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Research Article

# The signal crayfish, *Pacifastacus leniusculus* (Dana, 1852) [Crustacea: Decapoda: Astacidae], in the Brugneto Lake (Liguria, NW Italy). The beginning of the invasion of the River Po watershed?

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## Abstract

The recent finding of the signal crayfish, *Pacifastacus leniusculus* (Dana, 1852) in the Brugneto Lake (Trebbia River basin, Liguria, NW Italy) raises new management problems. In this paper, the results of trapping carried out between November 2005 and October 2006, the population structure and the diseases of *P. leniusculus* inhabiting Brugneto Lake are analysed. The total sex ratio observed was 1:1.03 (males/females) and it did not differ significantly from the theoretical 1:1 value, whereas the sex ratio recorded during winter differed significantly from the theoretical value. The CPUE (Catch Per Unit Effort) calculated was significantly related both to mean seasonal temperature and water-level variations. Regarding diseases only the presence of chitinoclastic bacteria on exoskeleton were found. Branchiobdellidae (Annelida, Clitellata) were not observed either on the exoskeleton or in the branchial-chambers, neither were ectocommensals, nor melanisation caused by bacterial infections on gill filaments. Fortunately, melanised spots on the legs usually caused by an infection of *Aphanomyces astaci* Schikora were not found.

**Key words:** *Pacifastacus leniusculus*, population structure, diseases, captures, Brugneto Lake, Italy

## Introduction

Biodiversity has important social and cultural values (Gherardi et al. 2003): unfortunately biological resources are threatened by several factors, often of anthropogenic origin. The introduction of alien species is recognized as one of the greatest biological threats to our planet's ecological well-being (Mooney and Hobbs 2000; Pimentel et al. 2000), and practically no habitat escapes from this risk. Freshwater ones are probably the most affected: lotic and lentic environments consist of a dynamic mosaic of spatial elements and ecological processes arrayed hierarchically (Ward et al. 2002) and their survival is due to the maintenance of delicate equilibriums (Amoros and Bornette 2002; Malmqvist 2002). The introduction of allochthonous species represents the main threat for freshwater catchments: fish, shellfish and crustaceans are easily transferred for food purposes, restocking and ornamental or aquacultural purposes. These introduced organisms are often able to become established in the wild by reaching high densities and having a large impact on native species or ecosystems (Light 2003).

Freshwater crayfish are important components of European aquatic fauna, and they can be considered as key-species in the habitat they colonised (Holdich and Gherardi 1999; Souty-Grosset et al. 2006): being the biggest freshwater macroinvertebrates (Holdich 2003), they are either predators and prey (Peris et al. 1994; Beja 1996; Elvira et al. 1996; Parkin et al. 2001, Renai and Gherardi 2004), they act as ecosystem engineers (Statzner et al. 2003) and also convert particulate organic matter in noble proteins (Reynolds 1979).

On the other hand, crayfish are also highly valued from a cultural, recreational and economical point of view, and theirs fisheries and culture are very widespread (Edsman 2004; Jussila and Mannonen 2004; Taugbøl 2004). The reasons for the historical introductions of alien crayfish stocks were mainly because of the perceived need to replace the impoverished native crayfish fauna, to fill a vacant niche and to control aquatic water vegetation, whereas accidental introductions have often been due to escapes from aquacultural facilities (Henttonen and Huner 1999).

In Italy the introduction of alien crayfish is widespread, producing significant changes in aquatic communities (Gherardi et al. 1999). Stable breeding populations of *Procambarus clarkii* (Girard) and *Orconectes limosus* (Rafinésque) are known in Northern and Central Italy, while there is little information about *Astacus leptodactylus* (Eschscholtz) and *Pacifastacus leniusculus* (Dana, 1852) (Gherardi et al. 1999; Souty-Grosset et al. 2006). The occurrence of signal crayfish *P. leniusculus* in the Italian freshwater habitat was first recorded by Machino (1997) and Füreder and Machino (1999) in the Adige River basin (Trentino Alto Adige, NE Italy): the recent finding of *P. leniusculus* in the Brugneto Lake (Trebbia River basin, Liguria, NW Italy) (Capurro et al. 2006) raises new management problems for the lake, especially as *P. leniusculus* is regarded as an invasive species (Guan and Wiles 1998; Guan and Wiles 1999; Huber and Schubart 2005; Stenroth and Nyström 2003; Vorburger and Ribi 1999; Westman et al. 2002).

The purpose of this paper is to relate captures of crayfish to two environmental features, i.e. water temperature and level variations. In addition, the population structure and occurrence of diseases of *P. leniusculus* established in the Brugneto Lake were analysed.

## Material and methods

### *Study Site*

The Brugneto Lake (44°32'N, 9°12'E) lies in the Trebbia watershed (Liguria, NW Italy) at 770 m above sea level, approximately 40 km northeast of Genoa. This lake, having a volume of 25 million $m^3$ and a maximum depth of 77 m, is the most important artificial water reservoir in Liguria (Arillo and Mariotti 2002). The lake, characterized by a muddy steep bottom, does not provide many available shelters, therefore the signal crayfish has to burrow in more compact clayey strata (M. Capurro, research in progress). The Brugneto Lake effluent streams flow into the Trebbia River. This one rises in the Ligurian Apennines at an altitude of 1406 m, and flows 115 km north-northeast across the northern Apennines and the Po lowland to enter the Po River, just west of Piacenza. Dense populations of endangered in Europe native crayfish *Austropotamobius pallipes* (Lereboullet) inhabit the Apennine effluents of the Trebbia basin (Salvidio et al. 2002).

*Pacifastacus leniusculus* was probably introduced into the lake around 2002, released from thoughtless aquarists or as bait by anglers (Capurro et al. 2006), and its population has markedly increased. We selected an area as a sampling station that is thought to be the initial point of release of *P. leniusculus* and where individual density seems to be the highest in the lake (Capurro et al. 2006).

### *Field sampling*

*Pacifastacus leniusculus* specimens were sampled biweekly from November 2005 to October 2006. Along the shores of the above-mentioned area, we identified ten sampling stations 30 m long. Then, for each sampling session, we randomly selected four stations and we set five traps for each one. Two-way traps baited with cat food (diameter 15 cm; length 60 cm; mesh size 1 cm) were thrown from the shore at intervals of approximately 5-6 m, between 5 and 8 m depth. We based the trap spacing on the effective trapping radius presented in previous study (Abrahamsson and Goldman 1970). Each trap was set in the afternoon and then visited two days later, to exploit also the diurnal activity of signal crayfish (Lozán 2000, Strempel 1974).

Crayfish trapped were immediately frozen after capture and then thawed for laboratory analysis. Each specimen was sexed and CL (carapace length in mm, from the apex of the rostrum to the mid-dorsal posterior edge of the carapace), recorded using a vernier caliper to the nearest 0.1 mm, was used as a size indicator. For female specimens we observed whether they carried eggs or hatchlings on the pleopods or not and if spermatophores were present. For each crayfish sampled we evaluated the disease condition at a macroscopical level, also analysing branchial-chambers and gill filaments by stereomicroscopy in the laboratory. Because samples were often small for individual months,

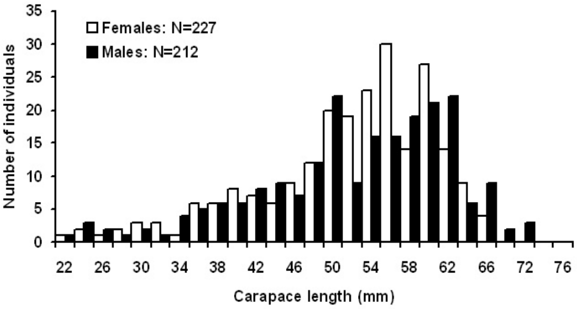


**Figure 1.** Size (carapace length) frequency distributions of male and female *Pacifastacus leniusculus* collected and measured during the whole study.

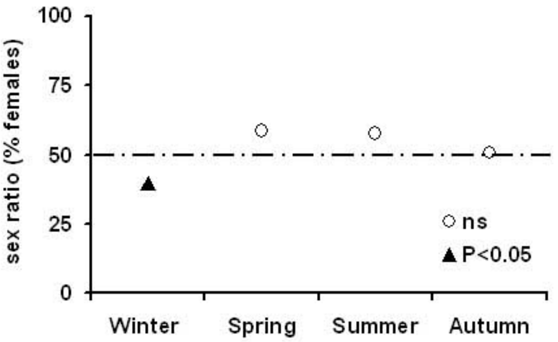


**Figure 2.** Seasonal sex ratio, as percentage of females, in *Pacifastacus leniusculus*.

data were seasonally pooled. So we calculated the mean cumulated seasonal Catch Per Unit Effort (CPUE), expressed as number of individuals trapped/number of traps used, and these values were related to mean water temperature (T) and to water level variations (WLV) in the same period. Temperature was measured every day at 5 m depth; water level, measured daily too, was expressed as altitude of water surface above sea level (Physical features were recorded by AMGA by means of electronic instruments). The possible presence of *P. leniusculus* in the main tributaries and in the effluent of the lake, the Brugneto Stream, was also investigated. The presence/absence of the crayfish was verified by manual survey conducted during the day (1 hour) in spring/ summer 2006: we could not use baited traps owing to streams morphology, characterised by small depth. The presence/absence of *A. pallipes* was noted too.

## Results

A total of 439 *Pacifastacus leniusculus* individuals (212 males and 227 females) were captured throughout the sampling period. The CL of male individuals ranged between 22 and 72 mm, whereas CL of female individuals ranged between 22 and 66 mm; length-frequency distribution (Figure 1) revealed that individuals between 48 and 64 mm CL values were caught more frequently in the traps. Although the majority of large individuals were males, there was no statistically difference in size between sexes (Student t test: $t=0.563$; $P>0.05$) and the medians were also equal (Kolmogorov-Smirnov test: $D=0.091$; $P>0.05$). The total observed sex ratio was 1:1.03 (males/females) and it did not differ significantly from the theoretical 1:1 value ($\chi 2= 0.083$; $P >0.05$). Figure 2 shows the seasonal sex ratio changes. In winter the sex ratio showed a relative decline of females, while from Spring to Autumn it did not deviated from 1:1 (Figure 2).

Mean seasonal water temperature increased from winter to summer and decreased from autumn to winter (Figure 3). The peak of water level variations recorded in spring is related with the snowmelt and the rainfalls in late winter and early spring (Figure 4).

The CPUE was significantly related to the mean seasonal temperature (Figure 3) and to water level variations (Figure 4). The correlation between water temperature and CPUE was significant ($r=0.821$; $P<0.05$) and the equation of the regression line was: Log CPUE = -0.623 + 5.985 Log T; the correlation between water level variations and CPUE was significant too ($r= -0.885$; $P<0.05$) and the equation for regression line was: Log CPUE = 776.35 + -6.226 Log WLV. The number of trapped crayfish decreased from winter to spring, during which we registered the lowest CPUE values, and then it increased from summer to autumn.

During the study period 21 berried females were trapped, ranging between 40.5 and 64.7 mm in CL: the first berried female was trapped in December 2005, the last one in July 2006. The number of pleopodal eggs ranged from 1 to 327. In June 2006 a female carrying only one second stage juvenile was captured. During sampling spermatophores were found on only 9 females, the first trapped in December 2005 and the last one in February 2006.

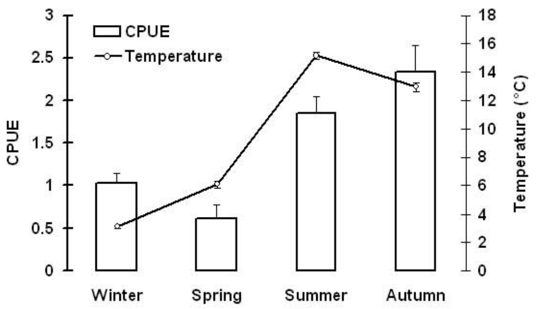


**Figure 3.** Seasonal Catch Per Unit Effort (CPUE) of *Pacifastacus leniusculus*, expressed as number of individuals trapped/number of traps used, related to mean/seasonal water temperature of Brugneto lake. Vertical bars indicate ±SE of means.

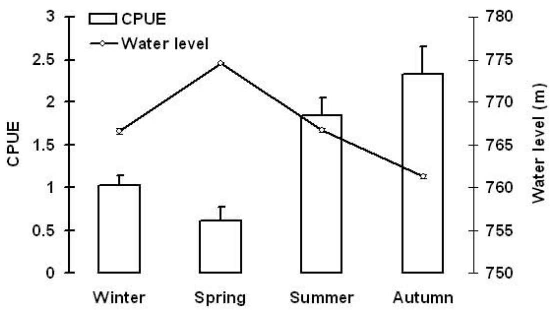


**Figure 4.** Seasonal Catch Per Unit Effort (CPUE) of *Pacifastacus leniusculus* related to mean/seasonal water level variations of Brugneto lake. Vertical bars indicate ±SE of means.

Regarding diseases, only the presence of chitinoclastic bacteria on the exoskeleton (carapace and chelipeds) of nine males (CL ranges from 50 to 71 mm) and four females (CL ranges from 49.7 to 61 mm) were observed. Branchio-bdellidae (Annelida, Clitellata) were not seen either on the exoskeleton or in the branchial-chambers, neither were ecto-commensals or mela-nisation caused by bacterial infections on the gill filaments. Our macroscopic investigations did not show black melanised spots on the legs, usually caused by an infection of *A. astaci* (Diéguez-Uribeondo 2006).

No *A. pallipes* individuals were captured with baited traps in the lake. *P. leniusculus* were not found in the Brugneto tributaries or in Brugneto Stream, whereas *A. pallipes* was found only in a little tributary of Brugneto Stream (Fosso Ciappa).

## Discussion

*Pacifastacus leniusculus* cannot be considered as an r-selected species such as *Procambarus clarkii* is (Lindqvist and Huner 1999); however its reproduction efficiency (Guan and Wiles 1999), feeding ecology (Guan and Wiles 1998) and beha-vioural and ecological characteristics (Nyström and Strand 1996, Söderbäck 1995, Vorburger and Ribi 1999, Westman et al. 2002) make it an highly invasive species. Signal crayfish can co-exist with some indigenous crayfish species (ICS) in Europe, but in the long run it usually out competes them (Souty-Grosset et al. 2006). The colonisation of Lake Brugneto by *P. leniusculus* seems to be in its early stages, and fortunately it has not yet been found in the tributaries or in the lake effluent; nevertheless its rate of spread (Abrahamsson 1981, Holdich et al. 1995, Guan and Wiles 1997, Kirjavainen and Westman 1999), activity beha-viour (Lozán 2000, Bubb et al. 2002) and the lack of obstacles (artificial or natural) along the shores of the lake, will probably allow a rapid coloni-sation of the whole lake. Unfortunately there is no previous quantitative data about the presence of *P. leniusculus* inhabiting Brugneto Lake: however some fishermen have occasionally caught this species since 2002 (Capurro et al. 2006). The growth of *P. leniusculus* has been studied using many different methods, e.g. use of a technique based on lipofuscin, a neuronal age pigment, indicates that some *P. leniusculus* individuals can live for 20 years (Souty-Grosset et al. 2006). Typically signal crayfish will attain a maximum carapace length of 50 to 70 mm, with a corresponding weigth of 60 to 110 g (Lewis 2002). In the present study a maximum carapace length of 66 and 72 mm for females and males was registered, respectively. Comparing the carapace length values with growth curves of *P. leniusculus* valued from several populations (Lewis 2002), it might be supposed that the signal crayfish population inhabiting Brugneto Lake could be more than 7-8 years old. Furthermore the native habitat of *P. leniusculus* ranges from small streams to large rivers and lakes (Mason 1963; Miller 1970), so it should have no problem in occupying the small tributaries and the effluent of the lake, where a small population of *A. pallipes* is still present. Other populations of the white-clawed crayfish are present in the Trebbia watershed (Salvidio et al. 2002), and the risk that signal crayfish could replace these populations is a possibility that should to be avoided.

The results of trapping during the study period provided evidence on the size-selectivity of traps and the seasonal variations of trappability (Abrahamsson 1981, Brown and Brewis 1977, Reynolds and Matthews 1993). The size distribution of trapped *P. leniusculus* in the Brugneto Lake is similar to that recorded by Westman et al. (2002) for a population inhabiting a Finnish lake. However, the present data are missing juveniles (0+) of both sexes, identified by the above-mentioned authors as sized less than 20 mm CL. This may be due to the fact that the catch of juveniles in a lake requires different methods, e.g. hydraulic diver-operated dredge sieve (Westman et al. 2002), since large individuals somehow prevent smaller ones from entering the traps (Kirjavainen and Westman 1999). However, the use of baited traps, set by the lakeshore or from a boat, is the only suitable method in the Brugneto Lake, since it seem to be the only effective one in turbid conditions (Peay 2004). As the traps used for the present study were all placed at the same depth, their range could not cover all habitats, and the size of the trappable population was probably underestimated.

The lower catchability during winter and spring with respect to summer and autumn could be related to the minor activity of crayfish after breeding and later, for females only, after spawning (Gherardi et al. 1997, Kirjavainen and Westman 1999, Grandjean et al. 2000 and therein). The deviation of the sex ratio from 1:1 recorded in winter could be related to the females being less vulnerable to capture as in this period of the year they remain in the burrows brooding their eggs. The increasing number of trapped individuals registered from late summer to autumn could be related to the foraging and the growing activity for the following mating season (Mason 1970).

Previous studies have shown that there is a strong correlation of activity of crayfish with water temperature (Abrahamsson 1981, Kirjavainen and Westman 1999, Riggert et al. 1999, Barbaresi and Gherardi 2001, Bubb et al. 2002). In the present study we confirmed this relation. Mean seasonal temperature during the trapping period appeared to influence crayfish catchability: the lower the temperature on the trapping, the smaller the CPUE. Such relationship was the one expected in an aquatic ectotherm species (Bubb et al. 2004).

Our results seem to provide evidence of a correlation between CPUE and the water level variations too, even if we could suppose that these variations influenced more the catchability than the activity of crayfish. At the same time we must remark that we threw the traps from the shores and so, when the water level increased, we were not able to reach the sites previously occupied by crayfish. However, the increase of water level occurred at the same time as the post-breeding period of lower crayfish activity: so we are not able to completely separate the effects of these two factors.

The period of presence of ovigerous females found in our study, was similar to that reported by Nakata et al. (2004) and also for North America and Europe (Lewis 2002).

The presence of pathogens or parasites, except for a few cases of chitinoclastic bacteraemias were not observed in the present study. However, more careful analysis will be carried out in future, since Souty-Grosset et al. (2006) mentioned that *P. leniusculus* is a chronic carrier of crayfish plague in Europe, and possibly of other parasites, e.g. *Psorospermium* sp., *Thelohania contejeani* (Henneguy), and Branchiobdellidae (Diéguez-Uribeondo et al. 1993, Ohtaka et al. 2005, Diéguez-Uribeondo 2006).

Management actions will be necessary to contain the growth of the signal crayfish population and to avoid its spread outside the lake, above all in the Trebbia River that flows into the Po River, the most important Italian fresh-water course. The rate of spread of *P. leniusculus* can vary from 0.2 km year-1 to 2.8 km year-1 (Peay and Rogers 1999 and therein). Therefore it is reasonable to suppose a time of about 7 year for the signal crayfish population to reach the Po River, which is only 115 km from the Brugneto Lake. However, such spread could be faster as the importance of juveniles and smaller size classes is poorly understood. In fact, Bubb et al. (2004) underlined the fact that although the smallest age class is unlikely to be capable of making substantial active movements, they could be passively transported downstream, since the passive drift of many macroinvertebrates is recognised as important element for species' dispersal ability (Bilton et al. 2001).

Teleost fishes are the only natural enemies of the signal crayfish present in Brugneto Lake. The importance of predation as a process structuring the distribution and abundance of crustaceans is difficult to assess (Blake et al. 1994); however predatory fish can have strong effects on the local distribution of crayfish, even if this influence on prey density and distribution are very variable, from trivial to overwhelming (Sih et al. 1985, Englund 1999). In Brugneto Lake, different teleost fish species prey on *P. leniusculus*: indeed, among the components of stomach content of *Perca fluviatilis* (L.), *Anguilla anguilla* (L.) and *Ictalurus melas* (Rafinésque) the remains of *P. leniusculus* have been found (I. Borroni pers. comm.). Eels are, however, extremely rare in the lake, whereas catfish is present only as juveniles individuals (I. Borroni pers. comm.). Perch is probably the most important predator for *P. leniusculus* in Brugneto Lake, since its influence is confirmed for other crayfish species too (Appelberg 1987, 1990; Appelberg and Odelström 1988, Svensson 1993, Nyström 2005); *Cyprinus carpio* (L.) and species of bass (*Micropterus salmoides* Lacépéde is present in Brugneto Lake) prey on crayfish (Garvey et al. 1992, Rabeni 1992, Lewis 1999), but their impact on *P. leniusculus* in Brugneto Lake has not been yet verified. Exploitation could be another method to prevent the future complete colonisation of the lake and of the entire watershed, although a more complete knowledge is necessary to plan any management proposal.

However, these efforts could be in vain since, compared to other European states (Ireland, Norway, Sweden, Finland, Spain, France, Poland), in Italy, as well as in Germany and Austria, the import of all live crayfish from abroad is not banned by customs legislation (Souty-Grosset et al. 2006).

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## References

Abrahamsson S (1981) Trappability, locomotion and diel pattern of activity of the crayfish *Astacus astacus* and *Pacifastacus leniusculus* Dana. *Freshwater Crayfish* 5: 239-253

Abrahamsson SAA, Goldman CR (1970) Distribution, density and production of the crayfish *Pacifastacus leniusculus* Dana in Lake Tahoe, California-Nevada. *Oikos* 21: 83-91, http://dx.doi.org/10.2307/3543843

Amoros C, Bornette G (2002) Connectivity and biocomplexity in waterbodies of riverine floodplains. *Freshwater Biology* 47: 761-776, http://dx.doi.org/10.1046/j.1365-2427.2002.00905.x

Appelberg M (1987) Some factors regulating the crayfish *Astacus astcus* L. in acid and neutralised waters. In: Witters H, Vanderborght O (eds), Ecophysiology of acid stress in aquatic organisms. *Annales de la Societe Royale Zoologique de Belgique* 117 (suppl 1): 167-179

Appelberg M (1990) Population regulation of the crayfish *Astacus astacus* L. after liming an oligotrophic, low-alkaline forest lake. *Limnology* 21: 319-327

Appelberg M, Odelström T (1988) Interaction between European perch (*Perca fluviatilis*) and juvenile *Pacifastacus leniusculus* (Dana) in pond experiment. *Freshwater Crayfish* 7: 37-45

Arillo A, Mariotti M (2002) Biodiversità in Liguria – La Rete Natura 2000. Le Mani, Genova

Barbaresi S, Gherardi F (2001) Daily activity of the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet): a comparison between field and laboratory studies. *Journal of Natural History* 35: 1861-1871, http://dx.doi.org/10.1080/00222930110098111

Beja PR (1996) An analysis of otter *Lutra lutra* predation on introduced American crayfish *Procambarus clarkii* in Iberian streams. *Journal of Applied Ecology* 33: 1156-1170, http://dx.doi.org/10.2307/2404695

Bilton DT, Freeland JR, Okamura B (2001) Dispersal in freshwater invertebrates. *Annual Review of Ecology and Systematic* 32: 159-181, http://dx.doi.org/10.1146/annurev.ecolsys.32.081501.114016

Blake M, Nyström P, Hart P (1994) The effect of weed cover on juvenile signal crayfish (*Pacifastacus leniusculus* Dana) exposed to adult crayfish and non-predatory fish. *Annales Zoologici Fennici* 31: 297-306

Brown DJ, Brewis JM (1977) A critical look at trapping as a method of sampling a population of *Austropotamobius pallipes* (Lereboullet) in a mark and recapture study. *Freshwater Crayfish* 3: 159-164

Bubb DH, Lucas MC, Thom TJ (2002) Winter movements and activity of signal crayfish *Pacifastacus leniusculus* in an upland river, determined by radio telemetry. *Hydrobiology* 483: 111-119, http://dx.doi.org/10.1023/A:1021363109155

Bubb DH, Thom TJ, Lucas MC (2004) Movement dispersal of the invasive signal crayfish *Pacifastacus leniusculus* in upland rivers. *Freshwater Biology* 49: 357-368, http://dx.doi.org/10.1111/j.1365-2426.2003.01178.x

Capurro M, Mori M, Salvidio S, Arillo A (2006) Presenza del gambero alloctono nord-americano *Pacifastacus leniusculus* (Dana) in Liguria. Quaderni ETP (in press)

Diéguez-Uribeondo J (2006) Pathogens, parasites and commensals. In: Souty-Grosset C, Holdich DM, Noël P, Reynolds JD, Haffner P (eds), Atlas of crayfish in Europe. Muséum national d'Historie naturelle, Paris (Patrimoines naturels, 64): 131-150

Diéguez-Uribeondo J, Pinedo-Ruiz J, Cerenius L, Söderhäll K (1993) Presence of *Psorospermium haeckeli* (Hilgendorf) in a *Pacifastacus leniusculus* (Dana) population of Spain. *Freshwater Crayfish* 9: 286-288

Edsman L (2004) The Swedish story about import of live crayfish. In: Taugbøl T, Souty-Grosset C (eds), 2004 Les écrevisses européennes autochtones, plus spécialement *Astacus astacus*: Reliant socioéconomie et conservation, CRAYNET. *Bulletin Française de la Pêche et de la Pisciculture* 2: 372-373: 281-288

Elvira B, Nicola GG, Almodovar A (1996) Pike and red swamp crayfish: a new case on predator-prey relationship between aliens in central Spain. *Journal of Fish Biology* 48: 437-446

Englund G (1999) Effects of fish on local abundance of crayfish in stream pools. *Oikos* 87: 48-56, http://dx.doi.org/10.2307/3546995

Füreder L, Machino Y (1999) Les écrevisses exotiques dans le Tyrol du Sud (Italie). *L'Astaciculteur de France* 61: 2-6

Gherardi F, Baldaccini G N, Barbaresi S, Ercolini P, De Luise G, Mazzoni D, Mori M (1999) The situation of Italy. In: Gherardi F, Holdich DM (eds), Crayfish in Europe as alien species How to make the best of a bad situation? *Crustacean Issues* 11: 107-128

Gherardi F, Souty-Grosset C, Reynolds J (2003) Understanding and managing biodiversity in relation to native crayfish population in Europe. In: Reynolds J, Souty-Grosset C (eds), 2003 The endangered native crayfish *Austropotamobius pallipes*, Bioindicator and heritage species, CRAYNET. *Bulletin Française de la Pěche et de la Pisciculture* 1: 7-14: 370-371

Gherardi F, Villanelli F, Dardi P (1997) Behavioural ecology of the white-clawed crayfish, *Austropotamobius pallipes*, in a Tuscan stream: preliminary results. *Freshwater Crayfish* 11: 182-193

Garvey JE, Stein RA, Heather TM (1992) Assessing how fish predation and interspecific prey competition influence a crayfish assemblage. *Ecology* 75: 532-547, http://dx.doi.org/10.2307/1939556

Grandjean F, Cornuault B, Archambault S, Brandmard M, Otrebsky G (2000) Life history and population biology of the white-clawed crayfish, *Austropotamobius pallipes*, in a brook from the Poitou-Charentes Region (France). *Bulletin Française de la Pêche et de la Pisciculture* 356 : 55-70, http://dx.doi.org/10.1051/kmae:2000004

Guan R, Wiles PR (1997) The home range of signal cray-fish in British lowland river. *Freshwater Forum* 8: 45-54

Guan R, Wiles PR (1998) Feeding ecology of the signal crayfish *Pacifastacus leniusculus* in a British lowland river. *Aquaculture* 169: 177-193, http://dx.doi.org/10.1016/S0044-8486(98)00377-9

Guan R, Wiles PR (1999) Growth and reproduction of the introduced crayfish *Pacifastacus leniusculus* in a British lowland river. *Fishery Research* 42: 245-259, http://dx.doi.org/10.1016/S0165-7836(99)00044-2

Henttonen P, Huner JV (1999) The introduction of alien species of crayfish in Europe: A historical introduction. In: Gherardi F, Holdich DM (eds), Crayfish in Europe as alien species How to make the best of a bad situation? *Crustacean Issues* 11: 13-21

Holdich DM, Rogers WD, Reader JP (1995) Crayfish Conservation. Final project report record to National Rivers Authority 1995 NRA R&D 378/10/N

Holdich D, Gherardi F (1999) Preface. In: Gherardi F, Holdich DM (eds), Crayfish in Europe as alien species How to make the best of a bad situation? Crustacean Issues, 11: VII-VIII

Holdich D (2003) Ecology of the white-clawed crayfish. Conserving Natura 2000 Rivers Ecology Series No I, English Nature, Peterborough

Hubert MGJ, Schubart CD (2005) Distribution and reproductive biology of *Austropotamobius torrentium* in Bavaria and documentation of a contact zone with the alien crayfish *Pacifastacus leniusculus*. In: Füreder L, Souty-Grosset C (eds), European native crayfish in relation to land-use and habitat deterioration with a special focus on *Austropotamobius torrentium*, CRAYNET. *Bulletin Française de la Pêche et de la Pisciculture* 3: 376-377: 759-776

Kirjavainen J, Westman K (1999) Natural history and development of the introduced signal crayfish, *Pacifastacus leniusculus*, in a small, isolated Finnish lake, from 1968 to 1993. *Aquatic Living Resource* 12(6): 387-401, http://dx.doi.org/10.1016/S0990-7440(99)00110-2

Jussila J, Mannonen A (2004) Crayfisheries in Finland, a short overview. In: Taugbøl T, Souty-Grosset C (eds), Les écrevisses européennes autochtones, plus spécialement Astacus astacus: Reliant socioéconomie et conservation, CRAYNET, volume 2, *Bulletin Française de la Pêche et de la Pisciculture* 372-373: 263-273

Lewis SD (1999) Abundance, activity, and diet of littoral fish in Lake Billy Chinook, Lake Simtustus, and Reregulating Reservoir, Oregon, 1997-1999. Portland General Electric Company, Portland, Oregon

Lewis SD (2002) *Pacifastacus*. In: Holdich DM (ed), Biology of Freshwater Crayfish. Blackwell Science Ltd., Oxford, pp 511-540

Light T (2003) Success and failure in a lotic crayfish invasion: the roles of hydrologic variability and habitat alteration. *Freshwater Biology* 48: 1886-1897, http://dx.doi.org/10.1046/j.1365-2427.2003.01122.x

Lindqvist OV, Huner JV (1999) Life history characteristics of crayfish: what makes some of them good colonizers? In: Gherardi F, Holdich DM (eds), Crayfish in Europe as alien species How to make the best of a bad situation? *Crustacean Issues* 11: 23-30

Lozán JL (2000) On the threat to the European crayfish: a contribution with the study of the activity behaviour of four crayfish species (Decapoda: Astacidae). *Limnology* 30: 156-161, http://dx.doi.org/10.1016/S0075-9511(00)80010-9

Machino Y (1997) Présence de l'écrevisse de Californie (*Pacifastacus leniusculus*) en Italie. *L'Astaciculteur de France* 52: 2-5

Malmqvist B (2002) Aquatic invertebrates in riverine landscapes. *Freshwater Biology* 47: 679-694, http://dx.doi.org/10.1046/j.1365-2427.2002.00895.x

Mason JC (1963) Life history and production of the crayfish *Pacifastacus leniusculus* trowbridgii (Stimson), in a small woodland stream. Master's thesis, Oregon State University

Mason JC (1970) Copulatory behaviour of the crayfish, *Pacifastacus trowbridgii* (Stimpson). *Canadian Journal of Zoology* 48: 969-976, http://dx.doi.org/10.1139/z70-172

Miller GC (1970) Western North America crayfish (*Pacifastacus*) in brackish water environments. Research Reports of the Fish Commission of Oregon 2, pp 42-50

Mooney HA, Hobbs RJ (2000) Invasive species in a changing world. Island Press, Washington, DC, 384 pp

Nakata K, Tanaka A, Goshima S (2004) Reproduction of the alien crayfish *Pacifastacus leniusculus* in Lake Shikaribetsu, Hokkaido, Japan. *Journal of Crustacean Biology* 24: 496-501, http://dx.doi.org/10.1651/C-2484

Nyström P (2005) Non-lethal predator effects on the performance of a native and an exotic crayfish species. *Freshwater Biology* 50: 1938-1949, http://dx.doi.org/10.1111/j.1365-2427.2005.01438.x

Nyström P, Strand JA (1996) Grazing by a native and an exotic crayfish on aquatic macrophytes. *Freshwater Biology* 36: 673-682, http://dx.doi.org/10.1046/j.1365-2427.1996.d01-508.x

Ohtaka A, Gelder SR, Kawai T, Saito K, Nakata K, Nishino M (2005) New records and distributions of two North American branchiobdellidan species (Annelida: Clitellata) form the introduced signal crayfish, *Pacifastacus leniusculus*, in Japan. *Biological Invasion* 7: 149-156, http://dx.doi.org/10.1007/s10530-004-8146-y

Parkin SM, Collier KJ, Hicks BJ (2001) New Zealand stream crayfish: functional omnivores but trophic predators? *Freshwater Biology* 46: 641-652, http://dx.doi.org/10.1046/j.1365-2427.2001.00702.x

Peay S (2004) A cost-led evaluation of survey methods and monitoring for white-clawed crayfish. In: Taugbøl T, Souty-Grosset C (eds), Les écrevisses européennes autochtones, plus spécialement *Astacus astacus*: Reliant socioéconomie et conservation, CRAYNET. *Bulletin Française de la Pêche et de la Pisciculture* 2: 372-373: 335-352

Peay S, Rogers D (1999) The peristaltic spread of signal crayfish (*Pacifastacus leniusculus*) in the River Wharfe, Yorkshire, England. *Freshwater Crayfish* 12: 665-676

Peris SJ, Briz FJ, Campos F (1994) Recent changes in the food of the Grey Heron *Ardea cinerea* in central-west Spain. *Ibis* 136: 488-489, http://dx.doi.org/10.1111/j.1474-919X.1994.tb01126.x

Pimentel D, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of non-indigenous species in the United States. *BioScience* 50: 53-65, http://dx.doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2

Rabeni CF (1992) Trophic linkage between stream centrarchids and their crayfish prey. *Canadian Journal of Fisheries Aquatic Sciences* 49: 1714-1721, http://dx.doi.org/10.1139/f92-190

Renai B, Gherardi F (2004) Predatory efficiency of crayfish: comparison between indigenous and non-indigenous species. *Biological Invasion* 6: 89-99, http://dx.doi.org/10.1023/B:BINV.0000010126.94675.50

Reynolds JD (1979) Ecology of *Austropotamobius pallipes* in Ireland. *Freshwater Crayfish* 4: 215-219

Reynolds JD, Matthews MA (1993) Experimental fishing of *Austropotamobius pallipes* (Lereboullet) stocks in an Irish midland lake. *Freshwater Crayfish* 9: 147-153

Riggert CM, Distefano RJ, Noltie DB (1999) Distributions and selected aspects of the life histories and habitat associations of the crayfishes *Orconectes peruncus* (Creaser, 1931) and *O. quadruncus* (Creaser, 1933) in Missouri. *American Midland Naturalist* 142: 348-362, http://dx.doi.org/10.1674/0003-0031(1999)142[0348:DASAOT]2.0.CO;2

Sih A, Crowley P, McPeek M, Petranka J, Stroheimer K (1985) Predation, competition and prey communities: a review of field experiments. *Annual Review of Ecology and Systematic* 16: 269-311, http://dx.doi.org/10.1146/annurev.es.16.110185.001413

Salvidio S, Mori M, Lattes A, Galli L, Arillo A (2002) The freshwater crayfish *Austropotamobius pallipes* (Lereboullet, 1858) in Liguria, NW Italy: implications for management at the regional level. *Bulletin Française de la Pêche et de la Pisciculture* 367: 663-670, http://dx.doi.org/10.1051/kmae:2002057

Söderbäck B (1995) Replacement of the native *Astacus astacus* by introduced species *Pacifastacus leniusculus* in a Swedish lake: possible causes and mechanism. *Freshwater Biology* 33: 291-304, http://dx.doi.org/10.1111/j.1365-2427.1995.tb01168.x

Souty-Grosset C, Holdich DM, Noël PY, Reynolds JD, Haffner P (eds) (2006) Atlas of crayfish species in Europe. Muséum national d'Histoire naturelle, Paris, 187 p (Patrimoines naturels, 64)

Statzner B, Peltret O, Tomanova S (2003) Crayfish as geomorphic agents and ecosystem engineers: effect of a biomass gradient on baseflow and flood-induced transport of gravel and sand in experimental streams. *Freshwater Biology* 48: 147-163, http://dx.doi.org/10.1046/j.1365-2427.2003.00984.x

Stenroth P, Nyström P (2003) Exotic crayfish in a brown water stream: effects on juvenile trout, invertebrates and algae. *Freshwater Biology* 48: 466-475, http://dx.doi.org/10.1046/j.1365-2427.2003.01020.x

Strempel KM (1974) Künstliche Erbrütung von Edelkrebsen in Zugergläsern und vergleichende Beobachtungen im Vehalten und Abwarchs von Edel- und Signalkrebsen. Arbeiten des Deutschen Fisch-Verbandes, H 16, Hamburg

Svensson M (1993) Predation by perch, *Perca fluviatilis*, and roach, *Rutilus rutilus*, on juvenile noble crayfish, *Astacus astacus*, in pond experiments. *Freshwater Crayfish* 9: 333-344

Taugbøl T (2004) Exploitation is a prerequisite for conservation of *Astacus astacus*. In: Taugbøl T, Souty-Grosset C (eds), 2004 Les écrevisses européennes autochtones, plus spécialement *Astacus astacus*: Reliant socioéconomie et conservation, CRAYNET. *Bulletin Française de la Pêche et de la Pisciculture* 2: 372-373: 275-279

Vorburger C, Ribi G (1999) Aggression and competition for shelter between a native and an introduced crayfish in Europe. *Freshwater Biology* 42: 111-119, http://dx.doi.org/10.1046/j.1365-2427.1999.00465.x

Ward JV, Tockner K, Arscott DB, Claret C (2002) Riverine landscape diversity. *Freshwater Biology* 47: 517-539, http://dx.doi.org/10.1046/j.1365-2427.2002.00893.x

Westman K, Savolainen R, Julkunen M (2002) Replacement of the native crayfish *Astacus astacus* by the introduced species *Pacifastacus leniusculus* in a small, enclosed Finnish lake: a 30-year study. *Ecography* 25: 53-73, http://dx.doi.org/10.1034/j.1600-0587.2002.250107.x