Invasive alien crayfish species

Identification and best management practices

RIPARIAS

Reaching Integrated and Prompt Action in Response to Invasive Alien Species

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SUMMARY

THE LIFE RIPARIAS PROJECT

Invasive Alien Species (IAS) are species that are accidentally or intentionally introduced outside their natural range, and which may cause many issues due to their rapid spread. In Europe, IAS represent a growing threat to ecosystems and biodiversity. The presence of IAS can also have socio-economic implications and adversely affect human health.

Nevertheless, responses to address the issue of biological invasion have often been insufficient and actions have had varying and sometimes limited results. The diversity of actors involved in IAS management along with the fragmented nature of available IAS data sources impede the implementation of concerted and coherent management actions.
Moreover, the number of IAS and associated costs are constantly increasing. It has therefore become essential to take efficient and coordinated decisions to determine which species and sites should be considered as a priority for management actions.

To address these challenges, Belgian authorities and their partners have joined forces through the LIFE RIPARIAS project, which aims to optimise the management of IAS in aquatic and riparian environments. To do so, a scientific evidence-based workflow, setting up priorities for action, has been developed. This efficiently guides decision-makers and managers throughout the IAS management decision-making process.

The project targets riparian and aquatic plant species that are listed as IAS of EU concern under the EU Regulation No 1143/2014. Other species, included in an alert list, are also targeted for early detection and rapid eradication.

The LIFE RIPARIAS project is developing and testing its innovative approach in the Dyle, Senne and Marcq river basins in the Scheldt river basin district. This pilot area covers 263,103,000 ha across the three regions of Belgium (the Walloon Region, the Flemish Region and the Brussels-Capital Region). This project is co-funded by the European Union as part of the LIFE Programme.

CRAYFISH SPECIES

Crayfish are among the largest freshwater crustaceans. They thrive in a wide range of aquatic or semi-aquatic habitats and have an opportunistic omnivorous diet. Often present in large numbers, they have a significant impact on trophic chains and the functioning of ecosystems.
Only one species is native to Belgium:

Astacus astacus – noble crayfish, or broad-fingered crayfish, distributed throughout Europe. It is a large crayfish that reaches sexual maturity quite late as it only starts reproducing from the age of 3. Requiring good quality waters and once very abundant, this species populations are in sharp decline everywhere. Only a few relict populations remain today in Belgium.

A European species, non-native to Western Europe and now widespread in our waters, was introduced in the 1950s for consumption:

Astacus leptodactylus – the narrow-clawed crayfish or Turkish crayfish, native to Eastern Europe and Turkey. This large crayfish is less demanding than the noble crayfish regarding water quality and reaches sexual maturity after two years. While the species competes for resources (e.g. habitat and food) with the noble crayfish, it is not considered as a major threat.

There is an increasing number of other species, originating from various parts of the world, entering Belgium and Europe. These non-native species are contributing to the rapid decline of the native crayfish as those highly invasive species directly compete for resources with our native species. But that's not all: species originating from North America are carriers of the crayfish plague, an infectious disease that decimates noble crayfish populations.

Caused by *Aphanomyces astaci*, an oomycete specific to crayfish, the crayfish plague has now become a widespread disease. The aquatic spores attach to the exoskeleton of the crayfish and form a mycelium that gradually colonises the body of the infected individual. While this is lethal for European crayfish, American crayfish are often quite resistant. The latter have the metabolic capacity to limit the development of the disease but remain infectious by allowing the production and the spread of spores.

Invasive alien crayfish reach sexual maturity quite early (capable of reproduction after one year, unlike the native species) and reproduce abundantly. Some of them are also very aggressive. Mainly active at night, they are able to move on dry land if necessary and when weather conditions are favourable. They dig burrows that serve as shelters, and spend a substantial part of their time in those burrows, especially in winter. They can withstand temporary drawdown of the aquatic environment.

Along with their significant impact on native crayfish populations, invasive alien crayfish have other negative impacts. They reduce invertebrate and plant communities' richness, deteriorate the banks by digging burrows, and can modify the physicochemical characteristics of the water. Their invasion can profoundly alter aquatic ecosystems.

Species of Union concern

Several invasive alien crayfish species are listed as " species of Union concern". These species represent a major threat to biodiversity and ecosystems. Since 2015, a European Regulation on invasive alien species (No 1143/2014) compels Member States to take measures to address the issue of IAS. This Regulation was established with the aim to prevent the introduction and establishment of listed species, while minimising and mitigating the adverse effects associated with their spread. The Union list entered into force in August 2016. Listed species are subject to restrictions which include restrictions on introduction, keeping, breeding, release into the environment, growing, transport, sale, exchange and use.

Regularly revised, the list was updated from 5 to 6 crayfish species in 2022:

Faxonius limosus – previously referred to as *Orconectes limosus* – the spiny-cheek crayfish, native to Eastern North America. This small crayfish was introduced to Europe in the 19th century for commercial purposes. It is now widespread in the wild, in ponds and slow-moving rivers. The spiny-cheek crayfish was the first species to spread the crayfish plague in Belgium. This invader is sometimes supplanted by other invasive alien species.

Faxonius rusticus – the rusty crayfish, native to Eastern North America (Ohio River basin). This medium-sized crayfish is considered as one of the most threatening invasive crayfish species in the world. It is the latest species to be added to the Union concern list. The rusty crayfish, which has not yet been observed in Belgium, is a potential carrier of the crayfish plague.

Faxonius virilis – *previously referred to as* *Orconectes virilis* – the blue-clawed crayfish, or virile crayfish, native to Eastern North America. This medium-sized crayfish, has not yet been observed in Belgium, but is already present in the Netherlands. The species is a potential carrier of the crayfish plague.

Pacifastacus leniusculus – California crayfish, Pacific crayfish, or signal crayfish, native to Western North America. It is a large, robust, and aggressive crayfish. Introduced and bred in Europe in the 20th century for its meat, this species quickly colonised waterways of southern Belgium. The signal crayfish outcompetes the indigenous noble crayfish as they share similar habitats. The signal crayfish is a potential carrier of the crayfish plague.

Procambarus clarkii – the red swamp crayfish, native to the Mississippi swamps. This medium-sized crayfish is becoming increasingly common in Belgium. It has colonised several networks of water bodies and canals at the north of the Sambre and Meuse river valleys. Imported for trade purposes in the 1980s, the species might have been introduced into the wild by anglers. Diverse varieties, displaying a wide variety of colours, are now being bred for the aquarium trade. This prolific and resistant crayfish can thrive in stagnant and poorly oxygenated waters. It has a considerable impact on ecosystems and digs deep burrows. It can be a potential carrier of the crayfish plague.

Procambarus virginalis – previously referred to as *Procambarus fallax f. virginalis* – the marbled crayfish, a parthenogenetic crayfish originating from the pet trade. It appeared for the first time in 1995 in an aquarium in Germany and is believed to be the result of a single natural mutation in an individual sourced from a wild *Procambarus fallax* population in the United States. This small crayfish reproduces by parthenogenesis, which means that its offspring are genetically identical clones and are all female, each capable of reproducing on its own again. This clonal reproduction is particularly rapid and worrying. The marbled crayfish was introduced into the wild through the aquarium industry. It has already been detected in multiple locations in Flanders but its distribution remains, so far, quite limited on the Belgian territory.


Procambarus clarkii


Pacifastacus leniusculus

LIFE RIPARIAS alert list species

In addition to the species recognised as "species of Union concern", other crayfish species pose an environmental risk. Alert lists can be defined as lists of alien species that are not yet present on a territory, or with a very limited distribution, and that pose a threat to biodiversity. Active surveillance and monitoring are recommended for a prompt response in the event of introductions and spread in the wild. An alert list was, therefore, established for the LIFE RIPARIAS pilot area. This list was developed using information such as species availability on the Belgian market, the risk of establishment, spread and impact on biodiversity (assessment made via the Harmonia+ risk scoring system). The alert list currently includes 4 crayfish species:

Cherax destructor – common yabby, native to Australia. This large crayfish, which does not carry the crayfish plague, was introduced to Spain for aquaculture purposes. It has not yet been documented in Belgium. While it could compete with other crayfish species for resources, the common yabby has paradoxically been listed as "vulnerable" in its native range by the The International Union for Conservation of Nature (IUCN) Red List.

Faxonius immunis – previously referred to as *Orconectes immunis* – the calico crayfish, native to Eastern North America. It is a small, fast-growing, and highly fecund crayfish, already observed in some European countries (Rhine valley). It has, however, not yet been recorded in Belgium. It is a potential carrier of the crayfish plague.

Faxonius juvenilis – previously referred to as *Orconectes juvenilis* – the Kentucky river crayfish, native to Eastern North America. It is a small crayfish, closely related to other species of the same genus. This crayfish was introduced to France at the beginning of the century, but its distribution is still relatively limited. It has not yet been observed in Belgium. It is a potential carrier of the crayfish plague.

Procambarus acutus – the white-river crayfish, native to Eastern North America. It is a medium-sized crayfish, closely related to the red swamp crayfish. It is traded for aquarium use and as an ornamental species for garden ponds, from where it can easily escape. The species has already been observed in the wild in Flanders, notably around the cities of Antwerp and Hasselt, and in the Netherlands. It is also a potential carrier of the crayfish plague.

HOW TO USE THIS GUIDE ?

This guide was written with the aim to meet two objectives. Firstly, to enable field managers to recognise the different crayfish species they might encounter in the field in Belgium. Secondly, to describe best management practices in order to help managers stop the spread of invasive alien crayfish as well as control or eradicate already established populations.

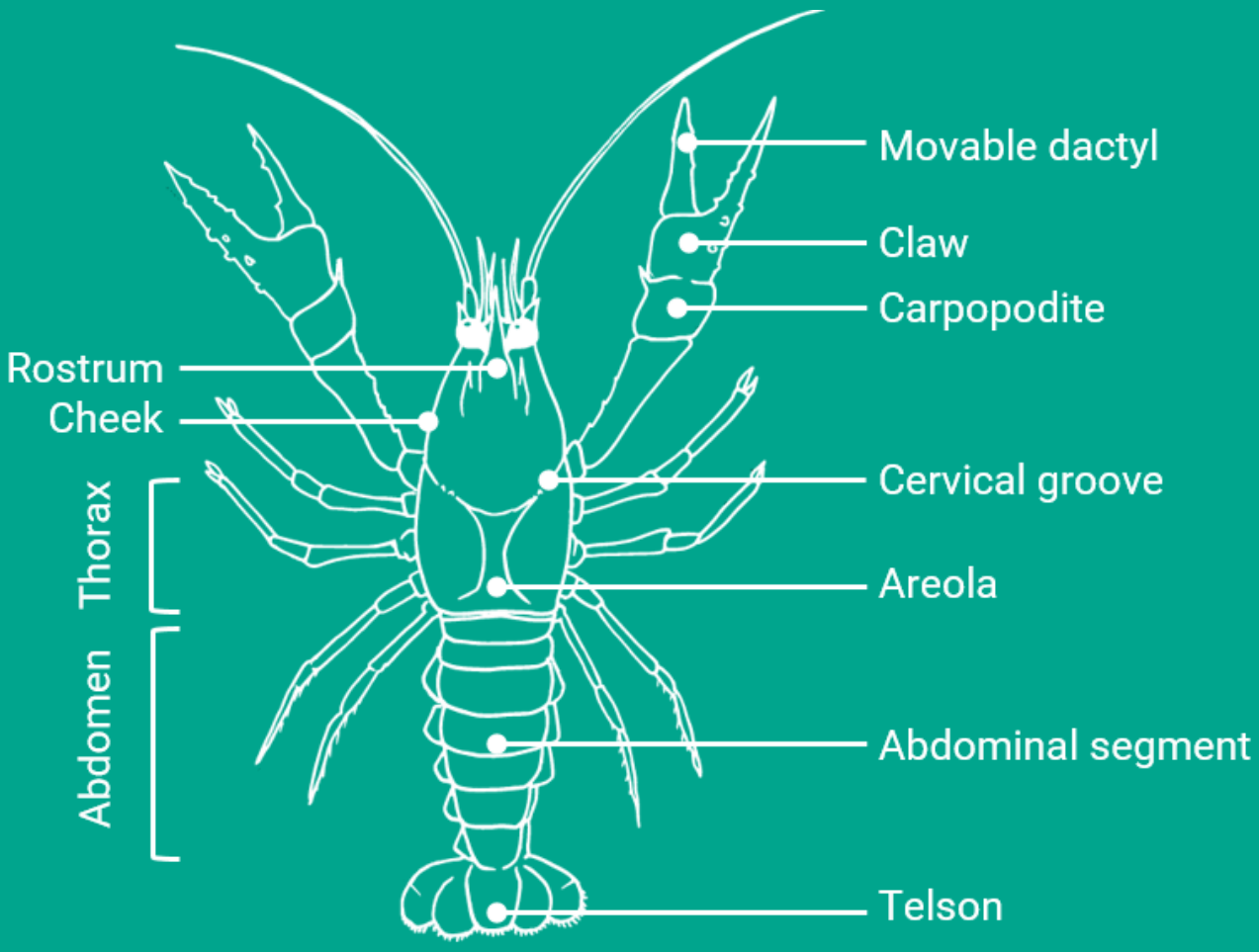
As many species are likely to be encountered, now or in the future, their accurate identification is an essential step. Handy identification sheets were developed for this purpose. Species are listed in alphabetical order by their scientific name (Latin name). In order to facilitate the recognition of species in the field and prevent identification errors, look-alike species (indigenous or exotic) are frequently presented for comparison. This look-alike species list is not exhaustive and only provides information on species found in the wild in Belgium. The identification sheets were designed based on morphological characteristics observed in Belgian populations. In their natural range, or in aquaria, some species may have different colouring and colour criteria should be taken with caution. For identification purposes, it is recommended to collect adult individuals. Ideally, several organs should be observed (claws, thoracic plates, carpopodite, etc.) before making a diagnosis, by comparing the specimen collected with the criteria illustrated in the sheets. Specimens observed and collected in the field must not be transported alive. Identifying and reporting crayfish species observed in the field enables scientists to map its distribution on the territory, and thus, helps to adapt management strategies at the regional or national level. Moreover, knowing the species is essential for any management actions.

When an invasive alien crayfish population is established in a water body, or in a stretch of river, it is extremely difficult to eradicate the population. This highlights the importance of preventing introduction in the first place. There are multiple management techniques that can be implemented for eradicating or controlling crayfish, but they will often have to be combined and applied for several years to achieve satisfactory results. The methods selected for this guide are described as “best management practices”, which means that those practices have shown an acceptable level of effectiveness while being ethically and legally acceptable while having minimal impact on ecosystems.

As this guide was produced as a tool for field managers, it was decided not to include scientific references directly in the text to facilitate the reading. However, interested readers will find useful references at the end of the guide.

Crayfish anatomy

Different criteria can be used to differentiate crayfish species. The most useful ones are shown in the figure below. Length, which can also be used as a criterion, is measured from the rostrum to the telson (It does not include antenna).



Crayfish identification sheets

Noble crayfish

Astacus astacus

Threatened indigenous species

©H.Zell

Native species to Central and Western Europe. **Decreasing populations** due to exotic crayfish introductions

Mostly found in well oxygenated **running waters** but also in **ponds**

Large sized crayfish (12-15 cm). Can reach 18 cm

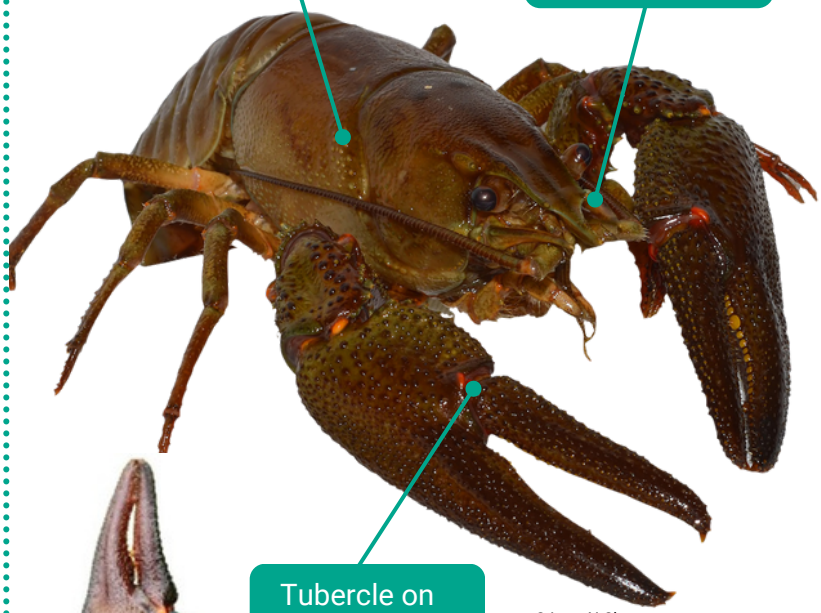
Dark-brown to beige crayfish with robust claws and an orange tubercle at the junction of the claw

The species is listed as vulnerable by the IUCN Red List. Very sensitive to the crayfish plague carried by exotic crayfish

©Xavier Vermeersch

Row of spines behind the cervical groove

2 spines near the base of the rostrum



©Anna N Chapman

Tubercle on inner fixed finger, on each side of the claws

©Bram Koese

Not to be confused with

Pacifastacus leniusculus

Exotic

- White-turquoise spot at the junction of the claw (only on the upper side)
- No spines behind the cervical groove

©Bram Koese

If you spot that species, record your observation on

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RIPARIAS

Danube crayfish

Astacus leptodactylus

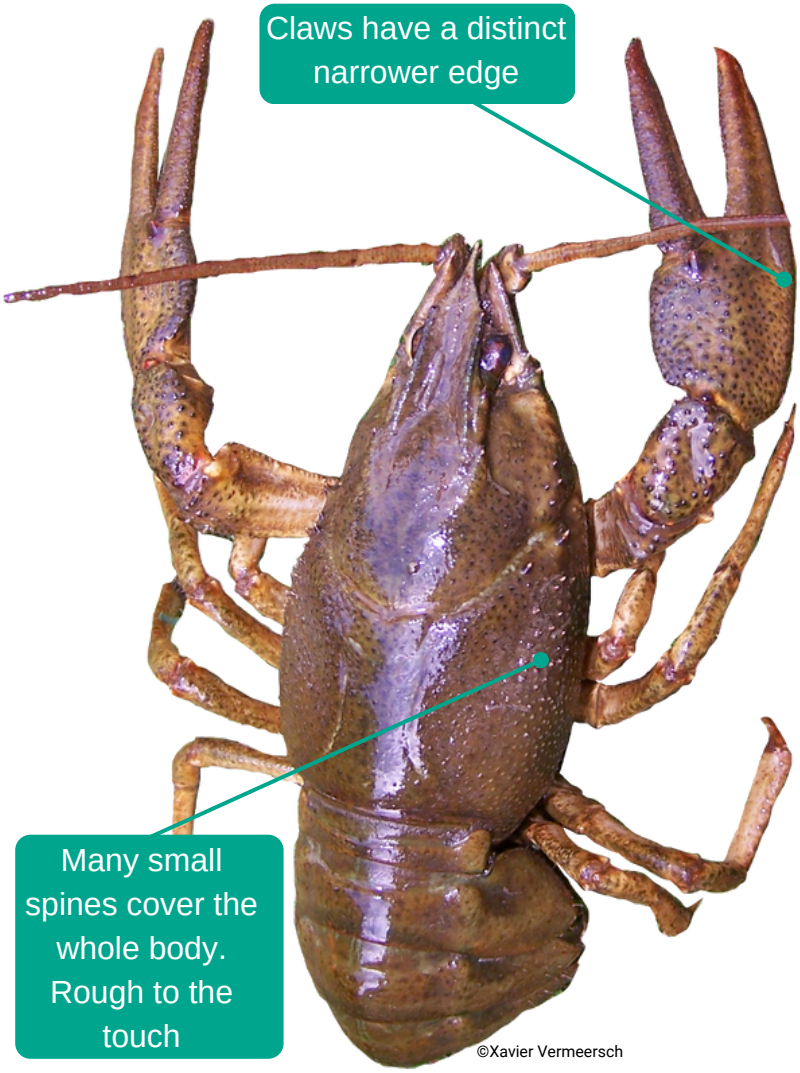
Invasive species native to the Ponto-Caspian river basin. It **has spread to most European countries**

Found in **lakes** and **canals**

Large sized crayfish (10-15 cm). Can reach 20 cm

Beige or brownish crayfish, occasionally bluish. Claws have the same colour as the body (uniform body colouration)

Males can have large claws that can be longer than the body. Females have smaller claws and a broader abdomen



Not to be confused with

Procambarus acutus
Exotic
- Black wedge V-shaped on dorsal abdomen

Procambarus clarkii
Exotic
- Red claws with red tubercles

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RIPARIAS

Common yabby

Cherax destructor

LIFE RIPARIAS alert list species

© quollsskinks

Invasive species native to Australia. **Has not been observed in Belgium yet**

Found in **turbid freshwater**, **ponds** and **streams**

Large sized crayfish (10 - 20 cm). Can reach 30 cm

Variable colouration depending on the environment, going from green-beige to almost black. Some ornamental varieties have a blue-grey colour

Variability of colouration. Do not rely on colours alone for identification

© Daiju Azuma

© missganoush

Smooth carapace with a single pair of post-orbital ridges

© quollsskinks

The rostrum is short, wide and triangular. No spines on the edges

The telson has no spines, it is membranous on the posterior half

© Asimakis Patitsas

Not to be confused with

Procambarus clarkii

Exotic

- Elongated claws with many red tubercles
- The areola is extremely narrow

©Arnaud Monty

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RIPARIAS

Calico crayfish

Faxonius immunis

LIFE RIPARIAS alert list species

©Daniel Folds

Invasive species native to North America. **Has not been observed in Belgium** yet

Found in slow moving **streams** and in **ponds**

Small sized crayfish (maximum 10 cm)

Typical pattern of colouration on the abdomen. Notch at the base of movable dactyl

©Daniel Folds

This species can be confused with other taxonomically related species

©Blake A. Mann

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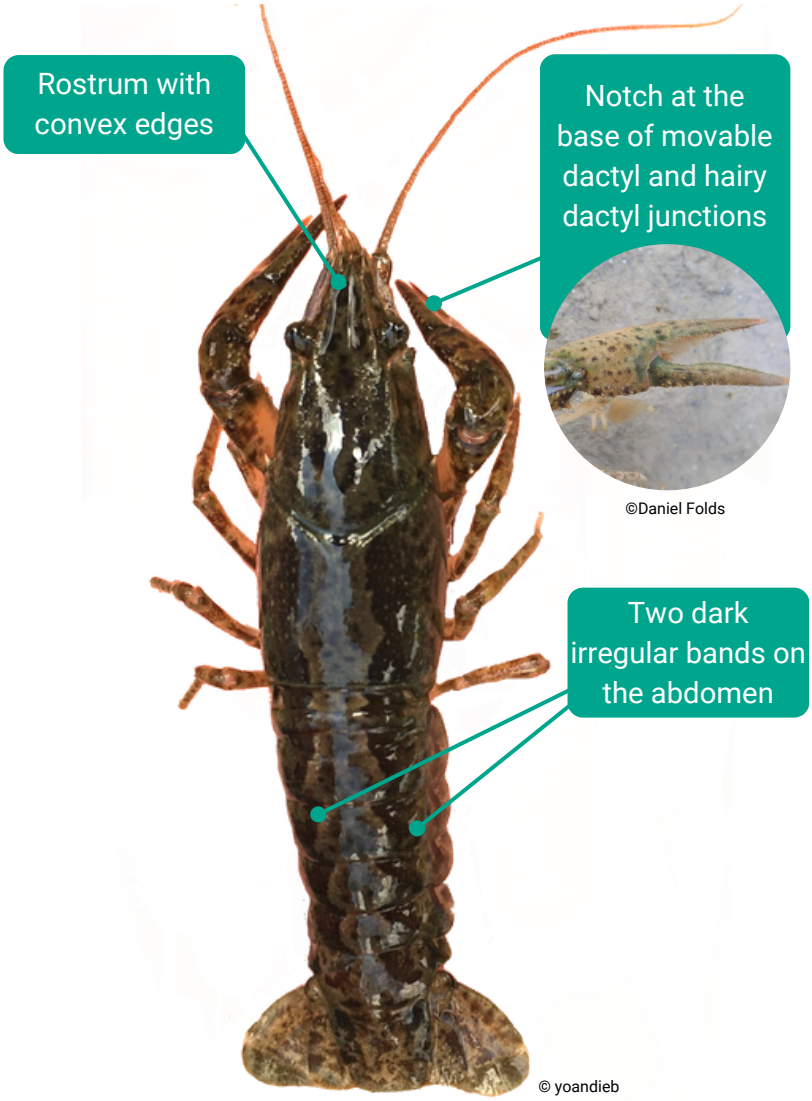


©Daniel Folds

© yoandieb

Not to be confused with

Faxonius limosus

Exotic

- Group of spines on the cheeks
- Red spots on top of the abdomen

©Dick Belgers

RIPARIAS

Kentucky river crayfish

Faxonius juvenilis

LIFE RIPARIAS alert list species

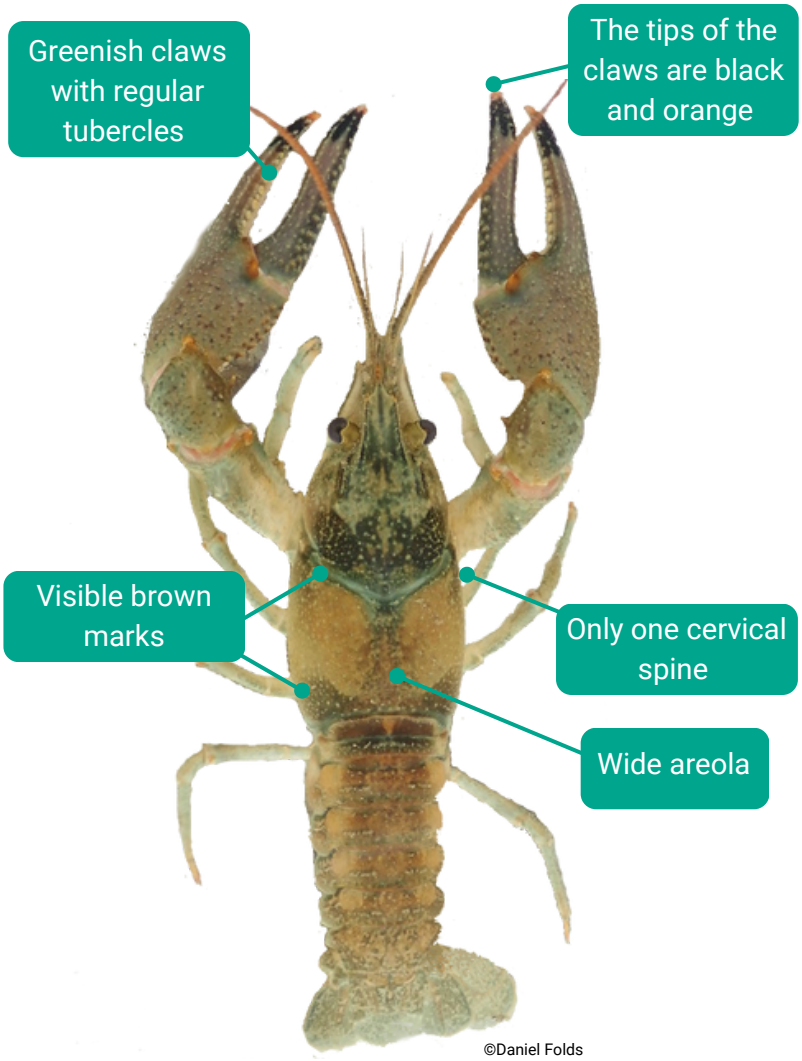
Invasive species native to North America. **Has not been observed in Belgium yet**

Found in **streams**, **ponds** and **swamps**

Small-sized crayfish (under 10 cm)

Variable patterns of colouration but visible brown markings behind and in front of the areola

This species can be confused with other taxonomically related species



Not to be confused with

Faxonius limosus

Exotic

- Group of spines on the cheeks
- Red spots on the top of the abdomen

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RIPARIAS

Spiny-cheek crayfish

Faxonius limosus

Species of Union concern

Invasive species native to eastern North America. **Becoming increasingly common** in the wild in Belgium

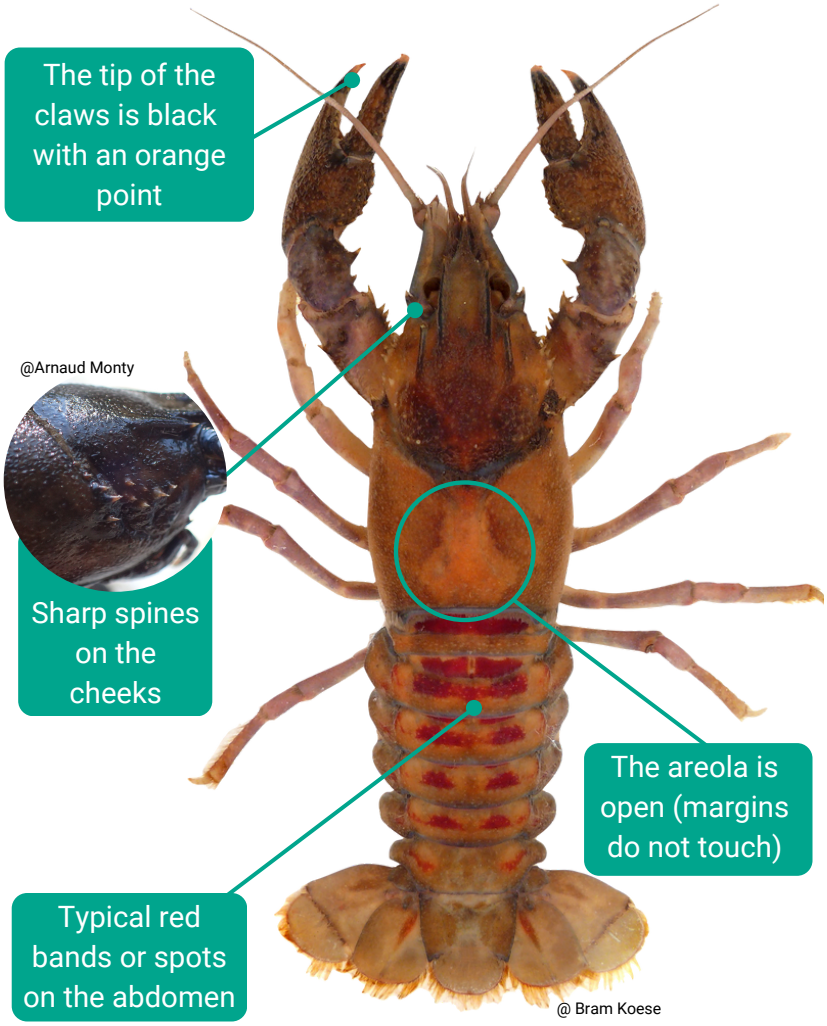
Present in **slow-moving streams** and in **ponds**

Small to medium sized crayfish (8-12cm)

Brown crayfish with small claws and very distinct orange marks on the tip of the claws

Easy to recognise due to the red markings on the abdomen and sharp spines on the cheeks

The tip of the claws is black with an orange point



Sharp spines on the cheeks

The areola is open (margins do not touch)

Typical red bands or spots on the abdomen

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Not to be confused with

Faxonius rusticus

Exotic

- Claws with orange and black bands
- No sharp white spines on either sides of the carapace
- Large rusty spot on each side of the body

RIPARIAS

Rusty crayfish

Faxonius rusticus

Species of Union Concern

©Andy Fyon

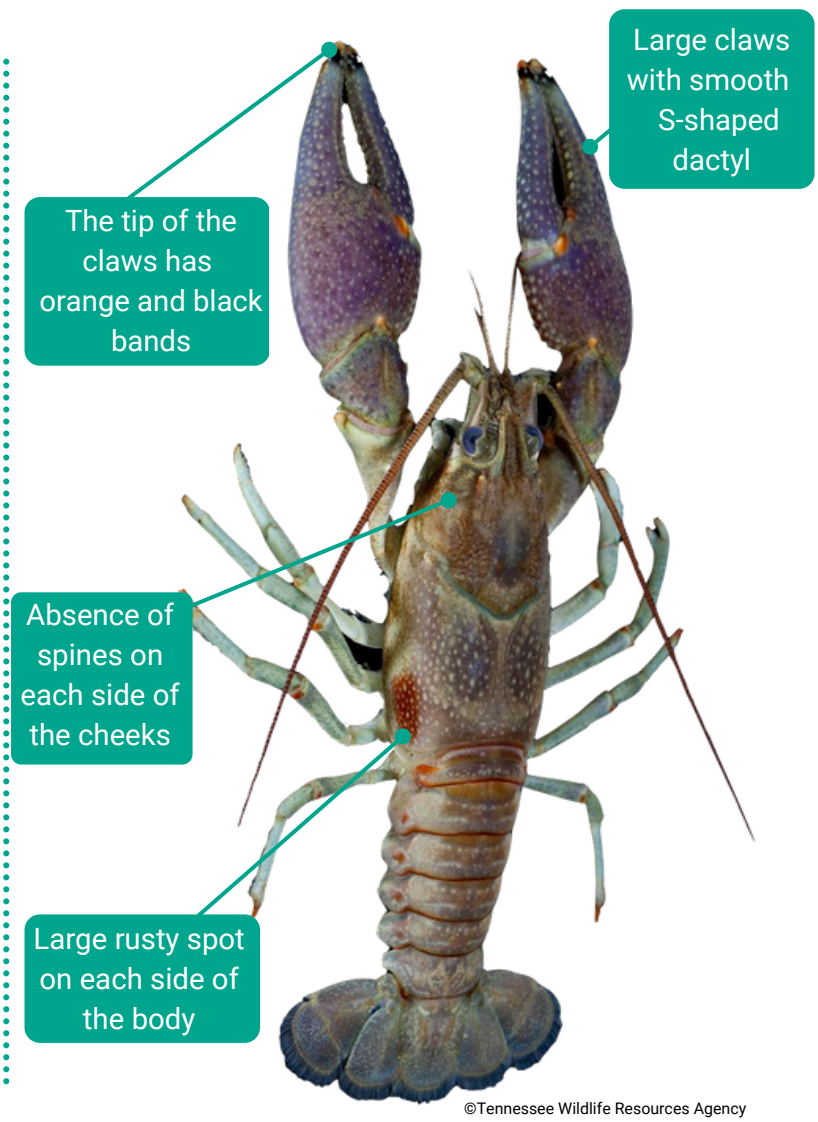
Invasive species native to Eastern North America. **Has not been observed in Belgium yet**

Found in **lakes**, **ponds**, and **streams. Preference** for areas with rocks, logs, or other debris for shelter

Medium sized crayfish (8-12cm)

Brown-green crayfish with large claws and a rust-coloured spot on each side of the body

©Peterwchenes



©Tennessee Wildlife Resources Agency

Not to be confused with

Faxonius limosus

Exotic

- Small claws with orange and black bands
- Group of spines on cheeks
- Red spots on the top of the abdomen

©Dick Belgers

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RIPARIAS

Virile crayfish

Faxonius virilis

Species of Union concern

©Curtis Eckerman

Invasive species native to North America. **Has not been observed in Belgium** yet

Found in **warmwater streams** but can also be found in **ponds**

Medium sized crayfish (10-12cm)

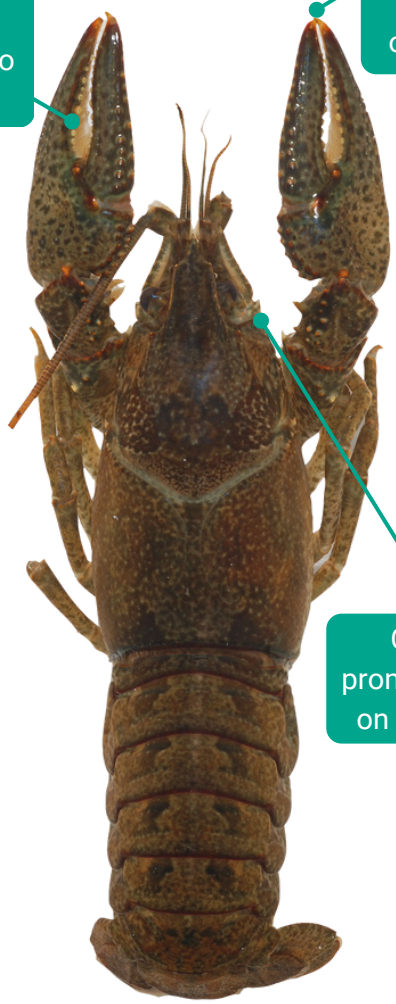
Variable patterns of coloration; from brown to green. Large blue claws covered with pale to yellow tubercles

This species can be confused with other taxonomically related species

Large grey or blue claws with multiple white to yellow bumps

The tips of the claws have orange bands

Only one prominent spine on the cheeks



©Smithsonian Environmental Research Center

Not to be confused with

Faxonius limosus

Exotic

- Small claws with orange and black bands
- Group of spines on cheeks
- Red spots on the top of the abdomen

©Dick Belgers

If you spot that species, record your observation on

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Signal crayfish

Pacifastacus leniusculus

Species of Union concern

©Holger.Ellgaard

Invasive species native to Western North America. **Widespread** in the wild in Southern Belgium

Found in **running waters** but also in **ponds**

Large sized (12-16 cm). Can reach 22 cm

Reddish-brown crayfish. Robust claws with a turquoise patch on the junction of the fingers

©Lucas Vogel

The clear spot on the claw is obvious to observe from the river bank. The underside of the claws is orange-red

©Xavier Vermeersch

If you spot that species, record your observation on

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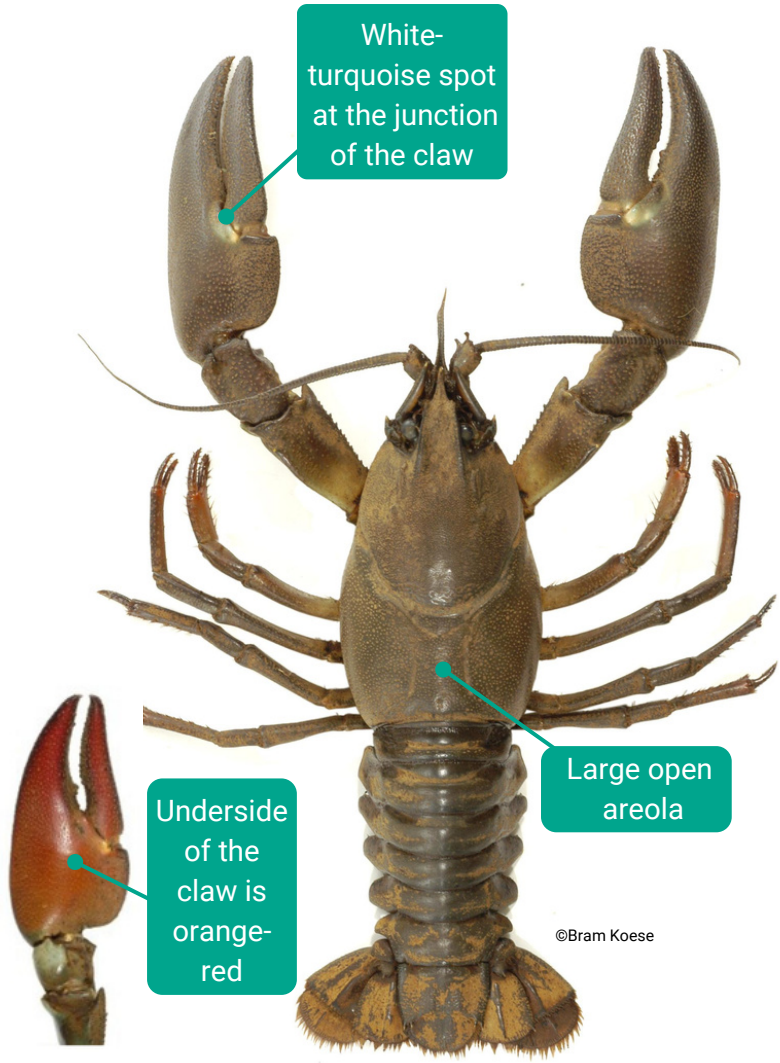


©Bram Koese

Not to be confused with

Astacus astacus
Native

- Red spot behind claw
- Jagged rostrum

©Anna N Chapman

Astacus leptodactylus
Exotic

- Claw with elongated fingers and narrow edge

©Xavier Vermeersch

RIPARIAS

White river crayfish

Procambarus acutus

LIFE RIPARIAS alert list species

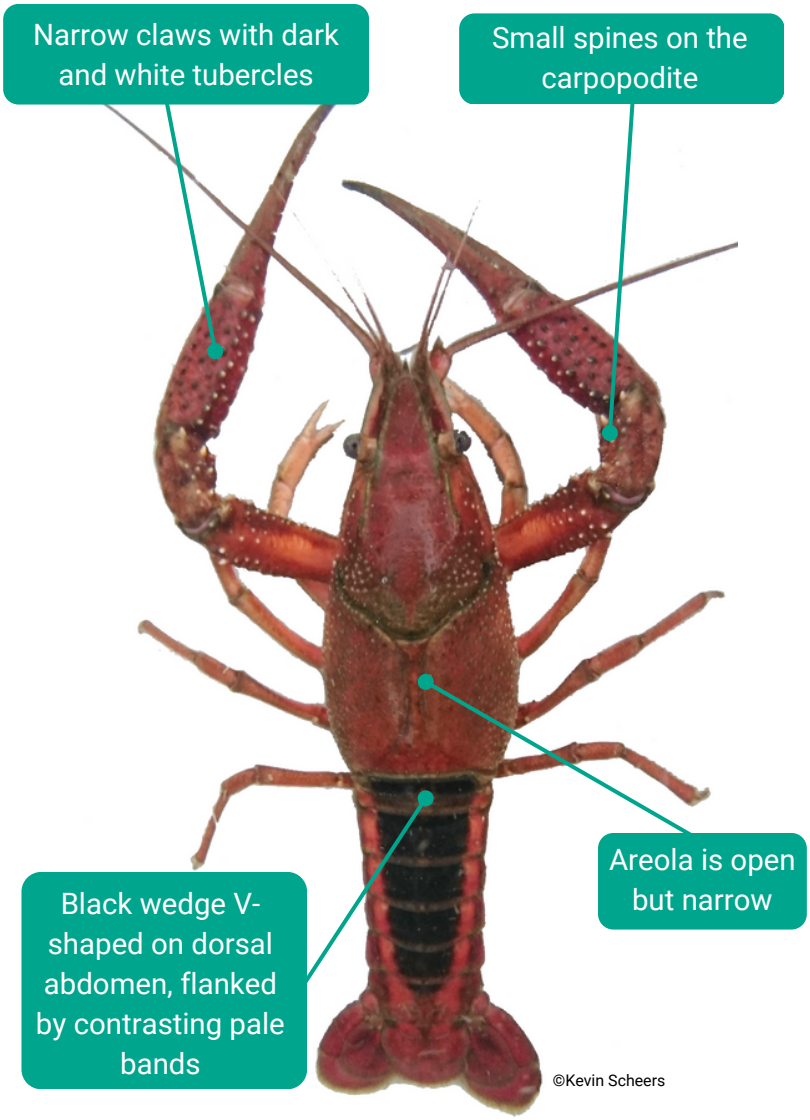
Invasive species native to Eastern North America. **Only a few populations have been recorded** in Belgium

Found in **shallow flowing water, swamps** and **ponds**

Medium sized crayfish (6-12 cm)

Reddish crayfish with contrasting black wedge on dorsal abdomen. Claws are slender and covered with both dark and white tubercles

Body color is highly variable. In their native range, young individuals' colour may range from pale brown to red. In Europe, all individuals are red



Not to be confused with

Procambarus clarkii

Exotic

- Red tubercles on claws
- Closed areola
- Black wedge on dorsal abdomen, poorly delimited

If you spot that species, record your observation on

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RIPARIAS

Red swamp crayfish

Procambarus clarkii

Species of Union Concern

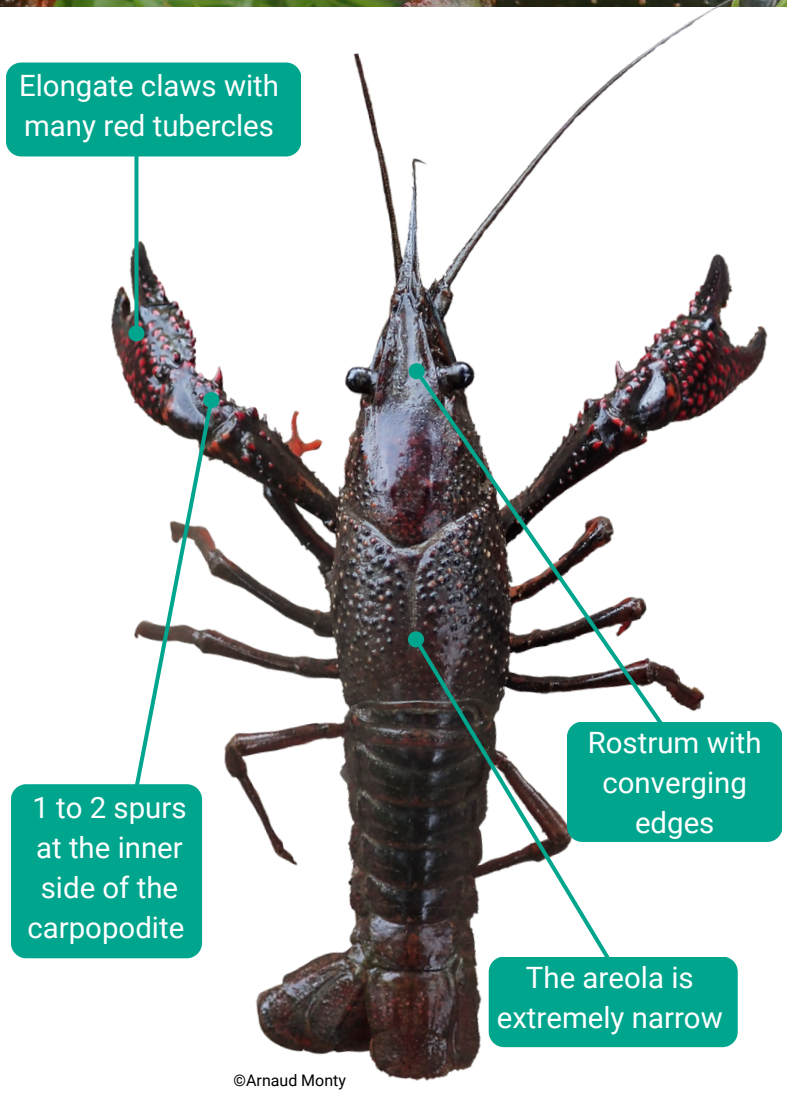
Invasive species native to America. **Becoming more common** in the wild in Belgium

Found in **fresh**, **stagnant** or **slow-moving** waters

Medium sized crayfish (10-12cm). Can reach 15 cm

Dark-red crayfish. Juveniles are greenish and gray. There is, however, a wide variety of colour morphs (white, orange or blue)

Variability in colouration.
Do not rely on colour alone for identification



Not to be confused with

Procambarus acutus
Exotic

- Open areola and rostrum
- Black wedge V-shaped on dorsal abdomen

If you spot that species, record your observation on

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Marbled crayfish

Procambarus virginalis

Species of Union concern

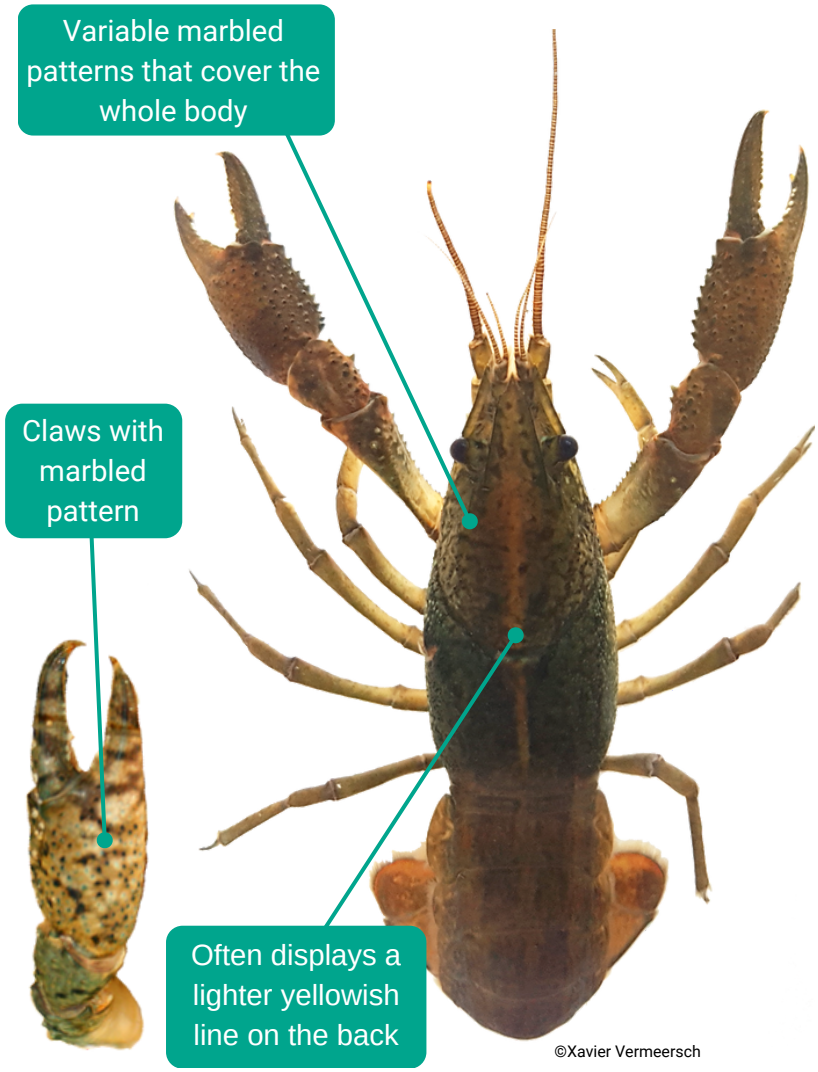
Invasive species resulting from a natural mutation in an individual belonging to the species *Procambarus fallax*.
Only **a few populations have been recorded** in Belgium

Found in **rivers, lakes, swamps and ponds**

Small to medium sized crayfish (6-10cm). Rarely longer than 12cm

Greenish, beige or brownish crayfish with a marbled pattern on the whole body, including claws. Relatively small claws.

All marbled crayfish are female and reproduce asexually. The marbled pattern covers the whole body, but is most visible on the lighter body parts



Not to be confused with

Procambarus acutus
Exotic
Orange-red crayfish with dark tubercles on claws

Procambarus clarkii
Exotic
Crayfish with red tubercles on claws

If you spot that species, record your observation on

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You will contribute to the protection of our ecosystems against invasive alien species

RIPARIAS

PREVENTION

Prevention is the most effective and economical approach to limit the spread of invasive alien species, especially the most challenging ones to control such as crayfish. Preventing the introduction of non-native species into the wild is therefore a priority. When introductions have however already taken place, some preventive measures can still be implemented to stop the spread of populations.

Banning the use of non-native crayfish species

Most non-native crayfish species were intentionally introduced to European countries for human consumption. Those species were therefore brought to fishing ponds or fish farms, and eventually spread from there. Another documented pathway of introduction is linked to aquarium keeping, with some crayfish species being acquired for aquariums, and sometimes released into the environment. In other words, humans play a major role in the invasion process of these extremely damaging and difficult species to control.

Nowadays, non-native crayfish species are still being traded or transported from site to site by individuals unaware of the impacts of these species. Fortunately, some species are subject to a ban on trade and transport in the territory. These are the so-called "species of Union concern", targeted by the European regulation n°1143/2014. If the sale or transport of these species is observed, the competent authorities* must be notified.

It is not easy to anticipate the invasiveness of a species but given the number of species considered as a major threat to biodiversity and ecosystems, the trade and the transport of living non-native crayfish should be more closely regulated.

Raising awareness of good practices

While the phenomenon of biological invasions has been known for decades, there is still a lack of understanding of the problem among many field managers. Awareness raising and training on good practices to effectively deal with the problem is therefore necessary. Indeed, everyone can act, at their own level, against the expansion of invasive alien crayfish on the territory. It is crucial to avoid illegal release of specimens into the wild.

*In Belgium, the competent authorities depend on the regions. The Département de la Nature et des Forêts (DNF) is the authority to refer to for the Walloon Region; Brussels Environment (BE) for the Brussels-Capital Region and Agentschap Natuur & Bos (ANB) for the Flemish Region

Aquarium enthusiasts should be informed about the risk engendered by the introduction of crayfish into the wild. Anglers are also among the actors to be prioritised for awareness-raising. Some might indeed plan to introduce non-native crayfish for some added interests like catching them from their fishing ponds for leisure or using them as baits for fishing. This poses, however, the significant risk to spread the species in the natural environment. When catching crayfish while fishing, caught individuals must not be transported alive.

More generally, providing information on populations observed in the field is a practice to be promoted. It is through good surveillance of the territory that field managers can intervene early in the management of a population. The earlier the intervention, the greater the chances of success: this is the principle of "early warning and rapid response". There are user-friendly websites and smartphone applications such as iNaturalist, Observations.be, etc. that make it quick and fun to inform about the occurrence of a species. Ideally, the geographical location and a photograph of the species should be provided when reporting an observation. Data generated should be open, and therefore, accessible to all.

Owners of invaded water bodies can contact the competent authorities to help them undertake management actions. Allowing access to their property as part of the management of invasive alien crayfish enables effective intervention on a catchment scale. This minimises the risk that the infested area acts as a potential hotspot from which species could spread and (re)invade neighbouring sites.

Preventing the propagation of the crayfish plague

The crayfish plague is a disease caused by the fungus-like organism *Aphanomyces astaci*. This disease is extremely damaging to European crayfish, particularly to the only native crayfish in Belgium, now locally threatened with extinction. While this disease is decimating native crayfish populations, it is much better tolerated by crayfish of American origin who have co-evolved with it: living individuals carrying the disease are not rare in invasive populations.

The disease can be carried by American crayfish as they move or by other animals. But it is human activities that present the greatest risk of dispersal from site to site: in addition to moving infected crayfish (e.g., through fishing), humans can inadvertently carry the pathogen on clothing, equipment, etc.

Biosecurity measures should therefore be put in place before any movement to a site and from a site invaded by alien crayfish: systematic disinfection of all equipment with a disinfectant with fungicidal action, followed by a complete drying of all equipment.

It may therefore be useful to have several sets of equipment (boots, waders, gloves, buckets, etc.) if several sites are to be surveyed in a short amount of time. Potentially contaminated items should be kept separate from other equipment.

Preventing spread from known populations

In some invaded sites, it may be decided not to intervene to reduce the crayfish population. Reasons for this may include lack of resources, difficulties of access, low biological interest of the site or its geographical isolation from other comparable sites. Even if there are no planned management actions (at least in the short term), containment measures are to be considered. Thus, it may be advisable to set up physical barriers to prevent the dispersion of individuals.

When management actions are considered, it is also important to avoid the dispersal of individuals to other sites. This is particularly true if the environment is disturbed by the management measures in place, which may increase the likelihood of individuals moving to find new favourable sites.

Physical barriers are relatively easy to put in place in terrestrial environments: the principle is to install a tarpaulin made of a strong, flexible, water-resistant material or a wire mesh barrier, partly buried. If implemented for large areas, dikes, parallel to the riverbank, with a slope greater than 10° may encourage individuals to return to the aquatic environment rather than disperse. In rivers, the creation of small specific dams, with a central spillway and walls, preventing crayfish to climb, have shown real effectiveness against upstream propagation, while allowing the passage of fish. In ponds, outlets can be screened, and water inlets raised (e.g., by a concrete pipe), but the possibilities depend on the site specificities.

CONTROL AND ERADICATION

General principles

While preventive measures are important, they are not sufficient to reduce the various impacts of invasive alien crayfish. In the following sections, different methods are explained to control the proliferation of species targeted by the LIFE RIPARIAS project. These methods are to be considered at the scale of an invaded site, and a distinction is made between local eradication (total and permanent elimination of the species from the site) and control (significant reduction, in the medium term, of the site population).

Local eradication is of course preferable to control but is not always achievable. Indeed, crayfish are among the most difficult invasive alien species to eradicate. Eradication will therefore be an objective to be kept for early invasion scenarios, small water bodies or sites considered as high priority (e.g., due to their conservation value or geographical location). The characteristics of the site will also be important elements to consider.
Control is usually considered for more heavily invaded areas. It allows the (re)development of a diversity of species, as well as a reduction of direct and indirect impacts of crayfish.

Before implementing management actions on a given site, whether aiming at eradicating or controlling, it is recommended to follow some general principles:

- **Integrating efforts into a general strategy**

The fight against IAS requires significant financial and human investment. It is therefore very likely that not all species can be managed in all invaded sites on a catchment, provincial, regional or national scale. Priorities for action should therefore be defined depending on the general strategy adopted for each species at national, regional and interregional levels (see text box p.32), the spatial positioning of the site and the chances of success.

Choosing to conduct management actions in a particular site must be done in accordance with the priorities for action at the regional, interregional and national levels. Otherwise, the resources invested may not have the desired effect. For example, managing a crayfish population in one pond when no one is eliminating populations in another nearby pond is likely to fail because of individuals' movement.

In general, priority should be given to species that are still not widespread and that can still be eradicated on a regional, interregional or national scale.

And for a given species, priority should be given to sites:

- of particular ecological interest and/or protection status
- where populations are likely to disperse massively
- which are not expected to be re-invaded quickly
- where local eradication, or at least a good level of control, is technically feasible
- with good ecological restoration potential
- which provide important ecosystem services

Management actions at site level must be conducted in accordance with the regional, interregional or national objectives

Management strategies

Invasion situations, on a national or regional scale, vary greatly between the different alien crayfish species. Therefore, objectives will differ from one species to another, as some species are too widespread to be eradicated from the territory. The national management strategies can be broken down as follow:

- **Total eradication from the territory**: all populations are known and eradicated, so that the species is no longer present in the territory. This strategy may seem ideal but can only be considered at the beginning of an invasion. It requires a good knowledge of the invaded sites.

- **Containment**: one or more areas are too heavily invaded to aim for an eradication of the territory. However, local eradication is still applicable outside these areas. Measures can be taken in heavily invaded areas to control populations and limit the spread of individuals.

- **The maintenance of "pest free areas"**: the species is widespread on the territory, but certain areas are subject to special efforts to prevent the species from settling there or to eradicate them in this area. These areas may be, for example, areas of high conservation value for native species.

- **Mitigation of impacts**: the species is widespread and abundant in the territory, but efforts are maintained in the long term to reduce the populations and thus reduce the various nuisances.

Strategies at interregional level will be developed in the framework of the LIFE RIPARIAS project for the period 2023-2031. The latter will set priorities for the management of several invasive alien species found in the basins of the Dyle, Senne and Marcq rivers, in collaboration with stakeholders.

- **Knowing the species and the invasion situation**

Before any intervention on site, it is necessary to clearly delimit the area invaded by the targeted species, and to identify the extent of the invasion. If there are ditches, pools, or other water bodies around the main site, they should be investigated. This can be done either by trapping or by direct observation, especially at night, when crayfish are active. CPUE (Catch per unit effort, i.e., the number of catches related to the trapping effort) is a standard variable for estimating crayfish density. Its use enables comparisons between sites (if the same traps are used). The inventory is also an opportunity to ensure that there are no other invasive alien crayfish species than the one already documented.
Moreover, it is important to have a good knowledge of the biology of the species to be eradicated or controlled. Invasive alien crayfish form a relatively homogeneous group, due to many morphological, ecological, physiological, and behavioural similarities. It is nevertheless interesting to understand the biology of the species, as the dispersal behaviour, the type of galleries dug or the tolerance to desiccation may vary from one species to another.

- **Planning and documenting the different steps**

A control programme for an invasive alien crayfish cannot be improvised. The first step is to ensure the overall feasibility of the project, by identifying sources of funding, the necessary budgets, and manpower. If the resources are insufficient to ensure the implementation of necessary interventions over time, the chances of success decrease drastically.
Before any field interventions, it is recommended to plan all the steps and to clearly identify actors responsible for the different aspects: supervisor, expert, biosecurity officer, possible subcontractors, etc.
Finally, it is also important to thoroughly document the actions taken, to obtain necessary permits, and to inform the authorities, if necessary.

- **Not delaying the implementation of management actions**

The development of a population can be rapid, and the chances of success decrease with it. Wherever possible, intervention should be taken as early as possible and management actions should not be delayed.

- **Respecting the legal provisions**

The required interventions to conduct a control management strategy may require permission from the competent authorities, specific permits or a derogation. It will therefore be necessary to consult the regulations in force, particularly regarding fishing (gear used, time of year), the transport and elimination of individuals, the possible impact of interventions on protected species, etc. and to initiate any requests to the authorities in time.

- **Adapting actions to site specificities**

The methods presented in this guide are based on scientific literature, technical works, and feedback from field actors. Nevertheless, invasion situations can vary greatly, and each site has its own specificities and constraints. It was not possible to deal with all these particular cases in the guide. It will therefore sometimes be necessary to show adaptability, even creativity, in the practical execution of the work, while keeping in mind the biology of the species being managed.

- **Combining the methods**

The methods presented in this guide can be applied on their own, but it is highly recommended to combine them to increase the chances of success:

- The combination of trapping and predator enhancement provides a satisfactory level of control.
- If eradication is the goal, a prior reduction of populations by trapping or netting will increase the chances of success of pond drawdown.

- **Monitoring the site and its surroundings for several years**

Once the management objective has been achieved, particularly in the case of local eradication, the area should be monitored regularly to ensure that the population does not re-establish if individuals have survived or dispersed from other invaded sites. Monitoring must be conducted for at least 3 years, and trapping implemented if necessary. It is recommended to scout the area around the treated area where the species could establish, to ensure that new outbreaks do not occur. If a new outbreak is detected early, it should be possible to eradicate the population.

Similar « best practices » for all species

In the remainder of this guide, different methods for controlling invasive crayfish populations at the site level are explained. The methods presented are considered "good practice", i.e., they have shown an acceptable level of effectiveness, have a relatively low to moderate impact on ecosystems and are legal and ethically acceptable. The use of biocides, for example, is not considered as such.

Given the similarity between different crayfish species, the "good practices" are valid for all alien invasive crayfish species. Occasionally, species-specific information may be provided if this allows better application of the methods.

To achieve good levels of control or potential eradication, a combination of "good practices" on the long term is often necessary.

Trapping

- This method can be used in most situations
- This method has little impact on the ecosystem
- The method enables the monitoring of the population size (CPUE)

- Risk of bycatch
- Risk to only capture large males
- The method is time consuming
- Method that enables control. Eradication is highly unlikely
- The real effectiveness of the method is difficult to predict

Trapping consists in placing crayfish traps in the water and collecting them at regular intervals, for one or several days. Crayfish that are caught, are killed using ethical methods, avoiding unnecessary suffering. Successful trapping depends on the use of baits, the season, and the weather conditions. Trapping usually takes place in the warmer months, when crayfish are most active and therefore most easily caught. For *Procambarus virilis*, it is recommended to intervene in early autumn, during the breeding season.

This method enables the reduction of crayfish populations, is relatively simple to set up and allow to follow the evolution of population density via the CPUE: if the same traps are used over time and lifted on a regular basis, the average number of captures per trap reflects the evolution of the crayfish density. This method is often used, although its real efficiency is not easy to predict because it is difficult to capture the youngest and least mobile individuals (such as ovigerous females).

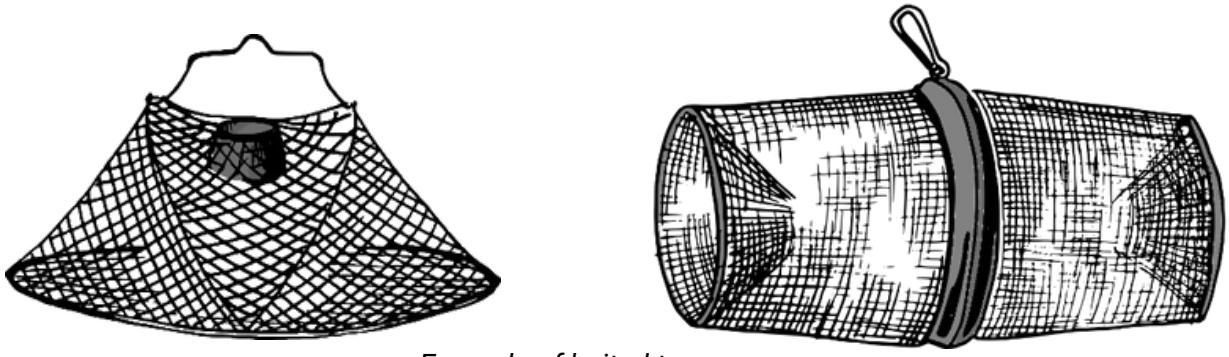
To increase the chances of success, it is necessary to combine different trap designs and to maintain a high capture pressure over several years. This is a time-consuming and labour-intensive method. It is therefore more adequate for small water bodies and when crayfish populations are still limited.

When implementing a trapping operation, it is necessary to have a sufficient number of traps. Traps come in a variety of sizes and shapes (cylindrical, rectangular, conical, etc.) and materials used are usually wire mesh or polyethylene netting (resistant to damages made by the claws). Some models are foldable, others are not.

The model(s) chosen should be effective while limiting the risk of bycatch (fish, amphibians, etc.), particularly in sites where species have a high conservation value. Very regular trap collection will reduce mortality within individuals accidentally captured. Traps should be disinfected and dried if they are moved to another site.

- **Baited traps**

Nets, baited with fish, dog food or other meat products, are widely used in both water bodies and slow-moving rivers. They are placed on the bottom of the water at a depth of at least 30-40 cm and attached to a support on the bank. It is important that they do not catch only large male individuals, otherwise the impact on the population will be limited or non-existent. When such individuals are present in a trap, smaller individuals are reluctant to enter. The use of large traps can mitigate this effect, as can the limitation of openings: traps with large openings (> 4 cm) capture mainly large crayfish, whereas small openings (< 4 cm or even < 2 cm) allow the capture of smaller individuals. In addition, the mesh size of the screen must be fine enough to prevent small individuals from escaping.

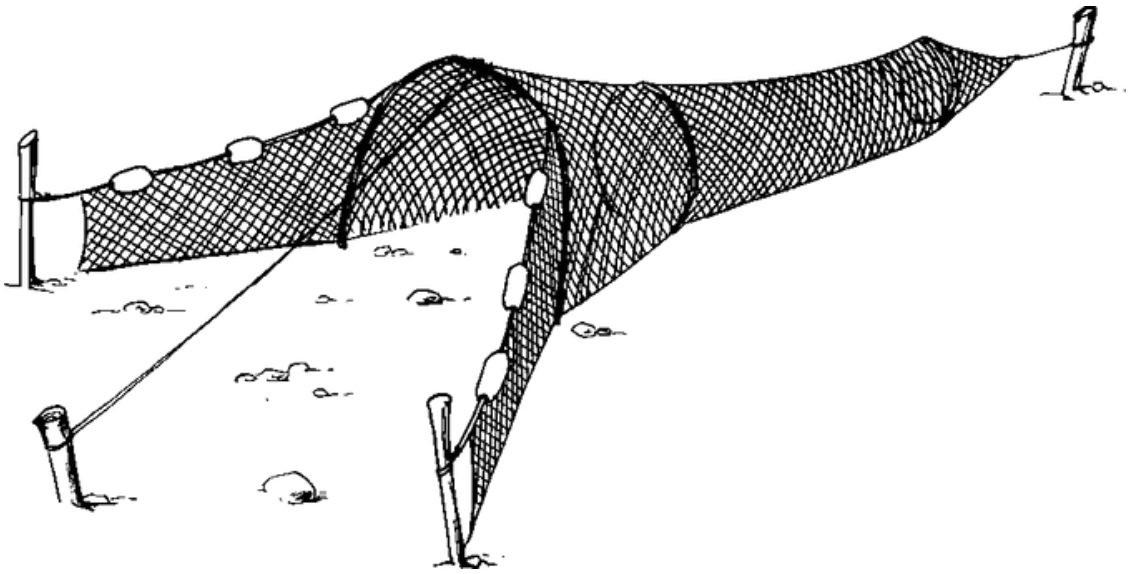


Example of baited traps

- **Fyke net**

A fyke net is a very long, more or less conical net mounted on a rigid frame. It is usually fitted with side wings that "flap" the crayfish towards the trap entrance. The installation of a fyke net is more difficult than that of a net: indeed, the fyke net must be maintained at the bottom by stakes and the aquatic vegetation can hinder the installation. In rivers, the opening is generally turned downstream. The fyke net can be baited or not.

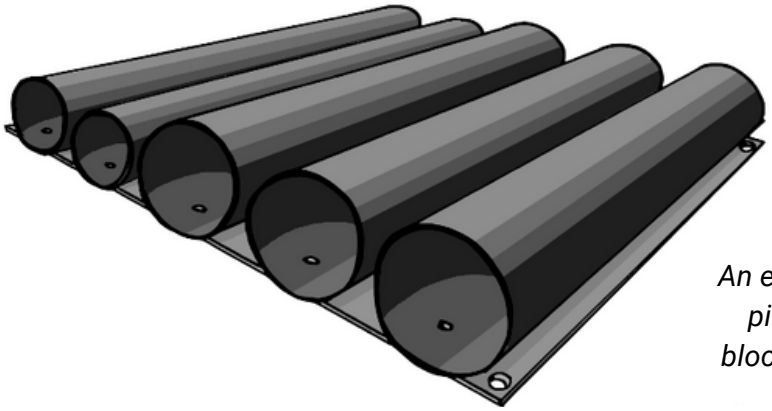
It has the advantage of trapping a large number of individuals and is also not very selective regarding their size. On the other hand, installation is complex and there is a real risk of accidental catches, with significant mortality.



Example of fyke net

- **Unbaited traps**

Unbaited traps are artificial refuges, which mimic the natural refuges of crayfish (galleries, cavities). Several structures exist: PVC tubes attached to a support, bricks with holes, etc. The principle is to leave the traps long enough, usually for a few days, for crayfish to take refuge in the cavities, and then to remove the traps. It is advisable to place the cavities horizontally, on the bottom of the water body, and perpendicular to the current. Stones may be needed to secure the traps. These traps have the advantage not to select individuals based on sex or size. They also do not require any bait, and limit bycatch. In addition, they can be used for long periods of time (April to November). On the other hand, their effectiveness, which has not been proven yet on all species, depends on the environment. The effectiveness has, however, been demonstrated for *Pacifastacus leniusculus* in running waters. Efficacy on *Procambarus clarkii* in ponds is very low. It is likely that effectiveness is reduced by the presence of many natural shelters.



An example of an artificial refuge trap, consisting in pieces of PVC pipe riveted to a metal plate and blocked on one side. It may be necessary to fill this type of trap with a stone, for example

Seine fishing

- Balanced catches of different sizes and sex

- Demanding method and qualified staff required
- Impacts on ecosystem due to operators' movement
- Method that enables control. Eradication is highly unlikely
- The real effectiveness of the method is difficult to predict

The seine is a large net that operators (usually two, walking in the water) drag along the bottom of the water during the day to catch crayfish. In rivers, other operators can turn over stones and disturb upstream vegetation to draw crayfish out of their shelters. Net fishing is most useful in small bodies of shallow water, which can be crossed on foot and where the water is relatively clear.

This method allows the capture of juvenile crayfish and ovigerous females, which is a clear advantage. It can therefore be a complement to trapping. It is also useful for collecting large quantities of crayfish when densities are high and when crayfish are active, in the summer period.

However, this method does not lead to local eradication and is relatively labour-intensive. Operators' movement and turning over obstacles is a non-negligible disturbance for the aquatic environment. The risk of bycatch is high, but operators have the possibility to release individuals of non-target species.

Catching crayfish

It is possible to fish for invasive alien crayfish with gears called "crayfish ring nets". These are circular nets with ledges, attached to strings, which are placed on the bottom of the water body and lifted regularly to capture the crayfish. The nets are baited with pieces of fish or any other baits crayfish find palatable. String catching is another possible technique to capture crayfish. Catching crayfish in public waters requires a permit, and the various regional regulations and opening periods must be respected. In private properties, the owner's authorisation is required. Although catching crayfish is a recreational activity which may present a culinary interest, it only plays a small part in the regulation of invasive alien crayfish. On the contrary, the risk of dispersal increases if individuals are transported alive. It is important to note that the transport of EU listed species is prohibited, with one exception being the transport of individuals to facilities in the context of eradication measures. In addition, it is not recommended to consume crayfish as they can accumulate heavy metals or other toxic substances in their tissues if they live in polluted waters. It is also absolutely forbidden to use any invasive alien crayfish as bait for fishing.

Drainage

- Method that can lead to local eradication
- Actions that can be integrated in the regular management of the water body (reduction of siltation)

- Significant impacts on the ecosystem and aquatic species
- Expensive method
- Success depends on the drainage possibilities of the water body

This method consists in completely draining a water body to make the habitat unfavourable to crayfish and in inducing maximum mortality by additional actions. Prolonged drainage over several years creates conditions that will lead to crayfish death by desiccation or predation. Drainage for 3 years (at least 2 winters) is strongly recommended, as crayfish are resistant to desiccation and frost.

Crayfish must not be able to leave the desiccated area: a physical barrier must surround the site, both on land and in water. In the event of pumping, the water must be filtered (plankton filter with a mesh size of 1 millimetre) before being discharged downstream in order to avoid any dispersion of juveniles. In the days following the drainage, manual harvesting can be implemented to eliminate a large number of individuals and limit the risk of accidental dispersion by predators. Afterwards, spreading slaked lime (calcium hydroxide) in the remaining wet areas and at the entrance to the galleries will eliminate part of the surviving individuals. Ideally, one should take advantage of the draining to clean out the bottom of the pond and/or to embank the shores, thus destroying the remaining galleries, where individuals can still survive. Occasional concreting of risky areas (rockfill where individuals persist) can be considered.

If properly done, this method can enable the local eradication of a crayfish population. This has been shown for several species, including *Procambarus clarkii*, which is known to be difficult to eradicate. It is important to note that simple maintenance dredging does not have the same effect, and that no method can ensure total eradication success.

This method has strong impacts on the aquatic environment, at least in the medium term (a few years). The transfer of individuals of non-target species to other sites is risky, as it could result in the dispersal of juvenile crayfish. The method is costly and burdensome for the users of the water body.

The method is of most interest in drainable water bodies of relatively small size, where emerging populations are likely to colonise other sites rapidly.

Example of pond drawdown. It can be complicated to obtain a complete drainage of a water body, which may hinder the effectiveness of the management measure. To mitigate this, different techniques can be implemented such as liming remaining water puddles or manual removal of crayfish.

Reinforcing predator populations

- Method that can be implemented in many situations
- Limited impact on the ecosystem
- Limited costs
- Method that is easy to combine with other methods

- Difficulty in supplying some predatory species
- Method that enables control. Eradication is highly unlikely
- The real effectiveness of the method is difficult to predict

Eel (*Anguilla anguilla*), burbot (*Lota lota*), perch (*Perca fluviatilis*) and pike (*Esox lucius*) are four native species that regularly consume crayfish if present in the environment. Other exotic carnivorous fish such as pike-perch (*Sander lucioperca*) or wels catfish (*Silurus glanis*) also consume crayfish. Juveniles are also consumed by other species, even omnivorous fish such as carp (*Cyprinus carpio*) or tench (*Tinca tinca*). Increasing the density of predators not only decreases the population size, but also limits the activity (and therefore the nuisance) of crayfish. This is a low-cost and sustainable method. It is recommended to introduce individuals of indigenous species already present in the environment, or to encourage the growth of their populations by adjustments (water purification, spawning grounds, renaturation of banks) or regulations (protection of species, fishing restriction).

The species considered as the most effective one is the eel, especially because eels consume young individuals, can detect crayfish by smell and can enter the galleries. However, the impossibility to manage its reproduction and its critically endangered status are strong constraints for its use. The introduction of eels into an environment must first and foremost be part of a plan to safeguard the species. If strong measures were to be taken in the future to conserve this species and restore its populations, this would probably have a positive impact on the control of alien crayfish populations.

The perch is a common, sometimes abundant, small predator. It can therefore have an impact on the youngest individuals, which is particularly interesting if predator reinforcement is combined with trapping. Pike-perch, although non-native, can have a similar effect. Pike are large consumers of crayfish, but the size of their prey changes with their size. Young pike consume crayfish from the youngest stages, but adult individuals select the largest individuals.

It is not only fish that act as crayfish predators. Various insects (dragonfly larvae, dytids, etc.) feed on the juveniles. Birds and mammals also feed on them. In addition to the occasional introduction of fish, the preservation of aquatic environments allows the development of a rich and diverse predatory fauna, which is better able to prevent or slow down the demographic growth of invasive alien crayfish.


Perch *(Perca fluviatilis)* - © Christa Rohrbach


Pike *(Esox lucius)* - © Gilles San Martin


Burbot *(Lota lota)* - © Achim R. Schloeffel


Eel *(Anguilla anguilla)* - ©Frederic-andre

Ecosystem modifications

- Positive impact on the ecosystem
- Long term approach

- Requires good knowledge of the species being managed
- Method that enables control. Eradication is highly unlikely

One of the reasons why invasive alien crayfish form very large populations so quickly, is the simplification of aquatic ecosystems. Aquatic systems are also becoming more and more artificial. For example, loose, vertical, or steep banks are known to favour the digging of galleries, especially for the Louisiana crayfish. These galleries, necessary for their life cycle, allow them to resist drought or frost and make their management more difficult. In addition, the absence of vegetation on the bank can facilitate the dispersal of individuals and the colonisation of new water bodies. As mentioned above, the decline of natural predators is another element that makes degraded aquatic environments particularly vulnerable to invasion.

It is clear from these various findings that the restoration of natural and diverse aquatic environments is an interesting approach to curbing invasions by alien crayfish in the long term. Measures that limit the digging of galleries, such as the restoration of gently sloping banks with a high degree of vegetation, or the introduction of stony substrates, are concrete elements that can be part of the development plan for a water body.

Natural banks are less likely to be invaded by crayfish species

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Cherax destructor

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2 © Asimakis Patitsas: https://www.inaturalist.org/observations/38419300
3 © Daiju Azuma: https://nas.er.usgs.gov/queries/greatlakes/FactSheet.aspx?Species_ID=3648&Potential=Y&Type=2&HUCNumber=
4 © missganoush: https://www.inaturalist.org/observations/90990008

Faxonius immunis

1 ©Daniel Folds: https://www.inaturalist.org/taxa/776085-Faxonius-immunis/browse_photos (non modifiée)
2 ©Blake A. Mann: https://www.inaturalist.org/taxa/776085-Faxonius-immunis (non modifiée)
3 ©Dick Belgers: https://www.nederlandsesoorten.nl/linnaeus_ng/app/views/species/nsr_taxon.php?id=143775&cat=CTAB_MEDIA#gallery-5
4 © yoandieb: https://www.inaturalist.org/observations/115181224

Faxonius juvenilis

1, 2, 3 ©Daniel Folds: https://www.inaturalist.org/observations/95788141
4 ©Dick Belgers: https://www.nederlandsesoorten.nl/linnaeus_ng/app/views/species/nsr_taxon.php?id=143775&cat=CTAB_MEDIA#gallery-5

Faxonius limosus

1©Tennessee Wildlife Resources Agency: https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=214

Faxonius rusticus

1©Andy Fyon: https://www.inaturalist.org/observations/103247867
2 ©Peterwchenes: https://commons.wikimedia.org/wiki/File:Faxonius_rusticus-male_dorsal.jpg
3 ©Tennessee Wildlife Resources Agency: https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=214
4 ©Dick Belgers: https://www.nederlandsesoorten.nl/linnaeus_ng/app/views/species/nsr_taxon.php?id=143775&cat=CTAB_MEDIA#gallery-5

Faxonius virilis

1 ©Curtis Eckerman: https://inaturalist.ca/observations/27568404
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Pacifastacus leniusculus

1 ©Holger.Ellgaard: https://commons.wikimedia.org/wiki/File:Kr%C3%A4ftor_levande,_2019.jpg
2 ©Lucas Vogel: https://commons.wikimedia.org/wiki/File:%C3%89crevisse_du_Pacifique_(Pacifastacus_leniusculus).jpg
3 ©Bram Koese: https://www.nederlandsesoorten.nl/linnaeus_ng/app/views/species/nsr_taxon.php?id=143791&cat=CTAB_MEDIA#gallery-8
4 ©Anna N Chapman: https://commons.wikimedia.org/wiki/File:European_crayfish_(Astacus_astacus).jpg

Procambarus acutus

1 ©evangrimes: https://www.inaturalist.org/observations/31145960
2 ©Chris Lukhaup: https://mdc.mo.gov/discover-nature/field-guide/white-river-crawfish

Procambarus clarkii

1 ©Don Loarie: https://commons.wikimedia.org/wiki/File:Procambarus_clarkii_-_inat_161296348.jpg

Procambarus virginalis

1 ©Chucholl C. : https://commons.wikimedia.org/wiki/File:Marmorkrebs_Procambarus_fallax_forma_virginalis.JPG

NOTES

LIFE RIPARIAS

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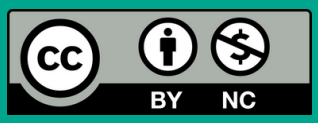

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