GLOBAL INVASIVE SPECIES DATABASE

FULL ACCOUNT FOR: ***Procambarus clarkii***

Procambarus clarkii **System:** Freshwater

Kingdom	Phylum	Class	Order	Family
Animalia	Arthropoda	Malacostraca	Decapoda	Cambaridae

Common name red swamp crayfish (English), Louisiana crayfish (English)

Synonym

Similar species *Procambarus zonangulus*

Summary
Procambarus clarkii is a highly adaptable, tolerant, and fecund freshwater crayfish that may inhabit a wide range of aquatic environments. It is native to parts of Mexico and the United States and has established throughout the world as a result of commercial introductions for harvest as a food source. Invasive populations have been reported from Europe, Asia, Africa, North America, and South America. Impacts include aggressive competition with native crayfish, introduction of the crayfish plague, reduction of macrophyte assemblages, alteration of water quality, predation on and competition with a variety of aquatic species, and negative impacts on agricultural and fishing industries. Management strategies for *P. clarkii* include trapping and removing populations, creating barriers to prevent its spread, prohibiting the transport of live crayfish, and improving public education about it risks to the environment. Encouraging farming of native species as well as research on economically productive harvesting of native crayfish has the potential to reduce further introductions.

view this species on IUCN Red List

Species Description
Typically dark red, *Procambarus clarkii* is capable of reaching sizes in excess of 50g in 3-5 months (NatureServe, 2003; Henttonen and Huner, 1999). Adults reach about 5.5 to 12cms (2.2 to 4.7 inches) in length. Its rostrum is cuminate with cervical spines present, and its areola is linear to obliterate. The palm and the mesial margin of the cheliped bare rows of tubercles. Their chela are elongate. There are hooks on the ischia of male at the 3rd and 4th pereiopods. A male's first pleopod terminates in four elements, and the cephalic process is strongly lobate with a sharp angle on the caudodistal margin that is lacking subapical setae. The setae have strong angular shoulders on their cephalic margin that are proximal to the terminal elements. The right pleopod is wrapped around the margin to appear reduced or absent (Washington Department of Fish and Wildlife, 2003). Additionally, it possesses a strong spur at the inner side of the carpopodite. The propodite is armed with strong spines on its inner side as well as conspicuous knots on its dorsal face. The branchiocardiac grooves of the carapace converge dorsally. Lateral spines or tubercles in front of and behind the cervical groove are absent or reduced. The rostrum is devoid of a median keel and has an obvious triangular shape, the sides tapering anteriorly. The head itself is elongated and narrowing towards the front. Juvenile are not red and appear very similar to other *Procambarus* species (Boets *et al*, 2009).

Lifecycle Stages
Procambarus clarkii exhibits a cyclic dimorphism of sexually active and inactive periods alternating during the lifecycle. After the young hatch, metamorphosis takes place, followed by two to three weeks of voracious eating. After this they molt and again assume their immature appearance (Hunter and Barr, 1994, in Ackefors, 1999). Egg production can be completed within six weeks, incubation and maternal attachment within three weeks and maturation within eight weeks. Optimal temperatures are 21-27 degrees and growth inhibition occurs at temperatures below 12 °C (Ackefors, 1999). *P. clarkii* shows two patterns of activity, a wandering phase, without any daily periodicity, characterized by short peaks of high speed of locomotion, and a longer stationary phase, during which crayfish hide in the burrows by day, emerging only at dusk to forage. Other behaviors, such as fighting or mating, take place at nighttime. During the wandering phase, breeding males move up to 17 km in four days and cover a wide area. This intensive activity helps dispersion in this species (Gherardi & Barbaresi, 2000).

Uses
Procambarus clarkii is an extremely widespread and common food source. Its ability to grow and mature rapidly and to adapt to seasonal waters enabled widespread commercial establishment of it and made it the dominant freshwater crayfish in the world (Henttonen and Huner, 1999). It accounts for 85–90% of the world's annual crayfish consumption (Huner, 1997 in Kerby *et al*, 2005). In Louisiana, USA *P. clarkii* has created a multi-million dollar industry, with more than 50,000 ha under cultivation (Guierrez-Yurrita *et al*, 1999). In Europe, the introductions especially benefited Spain, creating a flourishing crayfish industry and revitalizing the local economy in certain districts (Ackefors, 1999). The commercial success of *P. clarkii* in Europe is partly due to its ability to colonize disturbed habitats and resist the crayfish fungus plague, *Aphanomyces astaci* to which native European crayfish are susceptible (Lindqvist and Huner, 1999). Crayfishing for *P. clarkii* has become a significant source of income for many people throughout its range (Alcorlo *et al*, 2008).
In Kenya, *P. clarkii* has been introduced as a biological control for human schistosomes (*Schistosoma haematobium*) and (*S. mansoni*) because it preys on the parasite's intermediary snail vector *Bulinus* and *Biomphalaria* spp. (Lodge *et al*, 2005; Mkoji *et al*, 1992 in Foster & Harper, 2007). Under certain conditions *P. clarkii* has significantly reduced the spread of schistosomiasis in some locations of Kenya (Mkoji *et al*, 1999a in Foster & Harper, 2007).

Habitat Description
Procambarus clarkii may inhabit a wide variety of freshwater habitats including rivers, lakes, ponds, streams, canals, and seasonally flooded swamps and marshes. It is very tolerant and adaptable to a wide range of aquatic conditions including moderate salinity, low oxygen levels, extreme temperatures, and pollution (Cruz & Rebelo, 2007; Gherardi & Panov, 2006; NatureServe, 2003). *P. clarkia* thrives in warm, shallow wetland ecosystems of natural and agricultural lands as in the case of south and central Europe where it has established (Henttonen & Huner, 1999). In the cooler regions of Europe, it prefers small, permanent ponds because it is unable to survive predation by fishes in large water bodies (Troschel and Dehus, 1993; Roqueplo *et al*, 1995; Demastro and Laurent, 1997, Huner, pers. obs., in Henttonen and Huner, 1999). *P. clarkii* also frequently inhabits disturbed environments such as rice fields and irrigation channels and reservoirs (Oliveira & Fabião, 1998). Populations have been negatively correlated with high elevation and flow velocity (Cruz & Rebelo, 2007).

Reproduction
Procambarus clarkii employs an r-strategy, exhibiting a short life cycle and high fecundity. It matures when it reaches a size of between 6 and 12.5 cm. A 10 cm female may produce up to 500 eggs, while smaller females may produce around a 100 eggs. The eggs are 0.4 mm, notably smaller than those produced by European native members of the family Astacidae. Newly hatched crayfish remain with their mother in the burrow for up to eight weeks and undergo two moults before they can fend for themselves (Ackefors, 1999). Unlike the European native *Astacus* and *Austropotamobius* species, populations of *P. clarkii* contain individuals that are incubating eggs or carrying young throughout the year (Huner and Barr, 1994, in Lindqvist and Huner, 1999). This allows *P. clarkii* to reproduce at the first available opportunity, which contributes to its colonization success (Huner, 1992, 1995, in Gutierrez-Yurrita and Montes, 1999). In places with a long flooding period, greater than 6 months, there may be at least two reproductive periods in autumn and spring. The spring period is longer and more prolific and persists until the drying of the marsh. For large females to reproduce it is necessary to have hormonal induction induced by the photoperiod, a hydroperiod longer than four months, a temperature above 18 °C, and a pH between 7 and 8 (Gutierrez-Yurrita, 1997). If females have only a short period to prepare themselves for reproduction they must prematurely their burrow to feed; in such circumstances many females will die of dehydration, bringing about a depression in the population (Huner, 1995; Gutierrez- Yurrita, 1997, in Gutierrez-Yurrita and Montes, 1999).

Nutrition
Procambarus clarkii is considered an opportunistic omnivore with a primarily plant based diet (Rodreguez *et al*, 2005). The results of one study showed that *P. clarkii* is selective when offered fresh plants, consuming a relatively larger biomass of green algae (*Urtica* sp.) in spring, and *Polygonum* sp. in summer and autumn. *P. clarkii* did not exhibit preference for any animal and preferred *Urtica* sp. over earthworms (Gherardi & Barbaresi, 2007).

General Impacts
Procambarus clarkii is a successful colonizer which may quickly become established and eventually become a keystone species, a primary contributor to the ecosystem it inhabits. Its introduction may cause dramatic changes in native plant and animal communities (Schleifstein, 2003). *P. clarkii* may severely impact native crayfish through competition and transition of the crayfish plague, reduce macrophyte assemblages and diversity, alter water quality and sediment characteristics, accumulate heavy metals, interact with additional invasive species, damage agricultural irrigation systems, impact fishing industry, and reduce populations of invertebrates, mollusks, and amphibians through predation and competition.
P. clarkii has contributed to the dramatic decline of the European native crayfish in the Astacidae family through its transmission of the crayfish plague (*Aphanomyces astaci*) and direct competition. Specifically threatened species include the endangered white clawed crayfish *Austropotamobius pallipes*), the "vulnerable" noble crayfish (*Astacus astacus*), and the stone crayfish *Austropotamobius torrentium* (Garcia-Arberas *et al*, 2009; Dehus *et al*, 1999; Gherardi, 2006, Gil-Sanchez & Alba-Tercedor, 2006). *P. clarkii* is also known to compete with native crayfish in Japan (Kawai & Kobayashi, 2005).
Intense herbivory by *P. clarkii* often causes the reduction of macrophyte mass and biodiversity and has been recorded in the Lake Chozas, Spain (Rodriguez *et al*, 2003); Lake Naivasha, Kenya (Smart *et al*, 2002); Lake Massaciuccoli, Italy (Gherardi *et al*, 1999); Lake Doccia, Italy (Gherardi & Acquistapace, 2007); Mediterranean wetlands (Geiger *et al*, 2005); and the Iberian peninsula (Rodriguez *et al*, 2003 in Cruz & Rebelo, 2007). Affected species include *Nymphoides peltata*, *Potamopeton crispus*, *Ultricularia australis*, *Potamogeton* spp. (Gherardi & Acquistapace, 2007; Gherardi *et al*, 1999).
Another effect of the feeding, as well as burrowing, behavior of *P. clarkii* is altered water quality, increased bioturbation, and increased nutrient release from sediment (Angeler *et al*, 2001). These changes in water characteristics alter aquatic ecosystems and are believed to induce cyanobacterial blooms (Yamamoto, 2010). These effects have been recorded in Las Tablas de Daimiel National Park, Spain (Angeler *et al*, 2001); Alentejo, Portugal (Geiger *et al*, 2005); and Japan (Yamamoto, 2010).
P. clarkii is known to compete with, prey on, and reduce populations of a wide variety of aquatic species including amphibians, mollusks, macroinvertebrates, and fish. Competitive pressure and predation on native amphibians have been recorded from the Iberian Peninsula (Cruz & Rebelo, 2005), Sweden (Nystrom *et al*, 2002 in Ilheu *et al*, 2007), Europe (Gherardi, 2006). More specific reports include effects on *Rana* sp., *Bufo bufo*, and *Triturus vulgaris* in Italy (Gherardi *et al*, 2001; Renai & Gherardi, 2004 in Ilheu, 2007) and the Natterjack Toad (*Bufo calamita* in Donana Natural Park, Spain (Cruz *et al*, 2006b), and the California newt, *Taricha torosa*, in California (Gamradt & Kats, 1996 in Nystrom, 1999). Predation and competition pressure on mollusks include native snails in Doccia Lake, Italy (Gherardi & Acquistapace, 2007) and in the Iberian Peninsula (Cruz & Rebelo, 2007). *P. clarkii* preys on fish eggs and young as well and was found to consume lake trout (*Salvelinus namaycush*), gila chub (*Gila intermedia*), suckers (*Catostomus*spp.), and speckled dace (*Rhinichthys osculus*) in the laboratory (Mueller *et al*, 2006). It may also reduce macroinvertebrate populations and diversity (Correia *et al*, 2008).
Effects on agriculture and fisheries have been recorded from many locations. The burrowing and behavior of *P. clarkii* is often problematic to levees, dykes, and irrigation systems which can result in water loss and damage to fields (Holdrich, 1999; Yue *et al*, 2010a). This has been reported from China (Yue *et al*, 2010a), Japan (Sako, 1987 in Kawai & Kobayashi, 2005), Egypt (Hartnoll pers. Comm., in Holdich, 1999), Kenya (Picard, 1991 in Arrignon *et al*, 1999), Italy (Gherardi *et al*, 2000), Spain (Holdrich, 1999), and the United States (Chang & Lange 1967 in Holdich, 1999). *P. clarkii* frequently becomes a dominant species in disturbed habitats such as rice fields. If present in irrigation structures including reservoirs, channels of rice fields, *P. clarkii* may cause significant economic loss due to its burrowing activity, which alters soil hydrology and causes water leakage, and its feeding, which damages to rice plants (Correia, 1993; Ilhéu and Bernardo 1993a, b, in Oliveira and Fabião, 1998). Additionally, this damage may lead farmers to use aggressive pesticides such as organophosphorous to control *P. clarkii* (Ganhão, Germano and Grilo, 1991, in Oliveira and Fabião, 1998; MacKenzie, 1986, in Holdich, 1999).
P. clarkii interferes with commercial fishing by damaging nets, preying on fish eggs, competing for food with tilapia, reducing the number of submerged macrophytes, and disturbing nesting grounds of *Tilapia zilli* (Holdich, 1999; Gieger *et al*, 2005).
Additional impacts associated with *P. clarkii* include its accumulation of toxins and heavy metals, acting as an intermediary host for trematodes, and serving as a primary food source for other introduced species. It is known to accumulate heavy metals and toxins produced by cyanobacteria such as *Microcystis aeruginosa* and may transfer them up the food chain and to humans (Gherardi & Panov, 2006). *P. clarkii* also serves as an intermediary host to trematodes of the genus *Paragonimus* which are potential human pathogens if the crayfish are undercooked and consumed (Gherardi & Panov, 2006). *P. clarkii* has been found to promote other invasive species populations including largemouth black bass (*Micropterus salmoides* and pike by serving as a primary food source (Hickley *et al*, 1996 in Holdich, 1999; Elvira *et al*, 1996 in Holdich, 1999).
Finally, direct impacts of *P. clarkii* may cause additional indirect impacts and cascading ecological changes. Dramatic reduction of aquatic vegetation results in many indirect effects as it serves habitat for invertebrates, amphibians, and fry; as a substrate for epiphytic algae; source of refuge for prey, and a primary food source for birds and other species (Nystrom, 1999; France, 1996 in Nystrom, 1999; Steinman, 1996 in Nystrom, 1999). For example, the introduction on *P. clarkii* to Lake Chozas, Spain caused a reduction of macrophyte plant coverage by 99% which in turn caused a 71% loss in macroinvertebrate genera, 83% reduction in amphibian species, a 75 loss in duck species, and a 52% reduction in waterfowl (Rodriguez *et al*, 2005).

Management Info

Possible management options for *Procambarus clarkii* include the elimination or reduction of populations via mechanical, physical, chemical or biological methods; the restocking of native crayfish populations threatened by the crayfish plague fungus and interspecific competition with alien species; the development of plague-resistant strains of native crayfish; and the use of legislation to prohibit the transport and release of alien crayfish.

Preventative measures: Legislation designed to prevent the spread of crayfish has proven difficult to enforce due to the presence of conflicting social motivations such as the desire to propagate the species for recreational or commercial purposes. Political barriers, particularly in Europe, may also hinder conservation goals. For example the free trade policy backed by the European Union has hindered the attempts of European countries to prohibit the importation of live crayfish from other countries within the EU (Holdich *et al*, 1999).

Physical: Reduction of *P. clarkii* populations may be possible through physical control methods. However, eradication is unlikely unless the population is particularly restricted in range and size. All physical methods have environmental costs, which should be weighed up against the environmental benefits of employing them. Mechanical methods to control crayfish include the use of traps, fyke and seine nets and electro-fishing. Continued trapping is preferable to short-term intensive trapping, which may provoke feedback responses in the population such as stimulating a younger maturation age and a greater egg production. Bait, such as roach, bream, bleak or white bream, may increase the number of crayfish caught in traps, although freshwater fish should be avoided to prevent spread of the crayfish plague fungus, which may be transmitted on their scales (Gherardi & Panov, 2006; Westman, 1991; Alderman *et al*, undated in Holdich, Gydemo and Rogers, 1999; Kerby *et al*, 2005). A fair population reduction of *P. clarkii* by removal was achieved in Lake Naivasha, Kenya using traps and removal from floating vegetation in attempts to promote recovery of native macrophytes (Smart *et al*, 2002). Further control methods include the drainage of ponds, the diversion of rivers, or the construction of physical or electrical barriers to limit its spread (Kerby *et al*, 2005).

Chemical: Chemicals that can be used to control crayfish include biocides such as organophosphate, organochlorine, and pyrethroid insecticides; individual crayfish are differentially affected depending on their size, with smaller individuals being more susceptible (Gherardi & Panov, 2006). Furadan 5G, active ingredient carbofuran, has also been found fatal to *P. clarkii* in Kenya (Rosenthal *et al*, 2005). Since no biocides are crayfish-specific other invertebrates, such as arthropods, may be eliminated along with crayfish, and may subsequently have to be re-introduced. There is cause for concern about toxin bioaccumulation and biomagnification in the food chain, although this is less of a problem with pyrethroids. Another chemical solution lies in the potential to use crayfish-specific, or even species-specific, pheromones to trap *P. clarkii* (Gherardi & Panov, 2006).

Biological control: Possible biological control methods include the use of fish predators, disease-causing organisms, and use of microbes that produce toxins, for example, the bacterium *Bacillus thuringiensis* var. *israeliensis* (Pedigo, 1989, in Holdich *et al*, 1999). Only the use of predaceous fish has been used successfully; eels, burbot, perch and pike are predators are all partial to crayfish (Westman, 1991, in Holdich *et al*, 1999). Pike are being reintroduced into Massaciuccoli Lake, Italy to help control *P.clarkii* (Schleifstein & Fedeli, 2003). The amount of cover, type of fish predator used and location are all important variables in determining the success of such an approach, and in general reduced coverage is correlated with increased predation rates.

Integrated management: The application of 20 Gy x-rays ionizing radiation to males has been found to reduce the size of testes and alter spermatogenesis. Reproductive success decreased and hatchlings were reduced by 43% in a test study (Alquiloni *et al*, 2000).

Pathway

In Kenya attempts have been made to use *P. clarkii* as a biological control agent to reduce the numbers of snails that act as intermediate hosts for the disease-causing organism that causes schistosomiasis (*Bilharzia*) (Hofkin *et al*.,*Procambarus clarkii* can spread to new areas by anglers using them as bait (Aquatic Non-native Species Update, 2000). Popular as a bait species for largemouth bass, this is believed to have been the most likely cause for their introduction into Washington (The Washington Department of Fish and Wildlife, 2003).The crayfish that now occur in African freshwaters are thought to have been introduced without the knowledge and permission of the relevant authorities (Mikkola, 1996, in Holdich, 1999).*Procambarus clarkii* is a popular dining delicacy, accounting for the vast majority of crayfish commercially produced in the United States (Washington Department of Fish and Wildlife, 2003). It was the most dominant freshwater crayfish in the world during the 20th century and its commercial success led to intentional introductions throughout Spain, France and Italy during the 1970s and 1980s (Henttonen and Huner, 1999).The habit of selling *Procambarus clarkii* alive as an aquarium or garden pond pet may have accelerated the spread of the species through natural waterways in Europe (Henttonen and Huner, 1999).Commerce in live crayfish from neighbouring Spain and more distant countries including the Far East, the USA and Kenya have been responsible for some of the introductions of *P. clarkii* into England, the Netherlands, France, Germany and Switzerland (Henttonen and Huner, 1999).

Principal source: Holdich, D. M., Gydemo, R. and Rogers, W.D. 1999. A review of possible methods for controlling nuisance populations of alien crayfish. In Gherardi, F. and Holdich, D.M. (eds.) Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?) A.A. Balkema, Rotterdam, Netherlands: 245-270.
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ALIEN RANGE

[1] AFRICA
[1] BELGIUM
[1] BELIZE
[1] BRAZIL
[1] CHINA
[1] COSTA RICA
[1] CYPRUS
[1] DOMINICAN REPUBLIC
[1] ECUADOR
[1] EGYPT
[1] EUROPE
[1] FRANCE
[1] GEORGIA
[1] GERMANY
[1] ISRAEL
[9] ITALY
[2] JAPAN
[2] KENYA
[1] MEXICO
[1] NETHERLANDS
[1] PHILIPPINES
[3] PORTUGAL
[1] PUERTO RICO
[1] SOUTH AFRICA
[4] SPAIN
[1] SUDAN
[1] SWEDEN
[4] SWITZERLAND
[1] TAIWAN
[1] UGANDA
[1] UNITED KINGDOM
[18] UNITED STATES
[1] VENEZUELA
[1] ZAMBIA

Red List assessed species 39: EX = 1; CR = 2; EN = 6; VU = 2; NT = 8; DD = 4; LC = 16;

Alytes cisternasii **NT**
Aphanius baeticus **EN**
Astacus astacus **VU**
Astacus leptodactylus **LC**
Austropotamobius pallipes **EN**
Austropotamobius torrentium **DD**
Cambaroides similis **DD**
Cambarus lenati **NT**
Cambarus reduncus **LC**
Cambarus spicatus **DD**
Discoglossus galganoi **LC**
Discoglossus jeanneae **NT**
Epidalea calamita **LC**
Fallicambarus fodiens **LC**
Fallicambarus harpi **NT**
Fallicambarus macneesei **LC**
Fallicambarus oryktes **NT**
Fallicambarus petilicarpus **EN**
Fulica cristata **LC**
Hyla meridionalis **LC**
Libellula angelina **CR**
Lissotriton boscai **LC**
Lissotriton helveticus **LC**
Lymnaea stagnalis **LC**
Pacifastacus nigrescens **EX**
Pelobates cultripes **NT**
Pelodytes ibericus **LC**
Pelodytes punctatus **LC**

Pleurodeles waltl **NT**
Procambarus bouvieri **EN**
Procambarus digueti **EN**
Rana latastei **VU**
Taricha torosa **LC**
Triturus pygmaeus **NT**
Potamonautes mutandensis **EN**
Procambarus braswelli **DD**
Procambarus regiomontanus **CR**
Salamandra salamandra **LC**
Triturus marmoratus **LC**

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Summary: The electronic tool kits made available on the Cefas page for free download are Crown Copyright (2007-2008). As such, these are freeware and may be freely distributed provided this notice is retained. No warranty, expressed or implied, is made and users should satisfy themselves as to the applicability of the results in any given circumstance. Toolkits available include 1) FISK- Freshwater Fish Invasiveness Scoring Kit (English and Spanish language version); 2) MFISK- Marine Fish Invasiveness Scoring Kit; 3) MI-ISK- Marine invertebrate Invasiveness Scoring Kit; 4) FI-ISK- Freshwater Invertebrate Invasiveness Scoring Kit and AmphISK- Amphibian Invasiveness Scoring Kit. These tool kits were developed by Cefas, with new VisualBasic and computational programming by Lorenzo Vilizzi, David Cooper, Andy South and Gordon H. Copp, based on VisualBasic code in the original Weed Risk Assessment (WRA) tool kit of P.C. Pheloung, P.A. Williams & S.R. Halloy (1999).
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Summary: Information on description, economic importance, distribution, habitat, history, growth, and impacts and management of species.
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Summary: This chapter outlines the history and status of introduced and native crayfish in Portugal and Spain.
Hefti, D.; Stucki, P., 2006. Crayfish management for Swiss waters. Bulletin Francais de la Peche et de la Pisciculture.(380-81). 2006. 937-949.
Summary: Seven species of crayfish are present in Swiss waters: three native ones (Astacus astacus, Austropotamobius pallipes, Austropotamobius torrentium) and four exotic ones (Astacus leptodactylus, Orconectes limosus, Pacifastacus leniusculus, *Procambarus clarkii*). The occurrence of each species is known and distribution maps have been drawn at national level. Many of the non-native populations have been identified as carriers of the crayfish plague, acting as a vector for Aphanomyces astaci. Crayfish are regulated by the Swiss Fisheries Legislation. The catching of the native species is allowed but the effective fishing pressure is low. The non-native species are considered as undesirable. For that reason importation, introduction and transportation of live specimens are forbidden with the exception of Cherax sp. which may be kept in cool boxes without any contact with water until consumption. A national management plan has been developed by the Federal Off ice for the Environment. It aims at increasing protective measures for the native species and enhancing population control for the non-native ones. The elimination measures are targeted on the most problematic species Pacifastacus leniusculus and *Procambarus clarkii*.
Holdich, D. M. 1999. The negative effects of established crayfish populations. In Gherardi, F. and Holdich, D.M. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 31-48.
Summary: This chapter gives a good overview of the negative effects of crayfish populations on the environment. Global case studies are documented and general management solutions are mentioned.
Holdich, D. M., Gydemo, R. and Rogers, W.D. 1999. A review of possible methods for controlling nuisance populations of alien crayfish. In Gherardi, F. and Holdich, D.M. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 245-270.
Summary: This chapter gives an informative overview of methods of controlling crayfish, with an overview of the advantages and disavdantages of different methods and a good review of recent research.

Holdich, D. M., Rogers, W.D. and Reynolds, J.D. 1999. Native and alien crayfish in the British Isles. In Gherardi, F. and Holdich, D.M. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 221-242.
Summary: This chapter review the status of crayfish populations in the British Isles.
Indiana ANS (Aquatic Nuisance Species) Management Plan. 2003. *Appendix A. List of introduced fish and crayfish*. Indiana Department of Natural Resources, Funded by: Division of Fish and Wildlife. Edited by: Phil Seng and Gwen White, D.J. Case & Associates, Mishawaka, Indiana.
Summary: Information on description, economic importance, distribution, habitat, history, growth, and impacts and management of species.
Available from: http://www.in.gov/dnr/invasivespecies/inansmanagementplan.html [Accessed 09 August 2004]
IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4.
Summary: The IUCN Red List of Threatened Species provides taxonomic, conservation status and distribution information on taxa that have been globally evaluated using the IUCN Red List Categories and Criteria. This system is designed to determine the relative risk of extinction, and the main purpose of the IUCN Red List is to catalogue and highlight those taxa that are facing a higher risk of global extinction (i.e. those listed as Critically Endangered, Endangered and Vulnerable). The IUCN Red List also includes information on taxa that are categorized as Extinct or Extinct in the Wild; on taxa that cannot be evaluated because of insufficient information (i.e. are Data Deficient); and on taxa that are either close to meeting the threatened thresholds or that would be threatened were it not for an ongoing taxon-specific conservation programme (i.e. are Near Threatened).
Available from: http://www.iucnredlist.org/ [Accessed 25 May 2011]
Maezono, Y., and T. Miyashita. 2004. *Impact of exotic fish removal on native communities in farm ponds*. Ecological Research 19: 263-267.
Summary: Information on description, economic importance, distribution, habitat, history, growth, and impacts and management of species.
NatureServe. 2003. *NatureServe Explorer: An online encyclopedia of life* [Online Database]. Version 1.8. NatureServe, Arlington, Virginia.
Summary: Information on description, reproduction, habitat, and nutrition information.
Available from: http://www.natureserve.org/explorer/servlet/NatureServe?loadTemplate=tabular_report.wmt&paging=home&save=all&sourceTemplate=reviewMiddle.wmt [Accessed 22 August 2003].
Oliveira, J, and A. Fabiao. 1998. *Growth responses of juvenile red swamp crayfish, Procambarus clarkii Girard, to several diets under controlled conditions*. Aquaculture Research 29: 123-129.
Summary: Information on description, economic importance, distribution, habitat, history, growth, and impacts and management of species.
Stucki, T.P. and Staub E. 1999. Distribution of crayfish species and legislation concerning crayfish in Switzerland. In Gherardi, F. and Holdich, D.M. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 141-159.
Summary: This chapter outlines the distribution of native and introduced crayfish species in Switzerland and discusses the legislation designed to protect native species.
Washington Department of Fish and Wildlife. 2003. *Prohibited aquatic animal species: Procambarus clarkii*. Washington Department of Fish and Wildlife s Aquatic Nuisance Species Classification.
Summary: Brief summary of introduction into Washington state and of how the species is spread.
Available from: http://wdfw.wa.gov/fish/ans/ans_species.htm [Accessed 09 August 2004]
Williams, Ernest H., Jr.; Bunkley-Williams, Lucy; Lilyestrom, Craig G.; Ortiz-Corps, Edgardo A. R., 2001. A review of recent introductions of aquatic invertebrates in Puerto Rico and implications for the management of nonindigenous species. Caribbean Journal of Science. 37(3-4). December, 2001. 246-251.

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Ackefors, H. 1999. The positive effects of established crayfish introductions in Europe. In Gherardi, F. and Holdich, D.M. (eds.) *Crustacean Issues 11: Crayfish in Europe as Alien Species (How to make the best of a bad situation?)* A.A. Balkema, Rotterdam, Netherlands: 49-62.
Summary: This chapter overviews the commercial benefits gained from crayfish harvestinjg in Europe.
Angeler, David G.; Sanchez-Carrillo, Salvador; Garcia, Gregorio; Alvarez-Cobelas, Miguel, 2001. The influence of *Procambarus clarkii* (Cambaridae, Decapoda) on water quality and sediment characteristics in a Spanish floodplain wetland. Hydrobiologia.(464). 15 November, 2001. 89-98.

Appleton, C. C.; Hofkin, B. V.; Baijnath, A., 2004. Macro-invertebrate predators of freshwater pulmonate snails in Africa, with particular reference to *Appasus grassei* (Heteroptera) and *Procambarus clarkii* (Decapoda). African Journal of Aquatic Science. 29(2). 2004. 185-193.
Summary: A range of African and alien macro-invertebrates has been reported preying on freshwater pulmonate snails, including those that serve as intermediate hosts for bloodflukes of the genus Schistosoma. Predation by five molluscivorous taxa is reviewed here: indigenous leeches (Glossiphoniidae), marsh fly larvae (Sciomyzidae), waterbugs (Belostomatidae), crabs (Potamonautidae) and invasive crayfish (Astacidae). Common features are a lack of prey specificity but clear prey-size specificity. Attention is drawn to the ability of invasive snail species (Physidae and Lymnaeidae) to avoid predation by several of these taxa. Evidence suggests that only the alien invasive crayfish *Procambarus clarkii* has potential as a snail biocontrol agent, but that its use should not be encouraged.
Aquiloni, Laura; Ilheu, Maria; Gherardi, Francesca, 2005. Habitat use and dispersal of the invasive crayfish *Procambarus clarkii* in ephemeral water bodies of Portugal. Marine and Freshwater Behaviour and Physiology. 38(4). DEC 2005. 225-236.
Aquiloni, Laura; Ilheu, Maria; Gherardi, Francesca, 2005. Habitat use and dispersal of the invasive crayfish *Procambarus clarkii* in ephemeral water bodies of Portugal. Marine & Freshwater Behaviour & Physiology. 38(4). DEC 2005. 225-236.
Barbaresi, Silvia; Tricarico, Elena; Gherardi, Francesca, 2004. Factors inducing the intense burrowing activity of the red-swamp crayfish, *Procambarus clarkii*, an invasive species. Naturwissenschaften. 91(7). July 2004. 342-345.
Summary: The burrowing activity of the invasive red-swamp crayfish, *Procambarus clarkii*, was studied along a 25-m-long transect in an irrigation ditch system in Italy. Our objective was to understand the factors inducing this species intense digging, which can result in bank collapse and consequently in severe damage to both agricultural fields and natural ecosystems. Burrow morphology and position, together with their occupancy by crayfish and digging, were recorded once every 6 h for 10 consecutive days. The majority of burrows were simple, although a few had a chimney and were constructed at a farther distance from the water surface than simple burrows. Burrow occupancy and digging, together with their plugged/unplugged status, were constant throughout a 24-h cycle and were not related to any abiotic parameter of the habitat. Crayfish occupied and dug a burrow for a relatively short time (6 h on average). Once abandoned, old burrows were rarely reoccupied and often collapsed, while crayfish excavated new ones. As a result, the overall number of burrows increased. This massive use of banks by P. clarkii seems to be related to soil composition and humidity, which favour crayfish digging but also cause the easy collapse of burrows.
Boets, Pieter; Lock, Koen; Cammaerts, Roger; Plu, Dieder; Goethals, Peter L. M., 2009. Occurrence of the invasive crayfish *Procambarus clarkii* (Girard, 1852) in Belgium (Crustacea: Cambaridae) Belgian Journal of Zoology. 139(2). JUL 2009. 173-175.
CABI Bioscience (CABI), 2005. UK Non-Native Oganism Risk Assessment Scheme Version 3.3: To assess the risks associated with this species in GB, Prepared by CABI Bioscience (CABI), Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Centre for Ecology and Hydrology (CEH), Central Science Laboratory (CSL), Imperial College London (IC) and the University of Greenwich (UoG) under Defra Contract CR0293, February 2005.
Cai Feng-jin; Wu Zheng-jun; He Nan; Ni Lei; Huang Cheng-ming, 2010. Research progress in invasion ecology of *Procambarus clarkia*. Shengtaixue Zazhi. 29(1). JAN 2010. 124-132.
Summary: *Procambarus clarkii* is native to southern USA and northern Mexico, and regarded as one of the well-known invasive species. As one of the fishery economic resources, it has spread around the world. Owing to its wide habitat adaptability, rapid growth, and high reproduction rate, P. clarkii can establish wild populations rapidly. The studies in recent decade indicated that P. clarkii invasion had given great threat on the survival of native aquatic plants, amphibian, and aquatic invertebrate, and decreased the local biodiversity via predation and resource competition. Since P. clarkii is one kind of important fishery species, it will continue to spread with the help of human. In order to understand and to decrease the ecological impact of P. clarkii s invasion on local habitats, following studies are urgent; 1) ecological damage of P. clarkia in China, 2) population regulation and control of P. clarkia, and 3) ecological restoration on damaged habitats by P. clarkii.
Campos, Ernesto and Gabino A. Rodr?guez-Almaraz, 1992. Distribution of the Red Swamp Crayfish *Procambarus clarkii* (Girard, 1852) (Decapoda: Cambaridae) in Mexico: An Update. Journal of Crustacean Biology Vol. 12, No. 4 (Nov., 1992), pp. 627-630

Changeux, T., 2003. Changes in crayfish distribution in Metropolitan France according to the national surveys performed by the Conseil superieur de la peche from 1977 to 2001. Bulletin Francais de la Peche et de la Pisciculture.(370-71). 2003. 17-41.
Summary: When looking at the various national surveys performed in Metropolitan France since 1977 by the Conseil superieur de la peche, crayfish species distribution shows that nativespecies (Austropotamobius pallipes, Astacus astacus, Austropotamobius torrentium) are either rare, or in decline; while the introduced species (Orconectes limosus, Pacifastacus leniusculus, *Procambarus clarkii*, Astacus leptodactylus), are increasing. The ban of live introduced species transport, except for A. leptodactylus, didn t stop this process with a peculiar acceleration of P leniusculus propagation these last five years, certainly responsible for plague (Aphanomyces astaci) renewed outbreaks. The other measures in favor of native species, such as fishing limitations and reintroduction plans, have not reversed the trend. So, it seems necessary to develop a conservation policy based on habitat preservation and on the respect of certain prophylactic rules which are to be determined. That can only be considered on watersheds of small area, easily controlled if local authorities are involved. The 55 French habitat decrees, and the 154 Natura 2000 zones with their management plans, seem to be a promising way to implement this type of actions in France. The case of Corsica, recently colonized by O. limosus, would require special measures to prevent the island from invasion by P leniusculus and P clarkii in the future.
Correia, Alexandra M.; Anastacio, Pedro M., 2008. Shifts in aquatic macroinvertebrate biodiversity associated with the presence and size of an alien crayfish. Ecological Research. 23(4). JUL 2008. 729-734.
Cruz, Maria Joao; Andrade, Pedro; Pascoal, Sandra; Rebelo, Rui, 2004. Colonization of temporary ponds by the red swamp crayfish, *Procambarus clarkii*. Revista de Biologia (Lisbon). 22(1-4). 2004. 79-90.
Cruz, Maria Joao; Rebelo, Rui, 2005. Vulnerability of Southwest Iberian amphibians to an introduced crayfish, *Procambarus clarkii*. Amphibia-Reptilia. 26(3). SEP 2005. 293-303.
Cruz, Maria J.; Pascoal, Sandra; Tejedo, Miguel; Rebelo, Rui, 2006b. Predation by an exotic crayfish, *Procambarus clarkii*, on Natterjack Toad, *Bufo calamita*, embryos: Its role on the exclusion of this amphibian from its breeding ponds. Copeia.(2). MAY 26 2006. 274-280.
Cruz, Maria J.; Rebelo, Rui, 2007. Colonization of freshwater habitats by an introduced crayfish, *Procambarus clarkii*, in Southwest Iberian Peninsula. Hydrobiologia. 575 JAN 2007. 191-201.
Cruz, Maria J.; Rebelo, Rui; Crespo, Eduardo G., 2006a. Effects of an introduced crayfish, *Procambarus clarkii*, on the distribution of south-western Iberian amphibians in their breeding habitats. Ecography. 29(3). JUN 2006. 329-338.
de Moor, I., Potential impacts of alien freshwater crayfish in South Africa.
Summary: The habitat preferences and life history characteristics of four alien species of freshwater crayfish (Cherax tenuimanus, C. destructor, C. quadricarinatus and *Procambarus clarkii*) are reviewed. The potential impact of these species on South African freshwater ecosystems is assessed and the desirability of allowing their importation evaluated. On the basis of principles espoused in the European Inland Fisheries Advisory Council s Code of Practice on Aquatic Introductions, it is recommended that importation permits should not be granted for any of these species.
Ferey, M-P. 2003. Europe demands halt to invasion... by US crayfish. *International News*. 27 February 2003.
Summary: An article about invasive crayfish species in Europe.
Foster, John and David Harper, 2007. Chapter four: Status and ecosystem interactions of the invasive Louisianan red swamp crayfish *Procambarus clarkii* in East Africa. In Francesca Gherardi, Biological invaders in inland waters: Profiles, distribution, and threats, 91?101. Biological invaders in inland waters: Profiles, distribution, and threats Invading Nature - Springer Series In Invasion Ecology, 2007, Volume 2, Part 2, 91-101
Fullerton, Aimee H.; Watson, Brian T., 2001. New distributional records for two nonindigenous and one native crayfish in North Carolina. Journal of the Elisha Mitchell Scientific Society. 117(1). Spring, 2001. 66-70.
Summary: The nonindigenous crayfish, Orconectes (P.) rusticus, previously unknown to occur in North Carolina, has been discovered at three localities in the Broad River basin of the State. Its presence there could pose a threat to the native crayfishes of the basin, especially to two endemic species, Cambarus (C.) lenati and C. (P.) spicatus. New localities for wild populations of another invader, Procambarus (S.) clarkii, previously reported from the Neuse, Tar-Pamlico, Yadkin-Pee Dee, and Cape Fear river basins, reveal that it also occurs in the Broad and Pasquotank basins. A native crayfish, Procambarus (O.) braswelli, thought to be endemic to the Waccamaw River basin, has been found in the Lumber-Little Pee Dee basin.
Geiger, Walter; Alcorlo, Paloma; Baltanas, Angel; Montes, Carlos, 2005. Impact of an introduced Crustacean on the trophic webs of Mediterranean wetlands. Biological Invasions. 7(1). January 2005. 49-73.
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Gherardi, Francesca, 2006. Crayfish invading Europe: the case study of *Procambarus clarkii* Marine & Freshwater Behaviour & Physiology. 39(3). SEP 2006. 175-191.
Gherardi, Francesca; Acquistapace, Patrizia, 2007. Invasive crayfish in Europe: the impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. Freshwater Biology. 52(7). JUL 2007. 1249-1259.

Gherardi, Francesca and Vadim Panov, 2006. Data sheet *Procambarus clarkii*. DAISIE (Delivering Alien Invasive Species inventories for Europe)
Summary: Available from: http://www.europe-aliens.org/pdf/Procambarus_clarkii.pdf [Accessed 7 January 2011]
Gherardi, Francesca; Barbaresi, Silvia, 2000. Invasive crayfish: Activity patterns of *Procambarus clarkii* in the rice fields of the Lower Guadalquivir (Spain) Archiv fuer Hydrobiologie. 150(1). December, 2000. 153-168.
Summary: The activity of a naturalised population of the invasive Nearctic crayfish, *Procambarus clarkii*, in the Lower Guadalquivir rice fields (Andalucia, Spain), has been studied using both traditional and radio-telemetry techniques. Our results lead us to propose that P. clarkii shows two opposed patterns of activity, featuring (1) a wandering phase, without any daily periodicity, characterised by short peaks of high speed of locomotion, and (2) a longer stationary phase, during which crayfish hide in the burrows by day, emerging only at dusk to forage. Other behaviours (such as fighting or mating) also take place at night-time. During the wandering phase, breeding males move up to 17km in 4 days and cover a wide area (up to 20 km2 in 4 days). Breeding males fitted with radio-transmitters were tracked back to the point of release within four days. This intensive activity helps dispersion in this species. Further studies are required to understand the adaptive significance of this locomotory behaviour, which appears expensive and dangerous, and the mechanisms of home-range recognition and orientation.
Gherardi, Francesca; Barbaresi, Silvia, 2007. Feeding preferences of the invasive crayfish, *Procambarus clarkii*. BFPP-Connaissance et Gestion du Patrimoine Aquatique.(387). 2007. 7-20.
Gherardi, Francesca; Barbaresi, Silvia; Salvi, Gabriele, 2000. Spatial and temporal patterns in the movement of *Procambarus clarkii*, an invasive crayfish. Aquatic Sciences. 62(2). 2000. 179-193.
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Summary: To understand the relationship between the density of an introduced crayfish species (P. clarkii) and the abundance and composition of pelagic and surface microalgae (hereafter referred to as phytoplankton and phytoneuston, respectively) we ran an in situ experiment in a Mediterranean wetland. In May 2004, we delimited six 10 x 7 m areas along a channel in the Padule di Fucecchio (Italy). Each area was randomly chosen to host crayfish populations at either low (1 crayfish/m(2)) or high densities (14 crayfish/m(2)). Phytoplankton and phytoneuston samplings were conducted in August and in September 2004, corresponding to the periods in which the highest and the lowest numbers of free-moving crayfish were found, respectively, during the lentic phase of the water regime. Results showed that (1) phytoneuston biomass, composed of cyanobacteria and, to a lesser extent, of euglenoids, was strongly affected by the presence of dense populations of P. clarkii in August; (2) crayfish seemed to modify the composition of microalgal communities; (3) these effects were not accompanied by significant differences between experimental areas in water chemistry and temperature; (4) physico-chemical measures highly varied with sampling periods along with a change in phytoplankton and phytoneuston abundance; and (5) high crayfish densities did not to exert any measurable effect on phytoplankton abundance. The decrease of phytoneuston may be the result of top-down effects of crayfish removing invertebrate grazers or, most likely, of direct grazing of crayfish. Indeed, crayfish were often observed climbing on macrophytes and feeding on the floating film.
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Summary: Contains information about the introduction and impacts of the red swamp crayfish in Europe, and additional distributions.
Harper, David; Mavuti, Kenneth, 2004. Lake Naivasha, Kenya: Ecohydrology to guide the management of a tropical protected area. Ecohydrology & Hydrobiology. 4(3). 2004. 287-305.
Summary: The present ecological and hydrological state of Lake Naivasha, a tropical freshwater Ramsar site, is reviewed from existing research. The ecology of the lake was formerly regulated by ecohydrological control exerted on the inflowing hydrochemistry by the continuous fringing papyrus, with a full swamp on the inflow rivers delta. The ecology of the lake since that time has been severely disrupted by alien (or exotic) species invasions, particularly the Louisiana crayfish *Procambarus clarkii*. Lake-wide papyrus degradation has also been occurring since about 1980, following a lake level decline of up to 3m through agri-industrial abstraction. The river Malewa, which previously ran through a swamp, now runs directly into the lake, bringing high silt and nutrient loads in wet seasons, making the lake eutrophic. It is suggested that sustainable management of the lake should focus upon three ecohydrological objectives - control of abstractions to achieve hydrological balance, physical restoration of the former North Swamp and the control of illegal fishing. The latter would enable the commercial fishery returns to maximum sustainable yield so that large M. salmoides (large mouthed bass) individuals once again impose a top-down control upon P. clarkii, and the crayfish itself be commercially exploited.
Harper, David M.; Smart, Andrew C.; Coley, Stephanie; Schmitz, Sophie; de Beauregard, Anne-Christine Gouder; North, Rick; Adams, Chris; Obade, Paul; Kamau, Mbogo, 2002. Distribution and abundance of the Louisiana red swamp crayfish *Procambarus clarkii* Girard at Lake Naivasha, Kenya between 1987 and 1999. Hydrobiologia. 488 15 November, 2002. 143-151.
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Summary: This chapter gives an historical account of the F11introduction of alien crayfish populations into Europe during the 19th and 20th centuries.
Holdich, D. M.; Reynolds, J. D.; Souty-Grosset, C.; Sibley, P. J., 2009. A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. Knowledge & Management of Aquatic Ecosystems.(394-95). 2009. Article No.: 11.
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ITIS (Integrated Taxonomic Information System), 2005. Online Database *Procambarus clarkii*
Summary: An online database that provides taxonomic information, common names, synonyms and geographical jurisdiction of a species. In addition links are provided to retrieve biological records and collection information from the Global Biodiversity Information Facility (GBIF) Data Portal and bioscience articles from BioOne journals.
Available from:
http://www.cbif.gc.ca/pls/itisca/taxastep?king=every&p_action=containing&taxa=Procambarus+clarkii&p_format=&p_ifx=plglt&p_lang= [Accessed March 2005]
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Summary: This chapter gives an overview of the colonising strategies of introduced and European native crayfish and describes the competitive pressures imposed on native species.
Lodge, David M.; Rosenthal, Sadie K.; Mavuti, Kenneth M.; Muohi, Wairimu; Ochieng, Philip; Stevens, Samantha S.; Mungai, Benjamin N.; Mkoji, Gerald M., 2005. Louisiana crayfish (*Procambarus clarkii*) (Crustacea: Cambaridae) in Kenyan ponds: non-target effects of a potential biological control agent for schistosomiasis. African Journal of Aquatic Science. 30(2). 2005. 119-124.
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Summary: Information on description, economic importance, distribution, habitat, history, growth, and impacts and management of species.
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