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Original Citation:

Effect of urban isolation on the dynamics of river crabs / M. SCALICI; D. MACALE; F. SCHIAVONE; F. GHERARDI; G. GIBERTINI. - In: FUNDAMENTAL AND APPLIED LIMNOLOGY. - ISSN 1863-9135. - STAMPA. - 172:(2008), pp. 167-174. [10.1127/1863-9135/2008/0172-0167]

Availability:

The webpage <https://hdl.handle.net/2158/329866> of the repository was last updated on

Published version:

DOI: 10.1127/1863-9135/2008/0172-0167

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Effect of urban isolation on the dynamics of river crabs

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Francesca Gherardi² and Giancarlo Gibertini¹

With 3 figures and 2 tables

Abstract: European river crabs usually disappear from areas affected by human activities. However, a *Potamon fluviatile* population was recently recorded within an archaeological excavation in the historical centre of Rome. Since adaptation of river-dwelling brachyurans to urban habitat is rare, we focused on some aspects of population dynamics which are considered to be strictly related to important biological processes and to the adaptation degree of a population to its habitat. To do so, length-frequency distributions of four Italian populations were obtained using the carapace length and the subsequent data was analyzed by the FiSAT program. The Roman population exhibited a lower growth rate (as demonstrated by ANCOVA) and higher asymptotic length and longevity than the other populations, suggesting that Roman crabs are affected by gigantism. Isolation was confirmed by the absence of crabs in adjacent water systems and in the urban tract of the River Tiber, and could be a result of the progressive expansion of the city of Rome. On the other hand, an alternative explanation could be represented by a historical transfaunation from western Greece. Excluding recent intentional introduction by man, the presence of *P. fluviatile* in the city of Rome is thus probably the result of this species' ecological preferences and physiological constraints coupled with its evolutionary history, human interference, and colonisation events. It is, therefore, necessary to devise a conservation plan to protect this relict population as its preservation should be considered as important as the preservation of the historical monuments.

Key words: *Potamon fluviatile*, river crab, growth pattern, dynamics, urban isolation.

Introduction

Inland waters are among the systems most affected by human activities (Dynesius & Nilsson 1994, Naiman & Turner 2000). Among anthropogenic factors, land-use and urban development have, in fact, been responsible for altering species composition (e.g. Richter et al. 1997, Jansson et al. 2000), food web structure (Wootton et al. 1996), nutrient cycling (Johnes 1996, Meyer et al. 1999), and ecosystem functioning (Vörösmarty et al. 2000). The timing, amount, and type of inputs of water, light, organic matter, etc. associated with urban expansion may modify and lead to degradation of river functionality for large extensions, with serious consequences for the whole aquatic system (Strayer et al.

2003). These are the main reasons why today only a few aquatic sinanthropic species find space in urban areas (e.g. Wootton et al. 1996). Pollution, homogenization, habitat fragmentation, and geographic isolation further increase the risks of species extinction (Polis et al. 1997, Hanski 1998), these risks being amplified by a progressive fragmentation (e.g. Wolf 1987, Soulé 1991, Simberloff 1992, Kruess & Tscharnke 1994, Turner & Corlett 1996, Bascompte & Solé 1998, Didham et al. 1998).

Among the few aquatic sinanthropic species, the river crab *Potamon fluviatile* (Herbst, 1785) is considered a new urban species (Schiavone et al. 2007). It usually inhabits relatively undisturbed lentic and lotic habitats (Pretzmann 1987, Barbaresi & Gherardi 1997,

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Barbaresi et al. 2007) in Italy, Malta, southern Dalmatia, Albania, Macedonia, western and southern Greece, and the western Ionian and Aegean Islands (Brandis et al. 2000, Maurakis et al. 2004, Noel & Guinot 2007). In recent years, following the same trend revealed for other European indigenous freshwater decapods such as crayfish (see Souty-Grosset et al. 2006), populations of *P. fluviatile* have drastically declined in abundance across their entire distribution range (Barbaresi et al. 2007).

Ten years ago, a river crab population was recorded in the archaeological excavation of the Imperial Forum in the historical centre of Rome. This was the first record of a freshwater decapod in a metropolis, with the exception of two exotic species: the Asian crab *Eriocheir sinensis* in the River Thames, London (Herborg et al. 2005), and the Turkey crayfish *Astacus leptodactylus* in central London (Wiltshire & Reynolds 2006).

Given the peculiarity of this population, our goal here was to evaluate the adaptation of river crabs to this urban habitat by studying some aspects of its population dynamics, including growth and mortality rate, under the rationale that these are related to main biological processes, such as alimentation, predation,

and fecundity (i.e. Sparre & Venema 1996). To this aim, we used the sequential length-frequency data approach (Gayanilo & Pauly 1997), which provides information concerning the adaptation of a population to its habitat. This analytical approach can also serve as a useful tool to better understand the conservation status of a population of concern. Population dynamics have, in fact, become part of monitoring activities of aquatic ecosystems as stipulated by the Water Framework Directive (2000/60 ECC).

Material and methods

The Imperial Forum of Rome (instituted today as an archaeological area, Fig. 1) was built between the 1st century B.C. and the 2nd century A.D. in a small marshy valley, which today is completely altered through urbanisation. In order to canalise the drainage-water, the Romans built a drainpipe system called 'Cloaca Maxima' (the largest still-functioning basin) from the Roman Forum to the River Tiber. In spite of the uncontrolled development, a great part of the artificial water system (constantly fed by underground sources) has always remained above ground for at least 100 square meters. The superficial channels are 50 cm wide; water level ranges between few centimetres and 1.5 m, depending on precipitation.

The study was conducted in this area from May to September 2004–2006. During each sampling, crabs were caught by hand, sexed, and measured using the image analysis program

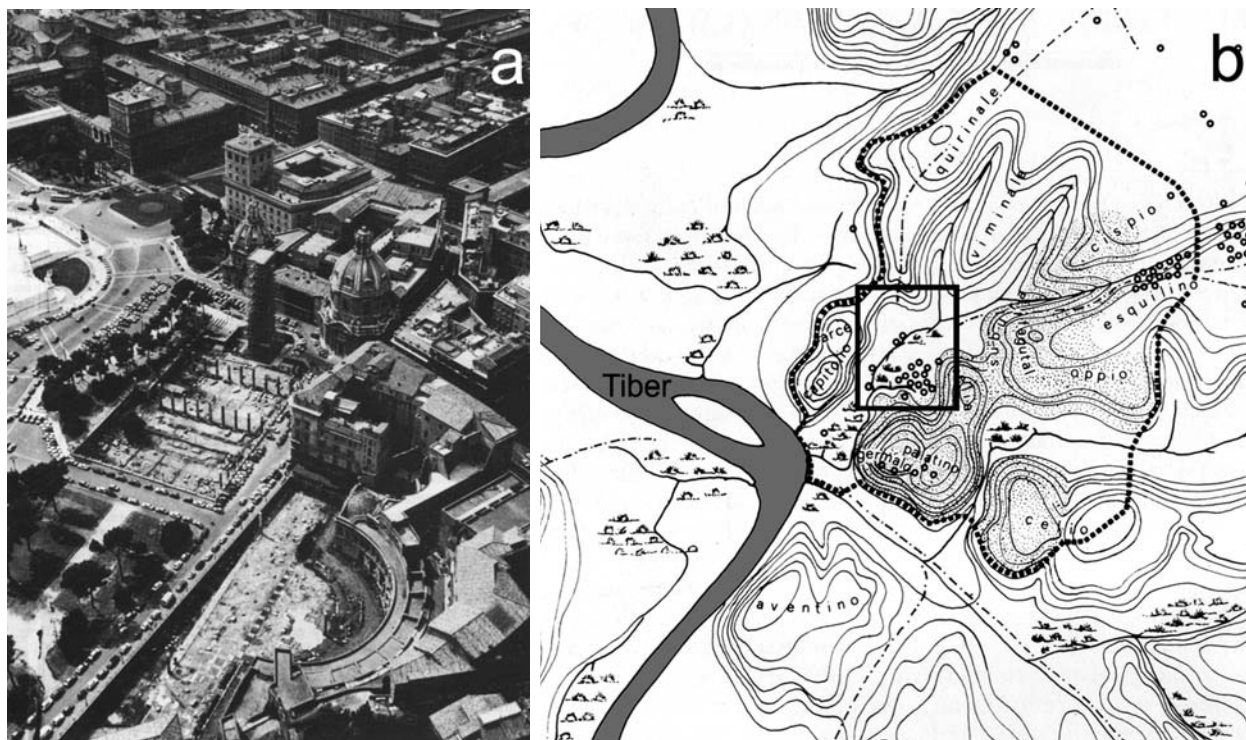


Fig. 1. A current panoramic view of the Trajan Forum (a) and a hypothetical condition of the study area before the Roman settlement (b). The rectangle in (b) delimits the sampling site, while the dotted line indicates the ancient perimeter of Rome (today the historical town centre).

Image Tool (available on <http://ddsdx.uthscsa.edu/dig/download.html>). To obtain the carapace length (CL), a picture (calibrated against a graph paper) was taken using a digital camera placed at 20–25 cm from the carapace in order to limit spherical distortion and parallax problems. Before release, crabs were individually heat-marked on the coxa of the right or left limbs by a little soldering gun and on the carapace by waterproof paint in order to avoid duplication of measurements on the same crab and then pseudo-replications during the statistical elaboration. Before their release crabs were disinfected using mercurochrome.

Body size data were used to generate polymodal frequency distribution histograms and then analyzed by the Electronic Length Frequency Analysis (ELEFAN) method. ELEFAN, part of the FiSAT computer program (FAO 2004), was used for the computation of the growth parameters by applying the Von Bertalanffy (1938) formula:

$$L(t) = L_{\infty} \{1 - \exp[-k(t - t_0)]\}$$

where $L(t)$ is the length at age t , L_{∞} is the asymptotic length (here computed as $L_{\max}/0.95$, where L_{\max} is the maximum recorded length, according to Beverton 1963, and Pauly 1981), k is the curvature parameter, and t_0 is the initial condition parameter. The ELEFAN method is based on the computation of two elements: “available sum of peaks” (ASP) and “explained sum of peaks” (ESP). Here we used the scan of k -values, which allows for an estimate of the curvature parameter by a plot of the fit index (i.e. $Rn = 10^{ESP/ASP}/10$) vs. k . The highest Rn value observed in the diagram corresponds to the estimated population curvature parameter (for more details see Gayanilo & Pauly 1997).

Size-frequency distribution analysis is a traditional method in aquatic science. It has been used to distinguish between modal size groups and to estimate demographic parameters when hard body structures with annuli (i.e. otoliths, opercular bones, vertebrae, etc.) are absent, making it particularly difficult to estimate the age of e.g. crustaceans (France et al. 1991, Sparre & Venema 1996, Reynolds 2002). Although crustaceans obviously differ from fish in their non-continuous growth pattern, their average body growth seems to conform to the Von Bertalanffy model, making it possible to perform a size-frequency distribution analysis (for discussion on the modelling of crustacean population dynamics see Garcia & Le Reste 1981, Jamieson & Bourne 1986, Caddy 1987, and Scalici et al. 2008).

Three other population parameters were also computed:

1) the growth performance index (\emptyset') from the equation (Pauly & Munro 1984)

$$\emptyset' = \text{Log}k + 2\text{Log}L_{\infty};$$

2) the expected longevity (t_{\max}) from the equation (Gayanilo & Pauly 1997)

$$t_{\max} = 3/k;$$

3) the total mortality index (Z , the sum of natural mortality and the mortality due to fishing) from the Powell-Wetherall Plot equation (Powell 1979; Wetherall 1986), i.e. the ratio between the mortality coefficient and the curvature parameter (Z/k).

In this study, Z is considered equal to natural mortality, since the study population is not subjected to fishing.

Finally, parameters obtained for the Rome population (RM) were compared with data from other crab populations collected by (1) M.S. during a monitoring project on freshwater decapods

in the summers 2003–2004 in the L.I.P.U. (Italian League for the Preservation of Birds) preserved area of Castel di Guido (CG, about 10 km from Rome), (2) by Scalici et al. (2007) in the Monterano Regional Reserve of Canale Monterano (CM, 25 km from Rome), and (3) by Gherardi (1988) in Borro San Giorgio, Antella, 5 km from Florence (FL, about 250 km north of Rome).

Comparisons among populations were made for the curvature parameter values, by testing the relationship between the curvature parameter and the asymptotic length using the Spearman regression test (r_s) for randomized data subsets (including about 30 individuals per set) of each population. We performed a total of 52 “ k vs. L_{∞} ” regressions, 16 for RM, 10 for CG, 12 for CM, and 14 for FL. Since the two parameters showed a close relationship (mean values of $r_s = 0.72, 0.63, 0.71$, and 0.75 , respectively for RM, CG, CM, and FL, with P always < 0.05), only the curvature parameters were used in order to test significant differences among growth curves of the analysed populations by the application of pairwise ANCOVA tests.

Results

In total, 451 crabs were collected in Rome: 184, 106, and 161, respectively in 2004, 2005, and 2006. In all the three sampling years, sex ratio was not significantly different from 1:1 (P always > 0.05 after the χ^2 test with Yates' correction). Moreover, during the study period we collected only few (5) females carrying juveniles (Table 1).

In order to perform the electronic length frequency analysis, crabs were grouped per sampling year (heat-mark method makes it possible to avoid statistical pseudo-replication), and three different CL-frequency distributions were obtained by using a 5 mm CL interval size-class. From the analysis of the polymodal frequency distributions, 15 growth lines were observed (Fig. 2), each line corresponding to 1 year of age.

Detailed results with Von Bertalanffy parameters (k and L_{∞}) and derivatives (i.e. \emptyset' , t_{\max} , and Z) are given in Table 2. The expected longevity ($t_{\max} = 14.29$) reflected the number of growth lines and the mortality index (Z) was very low. Table 2 also summarizes the population properties of the other three Italian crab populations analyzed. RM exhibited lower values of k

Table 1. Data entry, carapace length (CL) and litter size (number of juveniles, No.) of the recorded females carrying juveniles within the Trajan Forum drainage system.

date	CL (mm)	No.
8 th August 2004	44	8
12 th July 2005	55	64
24 th July 2005	48	35
27 th July 2005	49	53
19 th July 2006	52	43

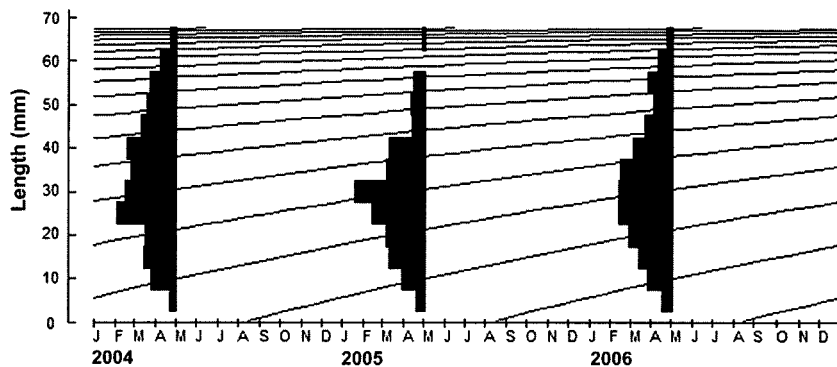


Fig. 2. Growth model of the Roman crab population obtained by ELE-FAN. Black lines correspond to age in years (1 line = 1 year) and black bars represent the size-frequency diagrams obtained by using the carapace length of each individual captured during the three study years. Size-frequency diagrams refer to May.

Table 2. Values of growth rate and dynamic parameters of the studied crab populations: RM = Rome, Imperial Forum); CG = Castel di Guido population; CM = The Monterano Regional Reserve of Canale Monterano (Scalici et al. 2007); FL = Borro San Giorgio, Antella, Florence (Gherardi 1988). Acronyms: \emptyset' = growth performance index; k = curvature parameter; L_{∞} = asymptotic length; t_{\max} = expected longevity; Z = total mortality.

site	k (1/year)	L_{∞} (mm)	\emptyset'	t_{\max} (year)	Z
RM	0.21	70.05	3.01	14.29	0.84
CG	0.34	58.43	3.06	8.82	1.63
CM	0.35	57.89	3.07	8.57	1.48
FL	0.31	62.11	3.08	9.68	1.31

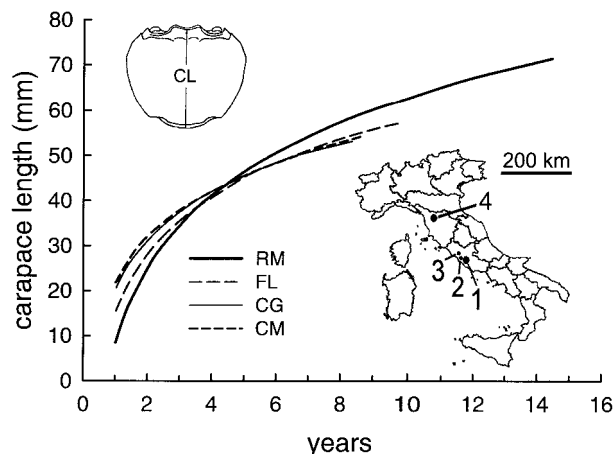


Fig. 3. Growth pattern comparison among four Italian river crab populations: 1) RM = Rome, Imperial Forum); 2) CG = Castel di Guido population; 3) CM = The Monterano Regional Reserve of Canale Monterano (Scalici et al. 2007); 4) FL = Borro San Giorgio, Antella, Florence (Gherardi 1988).

and Z and higher values of L_{∞} and t_{\max} than CG, CM, and FL. The growth performance index (\emptyset') showed no differences among populations, whereas k in RM had a significantly lower value than in the other populations (P always < 0.01 after pairwise ANCOVAs). Comparisons of growth patterns among populations are shown in Fig. 3.

Discussion

Our results show that, similarly to the indigenous crayfish *Austropotamobius pallipes* (Lereboullet, 1858) (Brusconi et al., in press; Scalici & Gibertini 2007, Scalici et al. 2008), *P. fluviatile* has a relatively slow growth rate, its curvature parameter value being typical of a tendentially K-selected species. However, the studied population exhibits a different growth pattern when compared with the other populations. Although all the analysed populations showed the same growth model (see the values of the growth performance index, \emptyset'), curvature parameter (k) and asymptotic length (L_{∞}) showed inter-population differences. In particular, in Rome, river crabs showed lower values of the curvature parameter and higher values in both the asymptotic length and the expected longevity than the other populations. These results suggest that the geographically isolated river crabs in Rome are affected by gigantism, a well known phenomenon widely studied in several other animal taxa, such as marine molluscs (McClain et al. 2006), freshwater and terrestrial insects (Peyrieras 1976, Reinel-Henao 2002), marine crustaceans (Timofeev 2001), poikilotherm (Makarieva et al. 2005) and homoeothermic vertebrates (Lomolino 2005, Meiri et al. 2005). Regarding this issue, Roman crabs also showed higher longevity and bigger body size than those of other 'non-urban' populations. Other crustacean species can also change their growth rate when exposed to stress, but in these cases, they decrease body size and also longevity (Li et al. 2002, Anger 2003, Seiler & Turner 2004, Goncalves et al. 2007). In the case of the studied crab population, isolation, low growth rate, big size, high longevity, and absence of ill, impaired individuals or specimens with abnormal behaviour seem to suggest that habitat and physical-chemical characteristics do not represent a limit for crab survival. The good health status of the Roman crab population may

probably also be due to urban isolation, which could represent a barrier for parasites and diseases, such as for the stone crayfish *Austropotamobius torrentium* (Schrank, 1803), the latter being able to increase its own survival rate due to anthropogenic isolation (Auer 2002). Additionally, lack of competitors and the scarce presence of predators may have facilitated gigantism in Rome. In fact, the only predator in the area could be *Rattus norvegicus* (Berkenhout, 1769), while other potential predators (e.g. the herring-gull *Larus argentatus* Pontoppidan, 1763 and the hooded crow *Corvus corone cornix* Linnaeus, 1758) usually avoid the area due to disturbance of permanent human presence and artificial illumination. Within the study area, feral cats could also be considered potential predators. But after several years of observation, the authors have noted that cats are more inclined to stay in neighbouring areas where they can be nursed by an association funded by the provincial administration. Only a limited number of cats can be observed within Trajan Forum and never to prey on crabs. They probably eat some decapods, but in this condition their occurrence seems to have little influence on the crab population. The limited predation pressure on crabs may explain the low values recorded for their mortality compared with those obtained for the indigenous crayfish species (Brusconi et al., in press; Scalici et al. 2008) and the other *P. fluviatile* populations. Crab fishing is an additional cause of mortality. In fact, it was extensively practised in several Italian regions until a few decades ago and still occurs today, despite the fact that the species is protected by local laws (Scalici & Gibertini 2005, Barbaresi et al. 2007, Brusconi et al., in press). It is plausible that high mortality due to predation and fishing has affected the growth of exploited river crab populations, such as in other marine (e.g. Prakash & Agarwal 1985, Gracia 1996, Gao et al. 2007) and 'inland water' decapods (Liu et al. 2007), also in accordance with the findings of Beverton & Holt (1964) who observed that overfishing can cause a decreased individual growth rate in clupeid populations. Conversely, a form of gigantism may occur in scarcely exploited populations, such as the river crab population inhabiting the centre of Rome.

Although the behaviour of river crabs has been extensively studied (e.g. Vannini & Gherardi 1981), their ecology has been relatively neglected. Therefore, our results are difficult to compare with previous studies. However, we found some interesting anomalies compared to other populations. Firstly, we observed a great difference in water quality between our study area and the other ones where crabs normally live. In-

habited waters in Rome are eutrophic, being characterized by a high content of nitrite ($0.8 < \text{NO}_2^- < 5 \text{ mg/l}$), nitrate ($3.5 < \text{NO}_3^- < 25 \text{ mg/l}$), and total phosphate ($1 < \text{P} < 3 \text{ mg/l}$) and by low pH values ($7.2 < \text{pH} < 7.6$) (Schiavone et al. 2007). It remains very difficult to understand how chemical features can affect crab survival in central Rome, since no specific evidence exists in literature concerning the correlation between water quality and crab abundance. Only Barbaresi et al. (2007) studied the habitat selection of two native freshwater decapods (*A. italicus* and *P. fluviatile*), but unfortunately, as the same authors admit, they were limited by the homogeneity of the studied rivers (all of good chemical quality). The high water quality of all the analysed streams made it impossible to establish whether *P. fluviatile* may be resistant to water pollution, as often only hypothesized on the basis of field observation and records in urban and pre-urban areas (Barbaresi et al. 2007). Also the total water hardness showed low values within the drainage system (Schiavone et al. 2007). However, in the authors' opinion, dissolved calcium, bicarbonate, and carbonate in the Trajan Forum do not constitute a real limit, as crab can prey on molluscs and eat musk and other epiphytic algae and plants. In this way, crabs assimilate calcium and carbonate through feeding.

A second anomaly shown by the *P. fluviatile* population in Rome regards its reproductive period beginning in May until July, in contrast to a population inhabiting the river of Tuscany, where females are found to carry juveniles in September (Micheli et al. 1990). In our study, we observed no coupling animals, but females carrying juveniles were observed only between the end of July and the beginning of August. This anticipation of the hatching period might depend on temperature, which reaches earlier the required level for ovarian maturation and reproduction in an urban aquatic system rather than in natural waterbodies, although at the same latitude (Schiavone et al. 2007).

Recent phylogeographic studies suggest that transfaunation might explain the occurrence of *P. fluviatile* in Rome, although the origin of the species on the Balkans and a natural expansion into Italy cannot be rejected. It currently appears plausible that the species was introduced to Italy through historic translocation (Jesse 2007, Jesse et al. 2007), contrasting Pretzmann's (1987) statement about a spontaneous movement of *P. fluviatile* from the Balkans. Apart from the origin of the crab population inhabiting the centre of Rome (this phylogeographic debate does not represent an issue of the present study), the hypothesis that this population has been isolated due to the development of Rome

seems to be confirmed by the absence of river crabs in adjacent water systems and in the River Tiber, as shown by sampling conducted with the help of local speleologists and professional river anglers. This allows to exclude that the Tiber might have served as a biological corridor for river crab dispersal. Neither do crabs seem to use the urban ground to disperse, despite its high mobility and amphibious habits (Gherardi et al. 1988a,b). The isolation of the river crab population as the result of the progressive expansion of the city of Rome could be a real possibility. Our results suggest that Roman crabs probably had no time to evolve a different growth pattern whether colonization of Imperial Forum was a consequence of recent transfaunation or incidental events (such as the flood that affected a large part of the historical centre of Rome at the beginning of the last century, Schiavone et al. 2007). In fact, intraspecific life history variation and reproductive isolation may have been established over a relatively long timeframe as a by-product of independent evolution of populations isolated from each others by geographical distance (Turelli et al. 2001, Irwin et al. 2005). For instance, Cook et al. (2006) showed that the freshwater life-history transitions due to the appearance of amphidromy in isolated *Paratya australiensis* Kemp, 1917 populations probably began in the early Pliocene. Unfortunately, we currently know little about the prevalence, and evolutionary and ecological causes and consequences of variation in life-history plasticity in the wild (Nussey et al. 2007).

The biological characteristics of a *P. fluviatile* population inhabiting the city of Rome is thus the result of this species' ecological preferences and physiological constraints coupled with its evolutionary history, human interference, and colonisation events according to the theory of Poff (1997). The latter stated that the presence and abundance of organisms at a specific site are the result of the action of several multi-scale filters, including both historical and ecological constraints ranging from landscape to micro-habitat scales.

We are not able to explain our observation in detail due to the lack of overall information on the ecology of *P. fluviatile*. Differences observed among the studied populations can also be attributable to environmental and population features, such as altitude, water flow, trophic status, distance from source, density, competition, and human exploitation, as it happens for crayfish (Momot et al. 1978, Aiken & Waddy 1992, Jones & Coulson 2006). There is considerable scope for further work on dynamic aspects of *P. fluviatile* and other crab species, as information on the variation in growth models for different localities, and an assessment of

the factors affecting moult increment and frequency remains insufficient. From this viewpoint, dynamics studies are also useful for planning in situ activities of monitoring. It is therefore, necessary to devise a conservation plan for this relict population of *P. fluviatile*, which must be compatible with the archaeological activity in the area. The underlying rationale is that this natural and presumably ancient population should be preserved with the same priority as historical monuments.

Acknowledgements

We would sincerely like to thank the Archeological Superintendency of Rome, and in particular Arch. Roberto Meneghini and Arch. Elisabetta Bianchi for their help and logistic support. We are also indebted to two anonymous referees for their helpful comments and suggestions towards the improvement of the manuscript, and to Dr Michael Kenyon for his linguistic revision. Finally, many thanks are due to several students of the Department of Biology at Roma Tre University, who worked so enthusiastically during the past years of intense research on *Potamon fluviatile*.

References

- Aiken, D. E. & Waddy, S. L. 1992: The growth process in crayfish. – *Rev. Aquat. Sci.* **6**: 335–381.
- Anger, K., 2003: Salinity as a key parameter in the larval biology of decapod crustaceans. – *Invertebr. Reprod. Dev.* **43**: 29–45.
- Auer, R., 2002: The stone-crayfish (*Austropotamobius torrentium* Schrank 1803) populations are surviving due to anthropogenic isolation. – *Oesterreichs Fischerei* **55**: 268–274.
- Barbaresi, S., Cannicci, S., Vannini, M. & Fratini, S., 2007: Environmental correlates of two macro-decapods distribution in central Italy: Multi-dimensional ecological knowledge as a tool for conservation of endangered species. – *Biol. Conserv.* **136**: 431–441.
- Barbaresi, S. & Gherardi, F., 1997: Italian freshwater decapods: exclusion between the crayfish *Austropotamobius pallipes* (Faxon) and the crab *Potamon fluviatile* (Herbst). – *Bull. Fr. Peche Piscic.* **347**: 731–747.
- Bascompte, J. & Solé, R. V., 1998: Effects of habitat destruction in a prey-predator metapopulation model. – *J. Theor. Biol.* **195**: 383–393.
- Beverton, R. J. H., 1963: Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. – *Rapp. Réunion CIEM* **154**: 44–67.
- Beverton, R. J. H. & Holt, S. J., 1964: Tables of yield functions for fishery management. – *FAO Fisheries Technical Paper* 38, Rome.
- Brandis, D., Storch, V. & Trkay, M., 2000: Taxonomy and zoogeography of the freshwater crabs of Europe, North Africa, and the Middle East. – *Senckenbergiana Biologica* **80**: 5–56.
- Brusconi, S., Renai, B., Scalici, M., Souty-Grosset, C. & Gherardi, F., in press: Stock assessment in the threatened crayfish *Austropotamobius italicus* in Tuscany (Italy): implications for its conservation. – *Aquat. Conserv.*

- Caddy, J. F., 1987: Size-frequency analysis for Crustacea: moult increment and frequency models for stock assessment. – *Kwait Bull. Mar. Sci.* **9**: 43–61.
- Cook, B. D., Baker, A. M., Page, T. J., Grant, S. C., Fawcett, J. H., Hurwood, D. A. & Hughes, J. M., 2006: Biogeographic history of an Australian freshwater shrimp, *Paratya australiensis* (Atyidae): the role life history transition in phylogeographic diversification. – *Mol. Ecol.* **15**: 1083–1093.
- Didham, R. K., Lawton, J. H., Hammond, P. M. & Eggleton, P., 1998: Trophic structure stability and extinction dynamics of beetles (*Coleoptera*) in tropical forest fragments. – *Phil. Trans. Roy. Soc. B* **353**: 437–451.
- Dynesius, M. & Nilsson, C., 1994: Fragmentation and flow regulation of river systems in the northern third of the world. – *Science* **266**: 753–62.
- FAO, 2004: Food and Agriculture Organisation FAO-ICLARM Fish stock-assessment tools. – <http://www.fao.org>.
- France, R., Holmes, J. & Lynch, A., 1991: Use of size-frequency data to estimate the age composition of crayfish populations. – *Can. J. Fish. Aquat. Sci.* **48**: 2324–2332.
- Gao, B. Q., Liu, P., Li, J., Dai, F. Y. & Ma, S., 2007: Analysis of morphological variations among four wild population of *Portunus trituberculatus*. – *J. Fishery Sci. China* **14**: 223–228.
- Garcia, S. & Le Reste, L., 1981: Life cycles, dynamics, exploitation and management of coastal penaeid shrimp stocks. – FAO Fishery Technical Paper 203.
- Gayanilo, F. C. Jr. & Pauly, D., 1997: FiSAT: FAO-ICLARM stock assessment tools. (FiSAT). Reference manual. – Computerized Information Series (Fisheries), FAO, Rome.
- Gherardi, F., 1988: Eco-etologia di *Potamon fluviatile* in Toscana. – PhD Thesis, La Specola University, Florence.
- Gherardi, F., Messina, G., Ugolini, A. & Vannini, M., 1988a: Studies on the locomotor activity of the freshwater crab *Potamon fluviatile*. – *Hydrobiologia* **169**: 241–250.
- Gherardi, F., Tarducci, F. & Vannini, M., 1988b: Locomotor activity in the freshwater crab *Potamon fluviatile*: the analysis of temporal patterns by radio-telemetry. – *Ethology* **77**: 300–316.
- Goncalves, A. M. M., Castro, B. B., Pardal, M. A. & Goncalves, F., 2007: Salinity effects on survival and life history of two freshwater cladocerans (*Daphnia magna* and *Daphnia longispina*). – *Annal. Limnol.* **43**: 13–20.
- Gracia, A., 1996: White shrimp (*Penaeus setiferus*) recruitment overfishing. – *Mar. Freshwat. Res.* **47**: 59–65.
- Hanski, I., 1998: Metapopulation dynamics. – *Nature* **396**: 41–49.
- Herborg, L. M., Rushton, S. P., Clare, A. S. & Bentley, M. G., 2005: The invasion of the Chinese mitten crab (*Eriocheir sinensis*) in the United Kingdom and its comparison to continental Europe. – *Biol. Invasions* **7**: 959–968.
- Irwin, D. E., Bensch, S., Irwin, J. H. & Price, T. D., 2005: Speciation by distance in a ring species. – *Science* **307**: 414–416.
- Jamieson, G. S. & Bourne, N., 1986: North Pacific Workshop on stock assessment and management of invertebrates. – *Can. Spec. Publ. Aquat. Sci.* **92**: 453 pp.
- Jansson, R., Nilsson, C., Dynesius, M. & Andersson, E., 2000: Effects of river regulation on river-margin vegetation: a comparison of eight boreal rivers. – *Ecol. Appl.* **10**: 203–224.
- Jesse, R., 2007: Phylogeography of the freshwater crab *Potamon fluviatile* in Italy and on the Balkans: present results and future research plans. – 13th Annual European Meeting of PhD Students in Evolutionary Biology, Lund, Sweden, August 2007, 28.
- Jesse, R., Fratini, S. & Schubart, C. D., 2007: The genetic population structure of the freshwater crab *Potamon fluviatile* in Italy – a historical human introduction? – Annual Meeting of the Study Group Evolutionary Biology of the German Zoological Society (DGZ), 23th–25th February 2007. 37.
- Johnes, J. P., 1996: Evaluation and management of the impact of land use change on the nitrogen and phosphorus load delivered to surface waters: the export coefficient modelling approach. – *J. Hydrol.* **183**: 323–349.
- Jones, J. P. G. & Coulson, T., 2006: Population regulation and demography in a harvested freshwater crayfish from Madagascar. – *Oikos* **112**: 602–611.
- Kruess, A. & Tschardtke, T., 1994: Habitat fragmentation, species loss and biological control. – *Science* **264**: 1581–1584.
- Li, C. H., Li, S. F., Xing, Y. Y., Hu, B. L. & Zhao, S. C., 2002: Growth performance and its genotype-environment interaction analysis of Chinese mitten crab (*Eriocheir sinensis*) populations from the Yangtze River and the Liaohe River in ponds. – *Acta Hydrobiol. Sin.* **26**: 335–341.
- Liu, K., Duan, J., Xu, D., Zhang, M., Shi, W. & Hupo, K., 2007: Studies on current resource and causes of catch fluctuation of brooders of mitten crab in estuary of the Changjiang River. – *Freshw. Fisher. Res. Center, Chinese Academy of Fisheries Science*, **19**: 212–217.
- Lomolino, M. V., 2005: Body size evolution in insular vertebrates: generality of the island rule. – *J. Biogeogr.* **32**: 1683–1699.
- Makarieva, A. M., Gorshkov, V. G. & Li, B. L., 2005: Gigantism, temperature and metabolic rate in terrestrial poikilotherms. – *Proc. R. Soc. B*, pp. 204–214.
- Maurakis, E. G., Grimes, D. V., McGovern, L. & Hogarth, P., 2004: The occurrence of *Potamon* species (Decapoda, Brachyura) relative to lotic stream factors in Greece. – *Biologia Bratislava* **59**: 173–179.
- McClain, C. R., Boyer, A. G. & Rosenberg, G., 2006: The island rule and the evolution of body size in the deep sea. – *J. Biogeogr.* **33**: 1578–1584.
- Meiri, S., Dayan, T. & Simberloff, D., 2005: Area, isolation and body size evolution in insular carnivores. – *Ecol. Lett.* **8**: 1211–1217.
- Meyer, J. L., Sale, M. J., Mulholland, P. J. & Poff, N. L., 1999: Impacts of climate change on aquatic ecosystem functioning and health. – *J. Amer. Water Res. Assoc.* **35**: 1373–1386.
- Micheli, F., Gherardi, F. & Vannini, M., 1990: Growth and reproduction in the freshwater crab, *Potamon fluviatile* (Decapoda, Brachyura). – *Freshwat. Biol.* **23**: 491–503.
- Momot, W. T., Gowing, H. & Jones, P. D. 1978: The dynamics of crayfish and their role in ecosystems. – *Amer. Midl. Nat.* **99**: 10–35.
- Naiman, R. J. & Turner, M. G., 2000: A future perspective on North America's freshwater ecosystems. – *Ecol. Appl.* **10**: 958–70.
- Noel, P. & Guinot, D., 2007: Non-indigenous freshwater crabs in France: a new occurrence of a potamid near Nice. – In: Gherardi, F. (ed.): *Invasion Ecology Biological invaders in inland waters: Profiles, Distribution, and Threats*. – Springer Series in Invasion Ecology, pp. 77–90.
- Nussey, D. H., Wilson, A. J. & Brommer, J. E., 2007: The evolutionary ecology of individual phenotypic plasticity in wild populations. – *J. Evol. Biol.* **20**: 831–844.
- Pauly, D., 1981: The relationships between gill surface area and growth performance in fish: a generalization of Von Bertalanffy's theory of growth. – *Meeresforsch.* **28**: 251–282.

- Pauly, D. & Munro, M., 1984: Once more on the comparison of growth in fish and invertebrates. – ICLARM Fishbyte, FAO, Rome.
- Peyrieras, A., 1976: Insectes coleopteres Carabidae Scaritinae. – Biologie. Faune de Madagascar **41**: 1–161.
- Poff, N. L., 1997: Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. – J. N. Amer. Benthol. Soc. **7**: 456–479.
- Polis, G. A., Anderson, W. B. & Holt, R. D., 1997: Toward an integration of landscape and food web ecology: the dynamics of spatially subsidized food webs. – Ann. Rev. Ecol. Syst. **28**: 289–316.
- Powell, D. G., 1979: Estimation of mortality and growth parameters from the length-frequency in the catch. – Rapp. Réunion CIEM, pp. 167–169.
- Prakash, S. & Agarwal, G. P., 1985: Studies on the effect of non-pollutional interference on freshwater prawn (*Macrobrachium birmanicum choprai*) fishery of middle stretch of River Ganga. – Uttar Pradesh J. Zool. **5**: 42–48.
- Pretzmann, G., 1987: A contribution to a historic analysis of Mediterranean freshwater decapods chorology. – Invest. Pesq. Barcelona **51**: 17–25.
- Reinel-Henao, E., 2002: The gigantism of tropical insects. – Boletín Científico Museo-de Historia Natural Universidad de Caldas **6**: 177–180.
- Reynolds, J. D., 2002: Growth and reproduction. – In: Holdich, D. M. (ed.): Biology of freshwater crayfish. – Blackwell Science, London, pp. 151–181.
- Richter, B. D., Braun, D. P., Mendelson, M. A. & Master, L. L., 1997: Threats to imperiled freshwater fauna. – Conserv. Biol. **11**: 1081–1093.
- Scalici, M., Belluscio, A. & Gibertini, G., 2008: Understanding the population structure and dynamics in threatened crayfish. – J. Zool., Lond., **275**: 160–171.
- Scalici, M. & Gibertini, G., 2005: Can *Austropotamobius italicus meridionalis* be used as a monitoring instrument in Central Italy? Preliminary observations. – Bull. Fr. Peche Piscic. **376–377**: 613–625.
- – 2007: Study of the native freshwater crayfish growth in the Monti Lucretili Regional Parc (Latium – Central Italy). – J. Freshwat. Biol., Quad. ETP **34**: 213–218.
- Scalici, M., Scuderi, S., Gherardi, F. & Gibertini, G., 2007: Growth of two river crab species of the genus *Potamon* (Savigny, 1816). – Crustaceana **81**: 119–123.
- Schiavone, F., Scalici, M., Gibertini, G. & Macale, D., 2007: Observation on the freshwater crab *Potamon fluviatile* (Herbst, 1785) in historical centre of Rome. – J. Freshwat. Biol., Quad. ETP **34**: 219–224.
- Seiler, S. M. & Turner, A. M., 2004: Growth and population size of crayfish in headwater streams: individual- and higher-level consequences of acidification. – Freshwat. Biol. **49**: 870–881.
- Simberloff, D., 1992: Do species-area curves predict extinction in fragmented forests? – In: Whitmore, T. C. & Sayer, J. A. (eds): Tropical Deforestation and Species Extinction. – Chapman and Hall, London, pp. 75–9.
- Soulé, M. E., 1991: Conservation: tactics for a constant crisis. – Science **253**: 744–750.
- Souty-Grosset, C., Holdich, D. M., Noël, P. Y., Reynolds, J. D. & Haffner, P., 2006: Atlas of Crayfish in Europe. – Museum National d'Histoire Naturelle, Paris.
- Sparre, P. & Venema, S. C., 1996: Introduction à l'évaluation des stocks de poissons tropicaux. – Document technique sur les pêches. FAO, Rome.
- Strayer, D. L., Beighley, R. E., Thompson, L. C., Brooks, S., Nilsson, C., Pinay, G. & Naiman, R. J., 2003: Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. – Ecosystems **6**: 407–423.
- Timofeev, S. F., 2001: Bergmann's principle and deep-water gigantism in marine crustaceans. – Izvestiya Rossiiskoi Akademii Nauk Seriya Biologicheskaya, Noyabr' Dekabr' **6**: 764–768.
- Turelli, M., Barton, N. & Coyne, J., 2001: Theory and speciation. – Trends Ecol. Evol. **16**: 330–343.
- Turner, I. M. & Corlett, R. T., 1996: The conservation value of small, isolated fragments of lowland tropical rain forest. – Trends Ecol. Evol. **11**: 330–333.
- Vannini, M. & Gherardi, F., 1981: Dominance and individual recognition in *Potamon fluviatile* (Decapoda, Brachyura): possible role of visual cues. – Mar. Behav. Phy. **8**: 13–20.
- Von Bertalanffy, L., 1938: A quantitative theory of organic growth. – Human Biol. **10**: 181–243.
- Vörösmarty, C. J., Green, P., Salisbury, J. & Lammers, R. B., 2000: Global water resources: vulnerability from climate change and population growth. – Science **289**: 284–288.
- Wetherall, J. A., 1986: A new method for estimating growth and mortality parameters from length-frequency data. – ICLARM Fishbyte **4**: 12–14.
- Wiltshire, E. & Reynolds, J. D., 2006: Bird predation on Turkey crayfish in central London. – The London Naturalist **85**: 121–124.
- Wolf, E. C., 1987: On the brink of extinction: conserving the diversity of life. – Worldwatch Paper n. **78**, Worldwatch Institute, Vision for a Sustainable World, 53 pp.
- Wootton, J. T., Parker, M. S. & Power, M. E., 1996: Effects of disturbance on river food webs. – Science **273**: 1558–1561.