayfish (low activity in autumn months probably caused by a lowering of the water temperature and the recession of water level (Huner, 2002) or may be a result of the inactive phase during moulting period (Dorr *et al*., 2006) and or mating period which occurred in autumn (Gherardi and Barbaresi, 2000). On the other hand, catchability reach to zero with the drop in temperature of the water during winter seasons (less than 10°C). These low temperatures seem to inhibit the activity of *P. clarkii* (Freitas *et al*., 2010), may also be the result of a suppression of temperature dependent metabolic processes such as heart rate and oxygen consumption rates (Chung *et al.*, 2012). Similar observations were recorded by Gherardi *et al*. (2002) who reported that individuals of *P.clarkii* stop their movement in winter. Crayfish in different size categories were seen throughout the whole year, except in the winter season, large crayfish were predominant in all seasons throughout the year of the study (Gherardi and Barbaresi, 2000), whereas medium size were more abundant in summer than spring and autumn. While small crayfish were abundant in spring and autumn and absent during summer as exactly formerly reported by Correia (2001).

As regard daylights and night individual activities, bimonthly total collection indicated that the night activity was more intense (Gherardi, 2002) for both large and medium size (males and females individuals), possibly as a result of an increase in feeding intensity and burrowing activity that occurred mainly at night (Barbaresi *et al*., 2004) or to avoid daytime predators such as birds and fishes (Aquiloni *et al*., 2005). The noticeable high activity of small crayfish (Juveniles) during daylights may be to avoid nocturnal predators of large ones (Furse *et al*., 2006), mammals (Beja,1996) or the maturation and survivorship require not only a hormonal induction by the longer daylight (Liu *et al*., 2013) but also a hydroperiod longer than four months, a temperature above 18 ^{0}C and pH ranged between 7 and 8 (Gutie´rrez-Yurrita, 1997). The two sexes were nearly equally found in nocturnal and diurnal hours during spring and summer months, similar results were represented by Barbaresi *et al.* (2004).

The finding that adult females were dominant over males during May and June, similarly as Ligas (2008). The dominance of male, compared to females in the trap specimens collected during summer and autumn was due to searching for the reproductive opportunities with females (Furse *et al*., 2004) or the most of females became ovigerous and need suitable shelters to protect their broods (Gherardi, 2002).

References

Ackefors, H. (1999): The positive effects of established crayfish. In: Gherardi F, Holdich DM, editors. Crayfish in Europe as alien species. How to make the best of a bad situation? Rotterdam: A.A. Balkema., pp 49–61.

Aquiloni, L. ; Ilheu, M. and Gherardi, F. (2005): Habitat use and dispersal of the invasive crayfish *Procambarus clarkii* in ephemeral water bodies of Portugal. Mar Freshw. Behav. Physiol., 38:225–236.

Barbaresi, S.; Tricarico, E. and Gherardi, F. (2004): Factors inducing the intense burrowing activity by the red-swamp crayfish, *Procambarus clarkii*, an invasive species. Naturwissenschaften 91: 342–345.

Barbaresi, S. ; Tricarico, E. ; Santini, G. and Gherardi, F. (2004): Ranging behaviour of the invasive crayfish, *Procambarus clarkii*. J. Nat. Hist., 38:2821–2832.

Beja, P. R. (1996): An analysis of otter Lutra lutra predation on introduced American crayfish *Procambarus clarkii* in Iberian streams. Journal of Applied Ecology 33:1156–1170.

Bohman, P.; Edsman, L.; Martin, P. and Scholtz, G. (2013): The first Marmorkrebs (Decapoda: Astacida:Cambaridae) in Scandinavia. BioInvasions Rec., 2: 227–232.

Chiesa, S. ; Scalici, M. and Gibertini, G. (2006): Occurrence of allochthonous freshwater crayfishes in Latium (Central Italy). Bull. Fr. Pêche. Piscic., 380-381, 883–902.

Chung, Y.S.; Cooper, R.M. ; Graff, J. and Cooper, R.L. (2012): The acute and chronic effect of low temperature on survival, heart rate and neural function in crayfish (*Procambarus clarkii*) and prawn (*Macrobrachium rosenbergii*) species. J. Mole. Integrat. Physiol., 2: 12.

Correia, A. M . (2001): Seasonal and interspecific evaluation of predation by mammals and birds on the introduced red swamp crayfish, *Procambarus clarkii*

(Crustacea, Cambaridae) in a freshwater marsh (Portugal). J. Zool. (Lond.), 255: 533–541.

Cruz, M.J.; Segurado, P.; Sousa, M. and Rebelo, R. (2008): Collapse of the amphibian community of the Paul do Boquilobo Natural Reserve (central Portugal) after the arrival of the exotic American crayfish *Procambarus clarkii*. Journal of Herpetology, 18: 197-204.

Dorr, A.J.M.; La Porta, G.; Pedicillo, G. and Lorenzoni, M. (2006)**:** Biology of *Procambarus clarkii* (Girard, 1852) in Lake Trasimeno. Bulletin Francais De La Peche Et De La Pisciculture, 380(81):1155-1167.

Espina, S.; Diaz-Herrera, F. and Bucle, L.F. (1993): Preferred and avoided temperature in the crayfish *Procambarus clarkii* (Decapoda, Cambaridae). J. Thermal Biol., 18: 35–39.

Farhadi, A. and Jensen, M.A. (2015): Effects of photoperiod and stocking density on survival, growth and physiological responses of narrow clawed crayfish (*Astacus leptodactylus*). Aquaculture Research, 47:2158–2527.

Freitas, V.; Cardoso, J.F.M.; Lika, K.; Peck, M.A. ; Campos, J.; Kooijman, S.A.L.M. and van derVeer, H.W. (2010): Temperature tolerance and energetics: a dynamic energy budget-based comparison of North Atlantic marine species. Phil. Trans. R. Soc. B, 365: 3553–3565.

Furse, J. M.; Wild, C. H., and Villamar, N. N. (2004): In-stream andterrestrial movements of *Euastacus sulcatus* in the Gold Coast hinterland:developing and testing a method of accessing freshwater crayfish movements. Freshwater Crayfish, 14: 213–220.

Furse, J. M.; Wild, C. H.; Sirottii, S. and Pethybridge, H. (2006): The daily activity patterns of *Euastacus sulcatus* (Decapoda: Parastacidae) in southeast Queensland. Freshwater Crayfish, 15: 139–147.

Gherardi, F. (2002): Behaviour. In: Holdich DM (ed) Biology of freshwater crayfish. Blackwell, London, 258–290.

Gherardi, F.; Acquistapace, P.; Tricarico, E. and Barbaresi, S. (2002): Ranging and burrowing behaviour of the red swamp crayfish in an invaded habitat: the onset of hibernation. Freshwater Crayfish, 13: 330–337.

Gherardi, F.; Aquiloni, L.; Diéguez-Uribeondo, J. and Tricarico, E. (2011): Managing invasive crayfish: is there a hope? Aquatic Sciences, 73: 185-200.

Gherardi, F. and Barbaresi, S. (2000): Invasive crayfish:activity patterns of *Procambarus clarkii* in the rice fields of the Lower Guadalquivir (Spain). Archiv fur Hydrobiologie, 150: 153–168.

Gherardi, F.; Barbaresi, S. and Salvi, G. (2000): Spatial and temporal patterns in the movement of the red swamp crayfish, *Procambarus clarkii*, an invasive crayfish. Aquatic Sci., 62:179–193.

Girard, C. (1852): Revision of the North American Astaci with observation on their and geographical distribution. Proc. Acad.Nat. Sci. Phila., 6: 87–91.

Gutie´rrez-Yurrita, P.J. (1997): El papel ecolo gico del cangrejo rojo de la marisma, *Procambarus clarkii* (Crustacea: Decapoda: Cambaridae),en el Parque Nacional de Don˜ ana. Una perspectiva bioenerge´ tica con implicaciones en la gestio´ n (Ph.D. thesis). Facultad de Ciencias, Universidad Auto´noma de Madrid, Spain, 380

(InSpanish, with English summary).

Huner, J.V. (2002): *Procambarus*. In: Holdich D.M. (ed.), Biology of Freshwater Crayfish, Blackwell Scientific Press, Oxford, 541–574.

Ibrahim, M.A.; Khalil ,M.T. and Mubarak, M.F. (1995): On the feeding behavior of the exotic crayfish *P. clarkii* in Egypt and its prospects in the bio-control of local vector snails. J.Union. Arab Biol. Cairo, 4(A):321-340.

Kalder,K.; Mezenin,A.; Paaver,T. and Kawai,T.(2016): A preliminary study on the tolerance of Marble crayfish *Procambarus fallax f. virginalis* to low temperature in Nordic climate. Freshwater Crayfish, 4:55–62.

Lagerspetz, K. Y. H. and Vainio, L. A. (2006): Thermal behavior of crustaceans. Biological Reviews, 81: 237–258.

Ligas, A. (2008): Population dynamics of *Procambarus clarkii* (Girard, 1852) (Decapoda, Astacidea, Cambaridae) from southern Tuscany (Italy). Crustaceana, 81: 601–609.

Liu, S.; Gong, S.; Li, J. and Huang, W. (2013): Effects of water temperature, photoperiod, eyestalk ablation, and nonhormonal treatments on spawning of ovary-mature red swamp crayfish. North American Journal of Aquaculture, 75: 228–234.

Lucic, A. (2004): Physiological characteristics of three species of the freshwater crayfish from the Astacidae family. Ph.D Thesis, pp. 122 ,University of Zagreb, Croatia.

Machino, Y. ; Füreder, L.; Laurant, P.J. and Petuschnig, J. (2004): Introduction of the white-clawed crayfish *Austropotamobius pallipes* in Europe. Ber. Naturwiss.-medizin. Ver. Innsbruck, 91: 187–212.

Maguire, I. (2002): Family Astacidae in north-west Croatia. PhD thesis (in Croatian with English abstract),pp.128, University of Zagreb, Croatia.

Noblitt, S.B.; Payne, J.F. and Delong, M. (1995): A comparative study of selected physical aspects of the eggs of the crayfish *Procambarus clarkii* (Girard, 1852) and *Procambarus zonangulus* Hobbs & Hobbs, 1990 (Decapoda,Cambaridae). Crustaceana, 68(5): 575-582.

Oluoch, A.O. (1990): Breeding biology of the Louisiana red swamp crayfish *Procambarus clarkii* (Girard, 1852) in Lake Naivasha, Kenya. Hydrobiologia, 208: 85–92.

Payette, A.L. and McGaw, I.J. (2003): Thermoregulatory behavior of the crayfish *Procambarus clarkii* in a burrow environment. Comp. Biochem. Physiol., 136: 539–556.

Provenzano, A. J. Jr. and Handwerker, T. S. (1995): Effects of photoperiod on spawning of red swamp crayfish, *Procambarus clarkii*, at elevated temperature. Freshwater Crayfish, 8:311–320.

Reynolds J. and Souty-Grosset, C. (2012) : Management of freshwater biodiversity: crayfish as bioindicators. Cambridge: Cambridge University Press, 384 pp.

Savini, D.; Occhipinti-Ambrogi, A.; Marchini, A.; Tricarico, E.; Gherardi, F.; Olenin, S. and Gollasch, S. (2010): The top 27 animal alien species introduced into Europe for aquaculture and related activities. Journal of Applied Ichthyology, 26 (2): 1–7.

Simberloff, D. (2003): How much information on population biology is needed to manage introduced species? Conserv Biol., 17:83–92

Souty-Grosset, C.; Reynolds, J.; Gherardi, F.; Aquilon, L.; Coignet, A.; Pinet, F. and Del, M.M.M. (2014): Burrowing activity of the invasive red swamp crayfish, *Procambarus clarkii*, in fishponds of La Brenne (France). Ethology Ecology and Evolution, 26: 263–276**.**

Tolba, M.R. (1981): The effect of water quality on the biology of *Asellus aquatcus* (L)(Crustacea, Isopoda) PH.D.Thesis, Nottingham Uni.England.

Torres, E. and Álvarez, F. (2012): Genetic variation in native and introduced populations of the red swamp crayfish *Procambarus clarkii* (Girard,1852) (Crustacea, Decapoda, Cambaridae) in Mexico and Costa Rica.Aquatic Invasions, 7: 235-241.

Trimble, W. C. and Gaude A. P.(1988): Production of red swamp crawfish in a low-maintenance hatchery. Progressive Fish-Culturist, 50:170–173.