

A real time extinction: the case of *Carabus clatratus* in Italy (Coleoptera, Carabidae)

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SUMMARY

In Europe, highly hygrophilic carabids in lowlands are markedly exposed to the risk of extinction due to the loss or modification of their habitat. Among these, *Carabus clatratus*, one of the few species of the genus *Carabus* characterized by a semi-aquatic way of life, is reported as threatened or disappeared in several areas in all European countries. In Italy, the historical distribution of this species is reported from some 25 localities. A chrono-geonomic survey, however, shows that in the last decade of the past century it was confined to not more than three localities in Tuscany, reduced to one only at the beginning of this century. We supposed that the rapid and unexpected extinction of *C. clatratus* in some undisturbed and not modified biotopes, where it was very abundant until a few years ago, was due to the massive colonization of an alien, very invasive species, the red swamp crayfish *Procambarus clarkii*, imported into Italy for aquaculture from the southeastern United States. An original experiment and a video, made under laboratory conditions, prove for the first time that this crayfish can be a very able predator on adult individuals of *C. clatratus*, and strongly supports the hypothesis that it is at present the primary factor of extinction of *C. clatratus* in Italy.

Keywords: Coleoptera, *Carabus clatratus*, Decapoda, *Procambarus clarkii*, predation, chronogeonomy, extinction

INTRODUCTION

As postulated by authors such as Wilson (1992), the extinction of invertebrate organisms - at a global or local scale - is an event difficult to prove on the ground of objective data: inadequate knowledge of population sizes, scarcity of investigations in the field, and the loss of information on the life histories of many so called "rare" taxa, make the assumption that a species has really and definitively disappeared from a given area difficult, and sometimes impossible.

Carabus (Limnocarabus) clatratus Linné, 1761 is species of nice large-sized carabids in which several peculiarities quite unusual among the congeneric species are summarized. At first, it presents - with several subspecies - a (virtually) very wide area of distribution, from southern France to Siberia (see map in Turin et al., 2003). The eastern vicariant and close adelphotaxon *C. maacki* Morawitz, 1862, of the Far East and Japan, previously treated as a subspecies of *C. clatratus*, is now recognized as a distinct species (Deuve, 2004). Secondly, it is one of the few *Carabus* species (not more than six among the over 800 described species) with a semi-aquatic way of life, able to dive voluntary and stay under water for several minutes (Sturani, 1962; Busato, personal observations) (Fig. 7). Finally, it is one of the very few *Carabus* species with a pteridimorphic state of wings, being some individuals fully winged and able to fly (Lindroth, 1985).

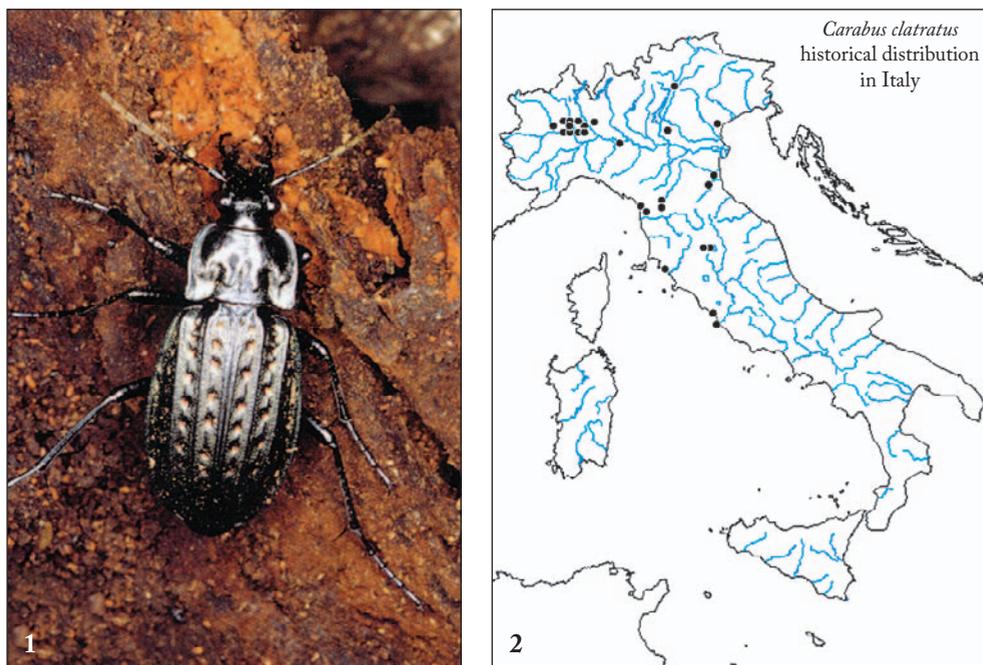
In spite of these morphological, chorological, and ecological features, *C. clatratus* is presently one of the most localized and endangered species on the European continent, and is reported as threatened or disappeared in several areas in all European countries (Assmann, 2003). This is a rather common situation: in all Europe, highly hygrophilic carabids in lowlands are very exposed to the risk of extinction due to the loss or modification of their habitat.

In Italy, the "historical" distribution of this species, represented by the subspecies *antonellii* Luigioni, 1921 (Fig. 1), was reported from 26 localities (Bucciarelli, 1963; Magistretti, 1965; Casale et al., 1982, 2006) (Fig. 2).

A chrono-geonomic survey, however, shows that in the last decade of the past century it was confined to not more than five localities in Tuscany, reduced to two only at the beginning of this century (Brandmayr et al., 2006) (Figs 3-5).

Recently, several amateur collectors informed us that the species had disappeared in some undisturbed and non-modified biotopes (among others, the Fucecchio marsh in Tuscany, where it was very abundant until a few years ago: Bordoni, 1995).

One of the authors of the present contribution (A.C.) supposed that this rapid and unexpected extinction was due to the massive colonization of an alien and very invasive species, the red swamp crayfish *Procambarus clarkii* (Girard, 1852) (Crustacea, Decapoda), imported into Italy for aquaculture from the southeastern United States in the eighties of the last century. The distribution of this species is now increasing, with incredible densities of population and a deep impact on both aquatic vegetation and fauna, being the young individuals predators, and the adults mostly vegetarian (see, for a review, Delmastro, 1999; Acquapace et al., 2006). This species is also able to move on the ground, in wet



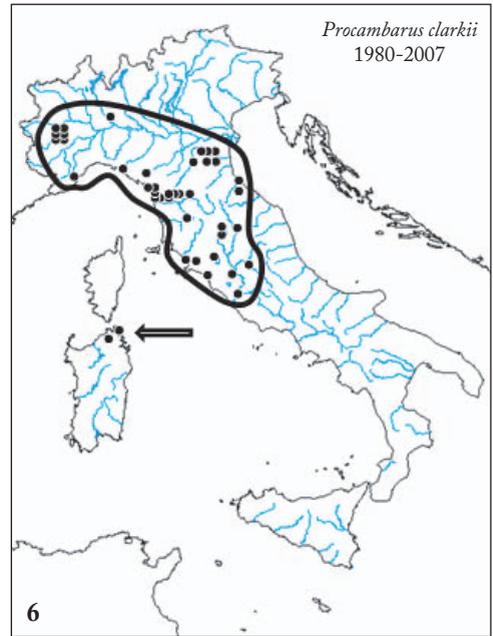
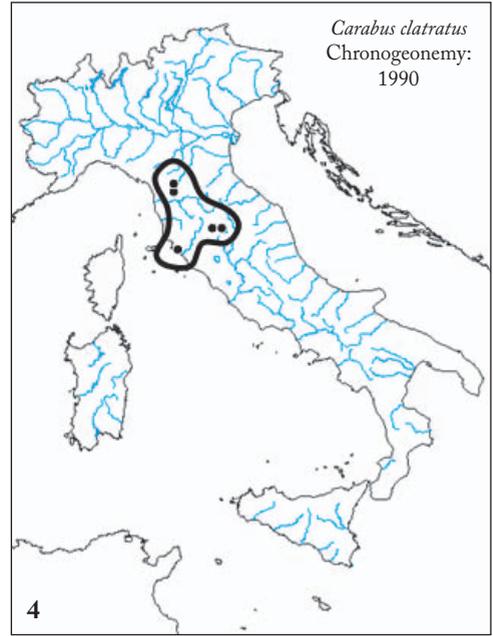
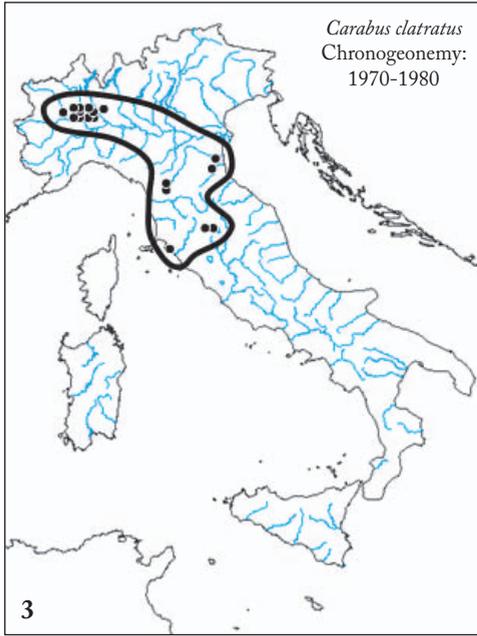
Figs 1-2. Fig. 1: *Carabus clatratus antonellii* Luigioni, 1921, a hibernating individual in rotten wood, dorsal aspect (Tuscany, Lago di Chiusi) (photo A. Vigna Taglianti). Fig. 2: *C. clatratus antonellii*, historical distribution in Italy (data from Bucciarelli, 1963; Magistretti, 1965; Casale et al., 1982, 2006).

conditions; surprisingly, its distribution in Italy (Frogliola, 2006) is presently overlapping on that of the former distribution of *C. clatratus* in this country (Figs 2, 6).

An original experiment and a video, made under laboratory conditions by E.B., proves for the first time that this is a real fact, not a theory.

MATERIAL AND METHODS

The data reported in the current paper concern some adult individuals of *Carabus* (*Limnocarabus*) *clatratus antonellii* collected on 5.III.2006 (3 ♂♂: Tuscany, Siena province, Lago di Montepulciano m 248, A. Petrioli legit), 13.II.2007 (2 ♂♂, 3 ♀♀: Tuscany, Siena province, Lago di Montepulciano m 248 and Lago di Chiusi m 251, P. Cavazzuti and A. Casale legit) and different instars of *Procambarus clarkii* (10 young stages and 5 adults) collected in Piedmont, Carmagnola (hamlet San Michele, locality Martinetto, Canale di San Grato m 235, 1.VI.2006, G. B. Delmastro legit) and of *Austropotamobius pallipes* (Lereboullet, 1858) collected in Piedmont, Giaveno (bridge of the provincial road no. 193, "Rio della Colletta" m 550, 2.VI.2006, G. B. Delmastro legit).



Figs 3-6. Figs 3-5: Chronogeometry and decline of *C. clatratus antonellii* in Italy (original). Fig. 6: Present distribution of the red swamp crayfish *Procambarus clarkii* in Italy (data from Froggia, 2006, modified).

Breeding of *C. clatratus* was carried out in a 240 L aquarium-terrarium (cm 99.5 x 45.0 x 55) characterized by a 14 cm layer of volcanic soil on the bottom (Fig. 8). Some aquatic plants (*Microsorium pteropus*, *Anubias barteri*, *Echinodorus osiris*) were introduced to simulate a natural surrounding and to help the beetles reach the surface of the water when the air reserves were low. A plastic container (cm 38.0 x 28.5) containing a 5 cm layer of soil was introduced into the aquarium-terrarium to let the beetles live outside the water and as an ovipositional site for the females. Every two days, food (apple and beef) was provided to *C. clatratus* on a piece of polystyrene to avoid moulds, and changed every two days.

Three quarters of the soil was covered with moss, and pieces of bark were placed to allow the movements of the beetles between the soil and the water. The terrarium was supported by a wooden framework covered by bark to simulate a hollow stump immersed in the water for almost 2/3 of its length (30 cm), half of which were beneath the bottom substrate.

A pump connected with a biological filter kept the water clean. To allow the growth of the aquatic plants, the aquarium-terrarium had, on the lid, a 25 watt (1000° Kelvin) neon lamp regulated by a timer according to the photoperiod of the rearing period. The aquarium-terrarium was located in a place with constant temperature ($20\pm 1^{\circ}\text{C}$), while the lid was raised to 45° to avoid moisture.

The two crayfish species were separately bred in two different aquariums of 48 L each (cm 49.5 x 29.7 x 33.0) with 8 cm of quartz sand on the bottom.

Predation trials were carried out moving two specimens of *C. clatratus* from the rearing aquarium to the aquarium with crayfishes. The remaining specimens of *C. clatratus* (2 ♂♂ e 3 ♀♀) reared in 2007 are still alive.

Preventively the water level was reduced to 15 cm and peaces of bark were placed on the bottom and partially immersed in the water to create a platform where the beetles could walk.

In the aquarium-terrarium just one or few specimens of crayfish were introduced for the time necessary for the observations.



Figs 7-8. Fig. 7: *C. clatratus antonellii*, an adult individual staying in water in breeding terrarium-aquarium (photo E. Busato). Fig. 8: Terrarium-aquarium for adult individuals of *C. clatratus antonellii* (photo E. Busato).

RESULTS

In the 48 L aquarium, the predation trials carried out with the local crayfish (*Austropotamobius pallipes*) assessed that this species is completely harmless towards *Carabus clatratus*. To further confirm this result, two specimens of *A. pallipes* were kept for 10 days in the aquarium-terrarium used for beetle breeding (240 L) and no predatory activity was observed.

Conversely, in the 48 L aquarium containing the red swamp crayfish (*Procambarus clarkii*), a predation activity was observed every time the beetles moved into the water. *P. clarkii* made an attempt to *C. clatratus*' life also when the beetles were outside the water, *P. clarkii* crouched under the surface of the water for many minutes moving closer to prey slowly and progressively. Then they jumped forward with the claws open to capture the insects dragging them under water and eating them (Figs 9-10).

The trials were carried out with two *C. clatratus* males. Both of them, when captured, floundered until the air reserves stored under the elytra were over. *C. clatratus* can stay immersed for quite a long time, until 17'30" (Sturani, 1962, and our personal observations). During this time the crayfish kept *C. clatratus* with a claw between the thorax and the abdomen, while the other claw was used to cut the antennae and the legs used by the insect to anchor itself to the substrate and to reach the water surface. When the beetle was deprived of the appendages but was still alive, the crayfish devoured it after ripping the cuticle. In both cases the beetle was eaten starting from the head; each part of the insect was emptied. The abdomen was devoured starting from the connection with the thorax (Figs 10-11), then after the elytra were discarded, the beetle was eaten thanks to the laceration of the cuticle.

Each meal, starting from the attack, lasted 2h 30' finally leaving only the elytra (nibbled at the attachment with the abdomen), some pieces of legs, and few remains of the integument (Fig. 12). During the trials, *P. clarkii* individuals, confirming their amphibious character, often went outside the water climbing onto the bark platform where the beetles rested.

DISCUSSION AND CONCLUSIONS

Our experiment proves for the first time that the crayfish *Procambarus clarkii* is a very efficient predator on the carabid *Carabus clatratus*.

In fact, in areas where the crayfish is more abundant, the rarity or the disappearance of the aquatic vegetation and several aquatic organisms, including Gastropoda, Odonata, Coleoptera Hydradephaga, local crayfish species, amphibians and smaller sized fishes, is reported (Diamond, 1996; Gamradt et al., 1997; Gutiérrez-Yurrita et al., 1998; Delmastro, 1999; Gherardi et al., 1999; Acquistapace et al., 2006; Fabbri, 2007). Furthermore, the present distribution of the crayfish (Fig. 6) is perfectly overlapping on the former distribu-

tion of *C. clatratus* in Italy (Fig. 2), the highest density of its populations is reported really in the last localities where this carabid was present and sometimes abundant (Padanian plain, Tuscany, Adriatic coast close to Ravenna) and, finally, the increasing spread of the crayfish in the last three decades is markedly coincident with the decline of *C. clatratus* in Italy, as showed by the chronogeonomy analysis of this species (Figs 3-5).

We can also propose that the crayfish, a thermophilic species, has over the past few years taken advantage of the increasing temperatures induced by the global change. These environmental conditions, on the contrary, probably induced a negative impact on *C. clatratus*, which is confined to wet biotopes and mesophilic forests in Northern and Central Italy, as a relict element of northern of Pleistocene origin in the Italian fauna (see Vigna Taglianti, 1998).

Unfortunately, this situation could be soon replicated in Southern France, where *P. clarkii* is spread in some localities (see Laurent et al., 1991), in which *C. clatratus* is represented by the endemic subspecies *arelatensis* Lapouge, 1903.

Another interesting datum, that we may anticipate, is that the predation seems to occur only on adult individuals, which are highly hygrophilous, stay for a long time in the water (Fig. 7), and have a long life span (more than one year, in laboratory conditions:



Figs 9-12. Four phases of predation by *P. clarkii* on *C. clatratus antonellii* (photo E. Busato).

Busato, personal observations on *C. clatratus antonellii*). On the contrary, the impact on larval stages has been probably moderate, or absent. In fact, larvae of *C. clatratus*, unlike those of other *Carabus* species with a semi-aquatic way of life (as *C. nodulosus* Creutzer, 1799; Sturani, 1964), are mostly terricolous, with fossorial behaviour; furthermore, they display a peculiarly short development (30–60 days), without having a diapause (Sturani, 1962; Huk, 1998; Huk & Kühne, 2000; in *C. clatratus antonellii*, bred for this experiment, duration larva-prepupa: 42–50 days: Busato, pers. obs.).

In spite of the fact that some of the biotopes where *C. clatratus* was, or is still present in Italy, are protected areas, currently no action has been realized to oppose the increasing distribution of the crayfish, which can be both active on the continent, and introduced by man on islands (see the recent introduction into Sardinia in last years: Fig. 6).

The extinction of the Italian populations of *C. clatratus* is much more dramatic, since these populations were attributed to an endemic, well characterized subspecies, highly interesting from the biogeographic point of view, on which a genetic survey is now in progress (Mossakowski, personal communication).

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