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Invasive freshwater crayfish in the Netherlands: a preliminary risk analysis

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Invasive crayfish in the Netherlands: a preliminary risk analysis

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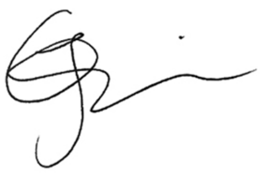

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PREFACE

During the last decade increasing numbers of exotic crayfish are introduced in the Netherlands. Especially since the discovery of the virile crayfish, great concerns about the impact of these exotic crayfish have developed. The Invasive Alien Species Team of the Ministery of Agriculture, Nature and Food Quality (LNV) commissioned Bureau Waardenburg to conduct a risk analysis. The aim of this analysis is to get more insight into the probability of establishment of exotic crayfish species in the Netherlands, any possible ecological, economical and social impacts, and the possibilities of risk management.

This risk analysis was carried out by Bureau Waardenburg:

- ir. D.M. Soes (project leader and report)
- MSc. M. Collier (review)

And Stichting European Invertebrate Survey - Nederland:

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Summary

A total of ten crayfish species have been observed in the Netherlands: one native species (the Noble crayfish *Astacus astacus*) and nine invasive species. Six invasive species are established (narrow-clawed crayfish *Astacus leptodactylus,* signal crayfish *Pacifastacus leniusculus*, spiny-cheek crayfish *Orconectes limosus,* virile crayfish *Orconectes* , white river crayfish *Procambarus acutus* and red swamp crayfish *Procambarus clarkii*), the status of one invasive species (marbled crayfish *Procambarus sp.*) is currently unclear. Two invasive species (the stone crayfish *Austropotamobius torrentium* and the redclaw *Cherax quadricarinatus*) have been recorded only once. The remarkable expansion of some of these invasive crayfish has raised questions about the possible impacts. In this study, the probability of entry, further establishment, geographic occurence and spread is assessed. Additionally, an outline is given of the possible impact of the species. Besides the species already observed in the Netherlands, four other species are evaluated.

Crayfish are imported either by the aquarium trade or the consumption trade. The consumption trade led to many of the early introductions (e.g. narrow clawed crayfish, red swamp crayfish, spiny cheeked crayfish). Nowadays, this trade has declined considerably due to the rise of imported, prepared crayfish from China. There remains however, a marginal international trade in living crayfish for consumption. In addition to the international trade, an opportunistic, seasonal trade in local species by some fishermen exists. The trade in consumption species in Europe is nearly limited to the species that are already established. Therefore, the probability of the introduction of new species through the consumption trade is low.

The aquarium trade has increased significantly and the number of trades species is high and variable. Most of the traded (tropical) specimes stand no chance surviving in the wild but some cold water specimens (for ponds) are also traded. The trade in crayfish for aquaria and ponds must be considered as the prime source of potential new invaders. Many of the established species occupy a larger niche than observed in their natural range. Therefore, the chance of succesful establishment can be easily underestimated. Overwhelming evidence of negative economic and/or ecologic impact has been observed abroad in five of the evaluated species (red swamp crayfish, white river crayfish, signal crayfish, virile crayfish and rusty crayfish). Also in the Netherlands, crayfish are accused of causing damage but so far, very little evidence of the negative impact of crayfish is available. Possibly due to a lack of data. Further academic research is strongly recommended to assess the possible impacts. Additionally, agreements with the aquarium trade and the consumption trade might significantly reduce the probability of establishment of new 'dangerous' crayfish species.

SAMENVATTING

Tien soorten kreeften zijn waargenomen in Nederland: één inheemse soort en negen invasieve soorten. Zes soorten hebben zich gevestigd (Turkse rivierkreeft *Astacus leptodactylus,* Californische rivierkreeft *Pacifastacus leniusculus*, gevlekte Amerikaanse rivierkreeft *Orconectes limosus,* geknobbelde Amerikaanse rivierkreeft *Orconectes* , gestreepte Amerikaanse rivierkreeft *Procambarus acutus* en de rode Amerikaanse rivierkreeft *Procambarus clarkii*), de status van één soort (de marmerkreeft *Procambarus* sp.) is onzeker en twee soorten (de steenkreeft *Austropotamobius torrentium* en de Australische roodklauwkreeft *Cherax quadricarinatus*) zijn slechts éénmaal waargenomen. Door de opmerkelijke opmars van een aantal soorten zijn er zorgen gerezen over de mogelijke gevolgen van de kreeften voor flora, fauna en infrastructuur. In deze studie is de waarschijnlijkheid van binnenkomst, vestiging en verspreiding van de verschillende soorten onderzocht. Daarbij is een inschatting gemaakt van de impact. Behalve de soorten die al in Nederland zijn aangetroffen, worden vier andere soorten besproken. De import van kreeften vindt plaats door de handel voor aquaria enerzijds en consumptie anderzijds. Aanvankelijk zijn veel soorten ingevoerd door de consumptiehandel (o.a. de Turkse rivierkreeft, rode Amerikaane rivierkreeft en gevlekte Amerikaanse rivierkreeft). Tegenwoordig is de handel in levende rivierkreeften voor consumptie sterk teruggelopen door de opkomst van de handel in gepelde rivierkreeften uit China. Desondanks is er nog steeds een marginale handel in levende kreeften voor consumptie. Naast de internationale consumptiehandel, is er een opportunistische, seizoensgebonden handel in kreeften voor consumptie door lokale vissers in opkomst. De huidige handel in consumptiesoorten is vrijwel beperkt tot de kreeften die zich al gevestigd hebben. Nieuwe soorten zijn via de consumptiehandel nauwelijks te verwachten.

De aquariumhandel is sterk toegenomen en het aantal soorten dat in de handel circuleert is hoog en variabel. De meeste (tropische) soorten maken geen kans om in het wild te overleven, maar ook koudwaterminnende soorten (voor de vijver) worden verhandeld. De handel in kreeften voor aquaria en vijvers moet beschouwd worden als de belangrijkste bron voor nieuwe soorten in Nederland.

Veel gevestigde soorten bezetten een grotere niche dan in hun gebied van herkomst. De kans op vestiging kan hierdoor makkelijk onderschat worden. Van tenminste vijf van de geëvalueerde soorten (rode Amerikaanse rivierkreeft, gestreepte Amerikaanse rivierkreeft, Californische rivierkreeft, geknobbelde Amerikaanse rivierkreeft en *Orconectes rusticus*) is in buitenlandse studies aanzienlijke economische of ecologische schade aangetoont. Ook uit Nederland wordt schade door kreeften gemeld, maar wetenschappelijke onderbouwing ontbreekt. Verder onderzoek hiernaar wordt sterk aanbevolen. Convenanten met de aquariumhandel en de consumptiehandel zouden de kans op vestiging van 'gevaarlijke' nieuwe soorten kunnen reduceren.

1. Introduction

In the last decade, the number of crayfish species in the Netherlands doubled due to the release of several American species. Some of the new invaders seem well adapted to their new environment, showing a rapid population increase. A number of independent releases resulted in a remarkable pattern of crayfish hotspots (fig. 1). Nowadays, invasive aquatic invertebrates are a far from unique phenomenon. Nevertheless, crayfish receive unequal attention due to a combination of factors:

- They are large. Everyone can see a crayfish;
- The tendency of several species to walk on land. A crayfish in the garden is not always appreciated;
- Alarming stories from abroad: they could have a significant impact on freshwater ecological systems and infrastructure.

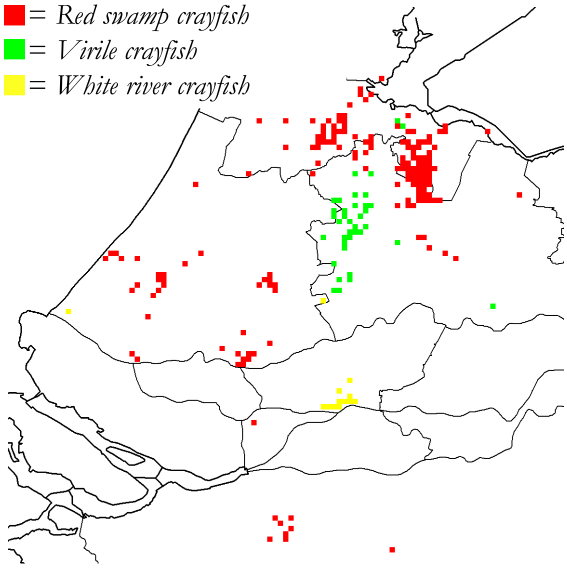


Fig. 1. Records from 2000 - 2009 at a 1 km level. In case records overlap, the most frequent recorded specimen is presented. The widely distributed spiny cheeked crayfish is not considered on the map.

A risk analysis was carried out to acquire information about any possible ecological, economical or social impact of the crayfish and to get insight in the probability of future establishment. The outcome of this analysis is presented in this report.

Goals and terms of reference

The purpose of this report is to accomplish a thorough risk analysis of the chances of established population of exotic crayfish and the probability of the spread of these exotic crayfishes across the Netherlands. Furthermore, the possible impacts on ecological, economical and social aspects are described.

Methods

In order to fulfil in the above-mentioned parts an extensive literature search was carried out. The search was not limited to the ISI Web of Science, Scopus, standard works, but also covered non-peer reviewed published material, newspaper fragments collected by the National Museum of National History in Leiden and the archive of the foundation European Invertebrate Survey - the Netherlands (EIS). A survey among voluntary crayfish researchers (120 email addresses) to obtain aditional information on crayfish introductions (see appendix 1, p 64). Additionally, the same call was posted on the webforum of www.garnalenkreeften.nl. Several wholesalers, both from the consumption industry as the aquarium trade, were approached to acquire information about the trade in living crayfish. Adressess of wholesalers were obtained from the survey, the newspaper archive as well as by asking within the wholesaler community. Only a selection of the largest wholesalers were approached, which was considered sufficient to give an outline of the major trades. The EIS database, containing about 3500 crayfish records (January 2010) collected by volunteers, was used to produce distribution maps of the established species as well as some graphs to illustrate the life cycle of some species (p. 10-11).

2 Overview of relevant crayfish species

Various species have been introduced in the Netherlands. Many more species are traded commercially in the Netherlands, but have not yet be found in the wild. Some of the traded specimens have a high potential to become established in the Netherlands, while other species have absolutely no chance of surviving. This chapter gives a brief motivation of the selected species for the risk analysis.

2.1 One indigenous species

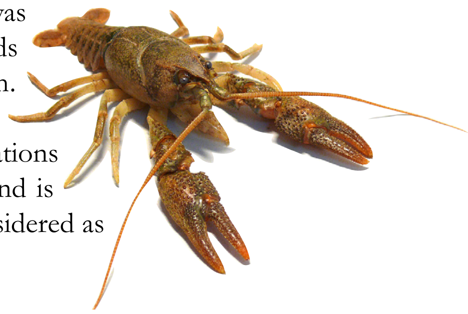
Of the five European species of crayfish, only the noble crayfish (*Astacus astacus*) is considered indigenous for the Netherlands (Souty-Grosset et al. 2006, www.faunaeur.org). This once common species of the southern and eastern parts of the Netherlands (Holthuis 1950) reached the edge of extinction in the last decade (Niewold 2002, 2003). Although habitat degradation has clearly played a role in this process it is most likely that the crayfish plague (*Aphanomyces astaci*) should be held especially responsible for the severe decline (Souty-Grosset et al., 2006). Due to the constant threat of the crayfish plague, the species is critically endangered in the Netherlands as it is occurring at one location only. As it is a native species, the noble crayfish will only be discussed in relation to the impact of exotic crayfish.

2.2 Exotic species

Nine exotic species have been observed in the wild (see table 1). It must be emphasized that many of those species became established at localities where the native species never occured. In other words, crayfish are a new phenomenon in many parts of the country. Already in 1890 the first exotic crayfish of North American origin was introduced in Europe. These introductions were purely for culinary reasons and were tried with the spiny-cheek crayfish (*Orconectes limosus*). Both in France and Germany the stockings gave rise to considerable populations that founded the basis for the colonization of large parts of Europe. In the Netherlands the spiny-cheek crayfish was first collected in 1968 and is nowadays the most abundant and widespread species of crayfish (Geelen 1978, Timmermans et al. 2003).
After the noble crayfish became protected with legislation in 1973 there have been several introductions of the Eastern European narrow-clawed crayfish (*Astacus leptodactylus*) within the Netherlands. This species has only established a few local populations (Adema 1982, Timmermans et al. 2003). Much more successful has been the red swamp crayfish (*Procambarus clarkii*). It has been recorded for the first time in 1985 and has currently established significant populations in the western parts of the Netherlands (Koese 2009).

In 2004/2005 four species were added to the list of exotic species occurring in the Netherlands (Soes & Eekelen 2006). The signal crayfish (*Pacifastacus lenisculus*) entered the Netherlands in the east from a German population. A second population has been discovered in the south of the Netherlands (Wielink & Spijkers 2008). The other three species are introduced as a result of the aquarium trade. The Netherlands was the first introduction site in Europe of the white river crayfish (*Procambarus acutus*) and the virile crayfish (*Orconectes*). They turned out to be very successful, invasive species. The marbled crayfish (*Procambarus* sp.) is only known from one site (city of Dordrecht) (Lipmann 2007) and its current status is unclear.

A single specimen of the stone crayfish (*Austropotamobius torrentium*) was collected on 10 November 1956 in a fish trap in the canal that surrounds the polder Haarlemmermeer between Haarlem and Amsterdam. Colonization from populations in other European countries is unlikely as this crayfish plague sensitive species has become rare with no populations near the Netherlands. The species is listed in the Habitat Directive and is highly unlikely to turn up in the trade. This observation should be considered as an unexplained, artificial rarity (Fransen & Holthuis 2006).



2.3 Elsewhere in Europe

In western Germany near Karlsruhe a population of the exotic calico crayfish (*Orconectes immunis*) exists in the River Rhine Basin. The first specimen of this population, which is probably also from aquarium trade origin, has been recorded in 1997. The population is expanding and it might be expected that this species will extend its range into the Netherlands (Gelmar et al. 2006).

In eastern France, a population of *Orconectes juvenilis* is present in a single river. This population was first

Table 1. List of evaluated species in the assessment

Native species						
English	**Dutch**	**Latin**	**1st record**	**Origin**	**Source**	**Evaluated**
Noble crayfish	Europese rivierkreeft	*Astacus astacus*	native	Europe	Geelen 1978	N
Invasive species already recorded in the Netherlands						
English	**Dutch**	**Latin**	**1st record**	**Origin**	**Source**	**Evaluated**
Stone crayfish	Steenkreeft	*Austropotamobius torrentium*	1956	Central Europe & Balkan	Fransen & Holthuis 2006	N
Narrow-clawed crayfish	Turkse rivierkreeft	*Astacus leptodactylus*	1977	Eastern Europe	Adema 1982	Y
Signal crayfish	Californische rivierkreeft	*Pacifastacus leniusculus*	2004	North America	Knol 2005	Y
Spiny-cheek crayfish	Gevlekte Am. rivierkreeft	*Orconectes limosus*	1968	North America	Geelen 1978	Y
Virile ceayfish	Geknobbelde Am. rivierkreeft	*Orconectes*	2004	North America	Soes & Eekelen 2006	Y
Red swamp crayfish	Rode Am. rivierkreeft	*Procambarus clarkii*	1985	North America	Adema 1989	Y
White river crayfish	Gestreepte Am. rivierkreeft	*Procambarus acutus*	2005	North America	Soes & Eekelen 2006	Y
Marbled crayfish	Marmerkreeft	*Procambarus sp.*	2004	unknown	Soes & Eekelen 2006	Y
Redclaw	Australische roodklauwkreeft	*Cherax quadricarinatus*	2007	Australia	D. Holdich (pers.comm.)	Y
Potential species: abroad						
English	**Dutch**	**Latin**	**1st record**	**Origin**	**Source**	**Evaluated**
Calico crayfish	-	*Orconectes immunis*	Not recorded	North America	Gelmar et al. 2006	Y
-	-	*Orconectes juvenilis*	Not recorded	North America	Chucholl & Daudey 2008	Y
Rusty crayfish	-	*Orconectes rusticus*	Not recorded	North America	Jansen et al. 2009	Y
Yabby	-	*Cherax destructor*	Not recorded	Australia	Souty-Grosset et al. 2006	Y
Potential species: trade						
English	**Dutch**	**Latin**	**First record**	**origin**	**source**	**Evaluated**
Everglades crayfish	Floridakreeft	*Procambarus alleni*	Not recorded	North America	Werner 2003	Y
-	Montezuma	*Cambarellus*	Not recorded	Mexico	Werner 2003	N

reported as rusty crayfish (*Orconectes rusticus*). Actually these two species are closely related and in most literature are not recognized as two species (Chucholl & Daudey 2008). The rusty crayfish is one of the most invasive crayfish species in North America and is actually replacing the virile crayfish in its original range (Jansen et al. 2009). Based on distribution, climatologic factors will probably not hold back these species when they enter Dutch waters and they should therefore clearly be considered as potential invasive species in the Netherlands.

Populations of the yabby (*Cherax destructor*) are present in Spain and Italy. This species is adapted to higher temperatures and stops growing below 15°C. But as it can survive temperatures as low as 1°C it cannot be excluded that this species can also establish itself in the Netherlands (Scalici et al. 2009, Souty-Grosset et al. 2006). Another species from Australia is the redclaw (*Cherax quadricarinatus*). This species has been found once in the Netherlands and it could be confirmed that it had not established itself (Soes 2008). There is a report about a population in northern Germany, but this has never been confirmed. As there are concerns about this species in Great Britain this species should be considered as potentially invasive (D. Holdich, pers. comm.).

Table 2. Synopsis of crayfish taxonomy and worldwide distribution (numbers in parantheses indicate the number of species currently recognised for each family and genus (after Taylor 2002). Genera considered in this assessment are in red. Genera in bold occur at the same latitude (+/- 500 km.) as the Netherlands.

Family Astacidae (8) Europe, West Asia and North America
Genus ***Astacus*** (3) Europe, West Asia
Genus ***Austrapotamobius*** (2) Europe
Genus ***Pacifastacus*** (3) North America
Family Cambaridae (403) North America and East Asia
Genus *Cambarellus* (19) North America
Genus *Barbicambarus* (1) North America
Genus ***Cambarus*** (87) North America
Genus *Distocambarus* (5) North America
Genus *Fallicambarus* (16) North America
Genus *Faxonella* (4) North America
Genus *Hobbseus* (7) North America
Genus ***Orconectes*** (88) North America
Genus ***Procambarus*** (168) North America
Genus *Troglocambarus* (1) North America
Genus *Cambaroides* (7) China and Japan
Family Parastacidae (154) Australia, Madagascar and South America
Genus *Astacoides* (6) Madagascar
Genus *Astacopsis* (3) Tasmania
Genus ***Cherax*** (43) Australia, Tasmania, Papua New Guinea
Genus *Engaeus* (35) Australia, Tasmania
Genus *Engaewa* (3) Australia
Genus *Euastacus* (42) Australia
Genus *Geocharax* (2) Australia, Tasmania
Genus *Gramastacus* (1) Australia
Genus ***Paranephrops*** (2) New Zealand
Genus *Parastacoides* (6) Tasmania
Genus *Parastacus* (8) South America
Genus *Samastacus* (1) South America
Genus *Tenuibranchiurus* (1) Australia
Genus *Virilastacus* (1) South America

2.4 More species in the trade

In the pet trade dozens of species of crayfish are available. Besides species already mentioned above, two species are most widely available: *Cambarellus montezumae* and Everglades crayfish (*Procambarus alleni*). *C. montezumae* are, like several other species of *Cambarellus*, a species of warm water aquaria which should preferable be kept at temperatures between 20°C and 25°C. Temperatures should not be below 12°C for a long period and the species are known not to be suitable for garden ponds (Werner 2003, www.garnalenkweker.nl). It is not likely that it will be able to deal with the Dutch climate. The Everglades crayfish is usually sold in a blue color form. It can be kept at a slightly lower temperatures at around 20°C, although its tolerance to low winter temperatures is probably low (Werner 2003). This species is considered as it is common in trade and having an uncertain potential to resist the Dutch climate.

Assessing the dozens of other imported species of crayfish is hardly achievable. Table 2 presents a systematic list of the diversity of freshwater crayfish worldwide. Especially species imported from North America (particularly the genera *Orconectes* and *Cambarus*) have ecological characteristics that make them candidates for establishing populations in the Netherlands.

3. Biology and ecology

3.1 Life cycle

The life cycle varies considerably between species and can be strongly affected by local conditions. The following stages can be defined:

- An egg stage. After spawning, eggs are carried externally by the female at the pleopods (thick, brush-like structures at the underside of the abdomen). Fresh eggs are small and black ('caviar-like'). Maturation of eggs normally lasts several weeks to months during which the (healthy) eggs become yellowish.
- A juvenile stage. After hatching, the first two juvenile stages remain attached to the mother. The stages are immobile and differ considerably from a 'normal crayfish' in order to facilitate the attachment. Stage 3 is (normally) the first free living stage (Reynolds 2002). Approximataly 9 subsequent moults are needed to reach maturity.
- An adult stage. It is not always easy to seperate juveniles from adults. Sexually active males are however recognizable by the secondary sexual characteristics such as disproportional inflated chelae and notable copulatory hooks on the middle leggs. Sexually active females normally display a prominent seminal receptacle ('sperm reservoir' or *annulus ventralis*). Adults normally moult once or twice a year.

Differences in the life cycle between species in the Netherlands can be illustrated based on the examples of the spiny-cheek crayfish and white river crayfish. In the spiny-cheek crayfish, mating takes place in autumn and early spring. Subsequently (just like anywhere else in Europe) females with eggs can be found from March to May (fig. 2a). A considerable drop in the relative proportion of females in trapping

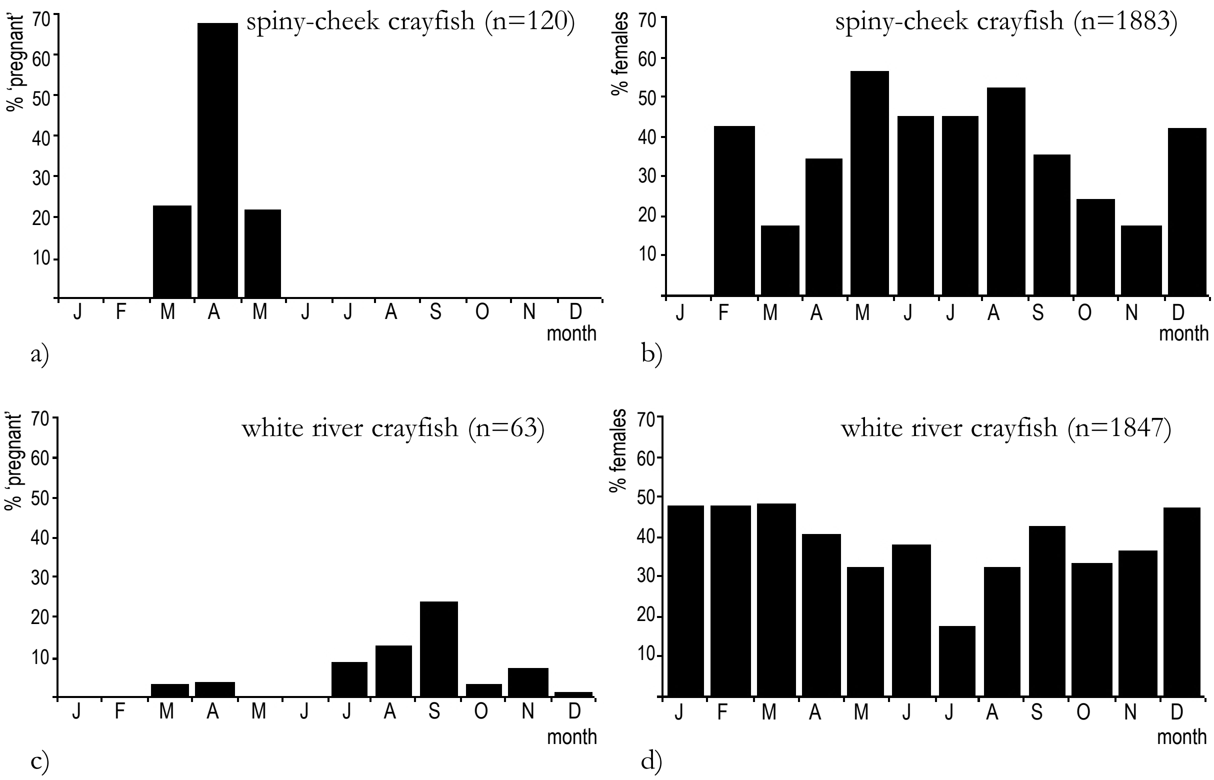
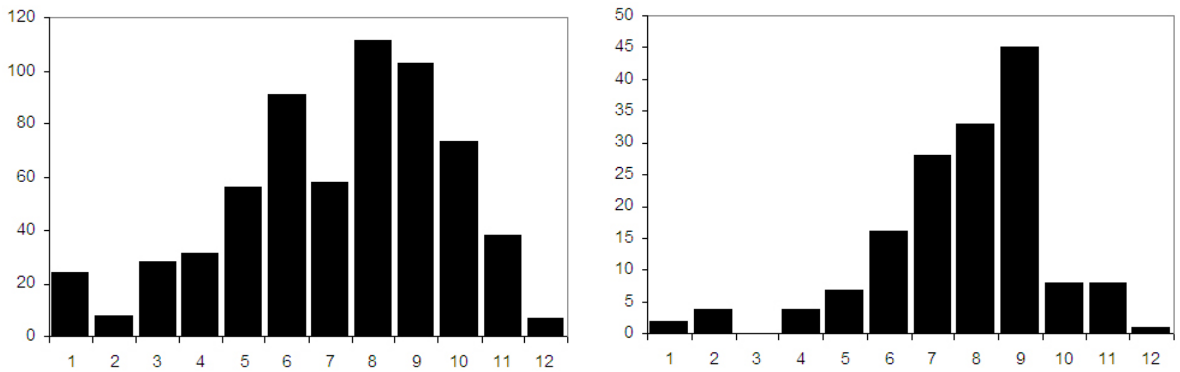


Fig 2. Phenology of the spiny-cheek crayfish (a-b) and the white river crayfish (c-d).
Left: Proportion of 'pregnant' females (females carrying eggs or juveniles) per month relative to the total number of females.
Right: Proportion of females per month relative to the total number of crayfish.
Source: EIS-Nederland/www.landschapsmonument.nl/www.fuiken.nl

data is often observed in the months prior and during hatching of the eggs (fig. 2b). In the Netherlands, a significant deviation from a 1:1 sex ratio is observed in spiny-cheek crayfish from October to March, with frequencies as low as 16% females (March). On the other hand, a disproportionally large number of females is often recorded in the month after hatching. For spiny-cheek crayfish, the highest proportion of females is indeed recorded in May. Juveniles that hatch in spring reach maturity in their second summer (Hamr 2002). Thus, the spiny-cheek crayfish needs two years in the Netherlands to complete its life cycle. Other than the spiny-cheek crayfish, which releases its juveniles in spring, a peak of 'pregnant' crayfish is observed in late summer in the white river crayfish (fig. 2c). Again, the ratio of females drops considerably prior to hatching, with a minimum of 17% females in July (fig. 2d). The juveniles grow fast during autumn and spring and are ready to mate in their first summer. This means that the white river crayfish is able to complete its entire cycle in one year instead of two years. Besides a reproduction peak in late summer, a small number of females of the white river crayfish with eggs or juveniles can be found at almost any time of the year. The species probably mates at any time whenever favourable conditions are available, but further study is needed to confirm this.
Although little data are available for other crayfish in the Netherlands, the data of the virile crayfish fit the pattern of the spiny-cheek crayfish, whereas the data of the red swamp crayfish fit the pattern of the white crayfish. The only breeding farm of red swamp crayfish in the Netherlands (eet-rivierkreeft.nl) also yields one generation per year in late summer. No inland data are available of the marbled crayfish and the narrow-clawed crayfish. The cycle of the signal crayfish in the Netherlands is studied in detail by Van Wielink et al. (2010). It matches largely with that of the spiny-cheek crayfish. Females with eggs and juveniles were observed from October to May.

In their native range, the average life span of the species considered here varies from one year (red swamp crayfish and white river crayfish) to two or three years (spiny-cheek crayfish, virile crayfish and signal crayfish) or up to more than 10 years (narrow-clawed crayfish) (Van den Brink et al. 1988, Lewis 2002, Skurdal & Taugbøl 2002). Based on the size of the Dutch specimens and an elaborate reference study in Europe (Dörr et al. 2006) we expect at least red swamp crayfish and the white river crayfish to have a prolonged life span in the Netherlands.

Pronounced specific differences have been observed in movement patterns in the Netherlands. Fig. 3a-b shows the different peaks in activity (represented by the number of 'accidental' encounters with crayfish by the general public) between the spiny-cheek crayfish and the red swamp crayfish. Besides the activities related to the general life cycle (mating, seasonal migration from shallow water in summer to deeper water in winter), environmental factors play a large role in crayfish movements. For example, heavy rainfall often leads to a considerable increase in activity of the red swamp crayfish and the white river crayfish (Gherardi 2002).



a) b)

Fig. 3. Number of observations by the general public per month.
a) spiny-cheek crayfish (n=628)
b) red swamp crayfish (n=156)

3.2 Dispersion

Crayfish movements are generally linked with local environmental parameters. Seasonal long distance migrations (as observed in a few other crustaceans such the chinese mitten crab *Eriocheir sinensis*) are not known in crayfish. This does not mean that crayfish are incapable of dispersing long distances. Often cited is the example of a radio-tracked specimen of the red swamp crayfish which moved almost 17 kilometers within 4 days in a rice field (Gherardi & Barbaresi 2000). Most species show temperature regulated movements to deeper regions to avoid freezing. Current has shown to be the only orientation mechanism observed so far. *Orconectes nais* displayed large upstream movements after lengthly downstream displacements due to heavy flooding (Gherardi 2002). Often, long distance movements are related to disturbances. Bohl (1999) observed small range movements of the noble crayfish in a familiar environment, in contrast to large distant moves (up to 1 km in a few days) of the species when individuals were released from a hatchery.

3.3 Diet

Although crayfishes are an ancient group of invertebrates they have never developed true specializations in feeding (Lukhaup 2003). They have remained typical generalists with a broad diet. They may eat plants, plant remains, detritus, roots and even wood. They can also be predatory and eat for example snails, mussels, leeches, amphipods and all kinds of insects. Fish and amphibians are unusual prey when they are healthy, as such prey items are in general too fast for crayfish to actually catch. Sick or dead specimens are readily taken, such as any carrion (Nyström 2002).

The food that is actually taken depends (beside the species) on factors such as age, season, sex, physiological condition of the animal and availability of the different food items (Lukhaup 2003). Juvenile crayfish feed mainly on aquatic invertebrates. With age the amount of detritus and/or vegetation increases (Goddard 1988). Species may respond differently to the same availability of resources. Species like the red swamp crayfish and the virile crayfish include plant material and detritus more willingly in their diets compared to species such as the narrow-clawed crayfish and the noble crayfish. Using gut-content analysis the importance of plant material and detritus in crayfish diets is likely to be overestimated. Whitledge & Rabeni (1997) used both gut-content and stable isotope analysis for evaluating the diet of *Orconectes punctimanus*. The stable isotope analysis showed that animal sources were of much greater importance than would be concluded on the gut contents. This difference is caused both by the greater assimilation efficiency for animal matter compared to plant material and detritus, and the methodological bias of the gut analysis towards plant material and detritus (Nyström 2002).

Fig. 4. Grey heron with a red swamp crayfish Amsterdam 2009. Photo: Ton Döpp

3.4 Predators

Although crayfish appear to be a unfavourable food source due to the relatively high contents in inorganic material (mainly $CaCO_3$) they are preyed upon by a large number of animals. Juvenile crayfish are reported to have been eaten by invertebrates like dragonfly larvae (Aeshnidae), large aquatic beetles and bugs, fishing spiders (*Dolomedes* sp.) and fresh water shrimp (*Macrobranchium* sp.) (Hobbs 1993).
Juvenile crayfish are eaten by almost any fish

species of suitable size, but adults can only be taken by larger predatory fish like perch (*Perca fluviatilis*), pike (*Esox lucius*), pike-perch (*Stizostedion lucioperca*) and wels catfish (*Silurus glanis*). One of the most effective predators is the European eel (*Anguilla anguilla*). One of the reasons is probably that it predates on both adult and juvenile crayfish. Small ones are eaten whole and large individuals that are too big to swallow in one piece are broken apart. Another aspect that makes the European eel effective is that it is capable of following crayfish into very shallow waters and tight shelters (Olsen 2005, Holdich et al. 1999, A. Frutiger in Hyatt 2004.).
In their areas of origin, crayfish are heavily preyed upon by various species of birds and mammals (Hobbs 1993), but also in Europe species have included exotic crayfish in their diet. One well known example are the herons and egrets (Ardeidae) that seem to have particular appetite for freshwater crayfish (e.g. Montesinos 2008, Geiger et al. 2005). A research conducted in the Camargue revealed that the relative abundance of red swamp crayfish explained 56% of the inter-annual differences in great bittern (*Botaurus stellaris*) density. Furthermore it is suggested that the recent increase in great bittern numbers in the Camargue, while other French populations were decreasing, could in part be related to the red swamp crayfish abundance (Poulin et al. 2007, White et al. 2006). Within the Netherlands species such as grey heron (*Ardea cinerea*) (fig. 4), purple heron (*Ardea purpurea*), great bittern, great crested grebe (*Podiceps cristatus*) and Eurasian coot (*Fulica atra*) are known to include exotic crayfish in their diet (J. van de Winden pers. comm., D.M. Soes pers. observ.).
Of the European mammals both the European mink (*Mustela lutreola*) and the Eurasian otter (*Lutra lutra*) are well known crayfish predators (Maran & Henttonen, 1995; Beja, 1996). Also in Europe the exotic muskrat (*Ondatra ziebethica*) and American mink (*Mustela vison*) include crayfish in their diet (Hobbs, 1993). The muskrat is probably responsible for several reports of crayfish remains in western parts of the Netherlands (D.M. Soes, pers. observ.). Other species such as brown rat (*Rattus norvegicus*), fox (*Vulpes vulpes*) and western polecat (*Mustela putorius*) are probably only incidental predators as records of less aquatic mammals eating crayfish are scarce (Hobbs 1993).

Also humans should be considered as important 'predators' of freshwater crayfish. The Swedish 'kräftskiva' and the Finish 'apujuhlat', the traditional summertime crayfish parties, are the most illustrative examples. Outside these Scandinavian countries crayfish fishing is in Europe nowadays of minor importance. The commercial market is dominated with crayfish from commercial farms and these originate often from outside Europe, e.g. China (Souty-Grosset et al. 2006, www.fao.org).

3.5 Parasites and diseases
The most well known disease is the crayfish plague, a typical crayfish disease caused by the water mold *Aphanomyces astaci.* The disease causes extremely high mortality rates in non-American crayfish, e.g. the noble crayfish. Of other diseases, much less information on pathoginicity in natural populations is available, although many of these diseases are well known due to the importance of these diseases in farming practices (Edgerton 2002, Edgerton et al. 2004, Alderman & Polglase 1988). In the following section the major diseases (see also table 3) reported for natural populations in Europe are briefly discussed.

Burn spot disease
A disease regularly found in the field is the burn spot disease. This disease is also present in Dutch populations of e.g. the virile crayfish (D.M. Soes, own observ.). It normally develops after injuries on the carapax and can in certain cases be fatal. It is caused by bacteria and fungi that feed on the exterior surface of the crayfish. The prevelance of this disease is seldom high and it is not considered a thread to crayfish populations (Reynolds 1998).

Porcelain disease
Porcelain disease - whitening of the undersides of the abdomen and claws through replacement of the muscles by a parasitic microsporidian protozoan *Thelohania contejeani* - is lethal to individuals but rarely

has a serious impact on populations. This infection rarely exceeds 1-2% of a healthy population. The infected crayfish lose their mobility, retreat to deeper waters and eventually die (Reynolds 1998). This disease has not yet been recorded in the Netherlands.

Saprolegniosis

Saprolegniosis is caused by members of the same group *Aphanomyces astaci* and belongs to the Oömyceta. These fungus-like organisms (*Saprolegnia* sp.) are wide spread and in healthy crayfish populations should only be regarded as parasitic, mainly occurring on the surface of the crayfish. Under adverse circumstances they can cause problems due to infecting eggs or injuries and become pathogenic. As these infections are secondary the occurrence should be used as a warning for other problems (Souty-Grosset et al. 2006).

Psorospermium sp.

Members of the microsporidium genus *Psorospermium* are widespread both in exotic and in native crayfishes. They can be found in connective tissue, muscles, gills, etc. The opinions on the pathogenity of *Psorospermium* are contradictory. Some studies have linked mortality during the moulting period to this parasite, others studies reported no mortality at all (Souty-Grosset et al. 2006). Clearly the recently revealed genetic diversity within the genus doesn't help clarifying the issue. It should be considered that different strains or species can have different effects on different crayfish species. No information on the presence and diversity in Dutch crayfish populations exists.

White spot disease

The white spot syndrome virus (WSSV), the disease agent that has caused significant mortality in marine shrimp farms around the world, is also known from outbreaks in European shrimp farms. Almost anything which has been in contact with infected hosts may act as a vector for the WSSV. Therefore, it is easily transmitted between areas. Furthermore it stays viable within frozen shrimps which are shipped all around the world. White Spot Disease is listed as a non-exotic pathogen in EC Directive 2006/88 (European Community Reference Laboratory for Crustacean Diseases, 2008, Souty-Grosset et al. 2006). Prawns with clear signs of the white spot disease are noticed in Dutch shops (D.M. Soes, own observ.). In 2007 it was identified in a commercial crawfish aquaculture operations for the first time. The disease occurred in Louisiana, USA but its prevalence and impact on crawfish production is not yet fully understood. Several species of freshwater crayfish have proven to be susceptible and mortality rates of up to 100% have been reported (Souty-Grosset et al. 2006). The actual impact on natural populations of e.g. the noble crayfish can only be speculated and clearly more research in this field is needed.

Crayfish plague

The crayfish plague (*Aphanomyces astaci*) is a notorious fungus-like organism, belonging to the water moulds (Oömyceta), infecting freshwater crayfish. The origin and native range of the crayfish plague is assumed to be North America, based on the fact that North American crayfish species have developed defense mechanisms against the crayfish plague and display a normal host-parasite relationship in contrast to European, Asian and Australian freshwater crayfish species, which are highly susceptible (Evans & Edgerton 2002). The noble crayfish for example has disappeared from large parts of its former

Table 3. Overview of pathogens on crayfish

Disease	Dutch	Agent	Type
Crayfish plague	kreeftenpest	*Aphanomyces astaci*	Oömyceta
		Psorospermium sp.	
Saprolegniosis	-	*Saprolegnia* sp.	Oömyceta
Porcelain disease	porseleinziekte	*Thelohania contejeani*	Protozoa
White spot disease	-	WSSV	virus
Burn spot disease	brandvlekziekte	*Chitinoclastic* bacteria and several species of fungi	

range due to the crayfish plague. Clear evidence for the first introductions of the crayfish plague in Europe are lacking, but mass mortalities reported in the mid-19th century are presumably a consequence of the introduction of North American crayfish, which are notorious carriers of this disease (Souty-Grosset et al., 2006).

With early reports from Germany (1877), Luxemburg (1880) and Belgium (1880) (Souty-Grosset et al., 2006), it is most likely that this disease has reached the Netherlands already in the 19th century. This implies that the disease reached the Netherlands long before North American crayfish have been reported. The crayfish plague reproduces exclusively asexually. It produces free swimming biflagellate zoospores. After locating a crayfish the zoospore attaches itself on the soft parts of the exoskeleton, forms a so-called cyst and grows a mycelium in deeper laying organs. This stage is generally fatale for crayfish species of European, Asian and Australian origin. A free swimming biflagellate zoospore can exist only a few days outside its host. In absence of hosts the crayfish plague will quickly disappear from a water system. Several instances of successful introductions of the noble crayfish after an outbreak of the crayfish plague have been described most notable in Scandinavia. In one case even in the presence of a crayfish plague free population of signal crayfish (Vrålstad et al. 2009).

3.6 Abiotic factors

A selection of abiotic factors which are likely to be important for explaining crayfish distribution in the Netherlands are discussed.

Temperature

Temperature tolerances vary greatly between species. Of the present genera, *Astacus*, *Pacifastacus* and *Orconectes* are well adapted to cold water, whereas specimens of the genus *Procambarus* prefer warm water. For some time, the Dutch climate was considered to be unfavourable for the red swamp crayfish (Adema 1989). Certainly, the activity of the red swamp crayfish is greatly reduced at temperatures below 10°C and the species could hardly move at temperatures below 4°C (Vletter 2008a), whereas the other genera can be found active during ice cover (pers. obs. B. Koese). Freezing is unfavourable for any crayfish but by gradually moving into deeper water, crayfish are hardly troubled by winter temperatures as long as they have time to anticipate. Järvenpää (2008) observed high mortalities of signal crayfish in a Finnish lake in 2002 when an exceptional warm autumn was abruptly followed by a strong winter, which killed many (freshly moulted) specimens.

Acidification

Acidification strongly affects crayfish. The calcium metabolism is disturbed by low pH levels, which might cause direct lethal effects, or indirect effects such as reproductive failure or an increased vulnerability for pathogens or predators (Nyström 2002). The effects of acidification in crayfish are well studied. Generally, crayfish are absent in waters with a pH below 5.5, although adult crayfish might tolerate shorter periods of lower acidity. Optimum pH values are normally around 7.5 (fig. 5). Yue et al. (2009) found and optimum value of 7.8 for survival and growth of the red swamp crayfish in aquaculture in China. Water acidity is likely to play a major role in explaining crayfish distribution in the Netherlands, especially in the east, where many (isolated) waters have a pH below 6 (Reemer et al. 2008). Some species show a relatively high tolerance towards increased **salinity** levels. Of the species considered here, especially the narrow-clawed-, red swamp-, spiny-cheek- and signal

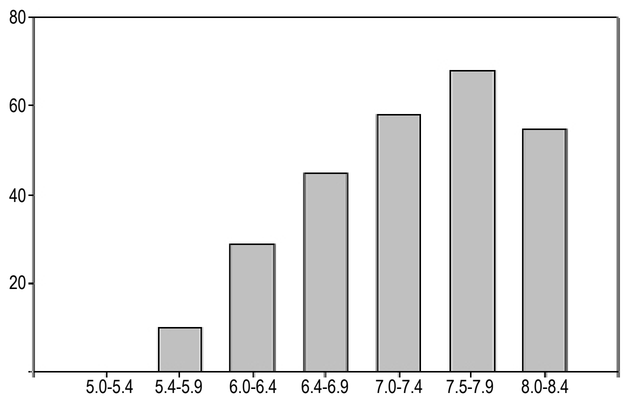


Fig. 5. Proportion of Swedish lakes (n=1080) with *Astacus astacus* in relation to pH (Nyström 2002, after Svardson 1974)

crafish are capable of withstanding relatively brackish water.

Structure

Finally the preferred **habitat structure** differs greatly between species. Some species are adapted to highly dynamic environments such as temporal habitats. The possibility to burrow during unfavorable conditions might play an important role in such environments. Thus, the structure of the **soil** can be of significant importance. Clay and bog are generally suitable structures for building sustainable burrows, whereas sand and grit are not.

4. Probability of entry

To examine the probability of entry, it is neccessary to study the availabily of crayfish on the one hand and the (motives behind) introductions on the other hand. Within the study of pathways, one could make a distinction between deliberate introductions and unintentional introductions. For deliberate introductions, such as the use of crayfishes as food or pet animal, one should consider the underlying interests. For unintentional introductions, such as crayfishes as stowaway in sediment translocations, the underlying mechanisms are more interesting.

4.1 Methods

Species and motives underlying introductions were reconstructed based on literature and a survey among voluntary crayfish researchers of Stichting-EIS (120 addresses). Additional indirect evidence for crayfish introductions was obtained by screening the EIS-database for crayfish records in isolated ponds and (fish)lakes. To determine the availability of crayfish, an internet survey of sales points was made. From every sales point, the target species and the sector of industry (in practice: aquarium- or consumption trade) were scored. For addional statistics, a selection of whole salers and specialized stores (Interfish, Kreeften en Garnalenshop, Ruinemans B.V., www.eet-rivierkreeft.nl, Roskam & Klaver B.V., Jan van As B.V.) were approached. The trade in dead, prepared crayfish (e.g. the import of tails from the red swamp crayfish from China) is not considered in the survey.

4.2 Documented introductions

Based on literature and 17 correspondents of the survey, we were able to collect information about twelve observations of crayfish introductions in the Netherlands (table 4). Probably the earliest account of a direct introduction of an invasive crayfish is documented by Janssen & Maris (1974). They report the observation of Germans using crayfish as fishbait during WWII in a pool near Ochten (in province of Gelderland), a location where the spiny-cheek crayfish showed up in 1972. The authors suggest a possible link, since the spiny-cheek crayfish was already widespread in Germany in the middle of the 20th century. A few subsequent (documented) introductions are the result of a general lack of information and awareness about invasive crayfish. Some specimens of spiny-cheek crayfish caught in the Hackfortse beek near Zutphen were mistaken for the native noble crayfish in 1978 and released in a nearby lake (Markeplas) which was considered to be less polluted (Anonymous 1978). Even in 1987, the spiny-cheek crayfish was mistaken for the noble crayfish: prior to the construction of a highway, 250 'threatened' specimens of spiny-cheek crayfish were translocated from Barendrecht to Delft during a large rescue (Knijnenburg 1988). Nowadays, 'rescue releases' still occur but from a general 'humanity' point of view. We noticed at least three accounts of crayfish (walking on the road) that were picked up by an animal ambulance. However, the eventual releases of such a rescued crayfish are not always

Table 4. Overview of observed and documented crayfish releases into the wild

Interest	Species	N	Source	Year	Reference
Aquarium	*Orconectes/Procambarus*	>1	Aquarium trade	1980-1990	Pers. comm.
Conservation	unknown	>1	unknown	1997	Anonymus 1997
Fish bait	unknown		unknown	1940-1945	Janssen & Maris 1974
Fish bait	spiny-cheek crayfish	200	Free nature	1999-2007	karperwereld.nl/rotary/deel67.php
Lack of interest	narrow-clawed crayfish	>1	Consumption trade?	1989	Anonymus 1989
Lack of interest	unknown	>1	Free nature	2004	kreeftengarnalen.nl/forum
Lack of interest	signal crayfish	3	Free nature	2008	Pers. comm.
Lack of interest	spiny-cheek crayfish	1	Free nature	1980-1990	Pers. comm.
Lack of interest	red swamp crayfish	10	Consumption trade	1985	Anonymus 1985
Rescue	spiny-cheek crayfish	2	Free nature	1978	Anonymus 1978
Rescue	spiny-cheek crayfish	250	Free nature	1987	Knijnenburg 1988
Rescue	red swamp crayfish	2	Free nature	2008	Pers. comm. Vogel- en egelopvang Delft

documented. Lack of interest was recorded five times as a motive for introduction, varying from the release of an excess of juvenile crayfish out from an aquarium (www.kreeftengarnalen.nl/forum), interference of a family member in the housekeeping policy of pet animals, and the accidental release of crayfish in a different water than obtained from during an education event. The first record of a red-swamp crayfish (The Hague 1985) is probably related to the release of ten specimens by restaurant 'Chez Eliza' in 1979. The restaurant received a test sample from Kenya from the catering company 'Twilt' but considered the specimens too small for consumption and released the animals in the canal (Hooikade, Den Haag) (Henny 1985).
The interest in crayfish in the sport fishing sector hasn't disappeared since WWII. The sector has an ambigious relation with crayfish. Some consider crayfish as a threat for fish populations (Emmerik & Laak 2008, Emmerik 2010) while others use crayfish to nourish their fish (see box 1). At least 14 isolated habitats with crayfish populations were identified (see appendix 3, p. 66). Many of the sites are notorious fish lakes managed by local fish societies. Most likely, the crayfish were introduced here by (members) of the fish society.

In the contrast with the variety of motivations underlying an introduction of a crayfish, three different origins could be identified. More than half of the observed releases were accomplished with specimens derived from the wild elswhere in the country (fig. 6).

4.3 Availability of crayfish
Two interests determine the availability of crayfish in commerce: the aquarium trade and the consumption trade (appendix 2). The aquarium trade is considerably more widespread and diverse (in terms of species) than the catering industry. In terms of the number of traded specimens however, a single catering company could sell considerably more specimens than a aquarium wholesaler. One of the largest aquarium wholesalers (Ruinemans B.V. pers. comm.) sells 'dozens of crayfish' per week to various companies in the Netherlands and Europe, whereas a single restaurant order contains normally 5 kg crayfish (ca. 100 specimens) (eet-rivierkreeft.nl, pers. comm.). Nevertheless, the national trade in crayfish for consumption is a marginal industry. Theoretically, the trade in living specimens could be of economic interest (the trade in dead specimens is not profitable due to cheap import) but the demand for living crayfish is low. Despite the 'decorative and social' advantage of fresh specimens, the average Dutch kitchen is still uncomfortable with the idea of killing a bucket full of crayfish.
To our knowledge (and to the knowledge of the breeder) there is currently only one local breeding company in the Netherlands: eet-rivierkreeft.nl. The company delivers living crayfish at approximately 10 restaurants on a regular basis. The company has about 10.000 specimens of red swamp crayfish (once acquired from Dutch nature) in stock. The business is rather new and the trade has not yet been profitable.

The interest in living crayfish in the fisheries wholesale industry seems to have dropped since the 'mass' import of prepared specimens from China. Fisheries wholesaler Roskam & Klaver B.V. (Zwartsluis) used to sell 'hundreds of living crayfish from Kenya [= red swamp crayfish] and Turkey [=narrow-clawed crayfish] weekly' (Anonymous 1984). Nowadays, only dead specimens from China are traded (pers. comm. Roskam & Klaver B.V.). One of the largest wholesalers (Jan van As B.V., Amsterdam) sporadically imports live specimens of narrow-clawed crayfish ('a couple of hundred kilo's a year') from Turkey (Jan van As B.V. pers. comm.).
Locally and seasonally, the professional freshwater fisheries

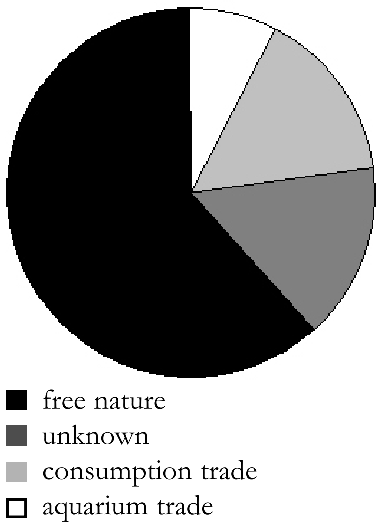


Fig. 6.
Origin of released crayfish

Box 1. Report of an introduction at http://www.karperwereld.nl/rotary/deel67.php

"Crayfish are the ultimate nutrition for our friend, the carp. They contain lot's of protein, which fish need for excellent growth. We bought specimens from a professional fisher, who would normally sell them to restaurants. […]. We introduced only 200 crayfish in a water of approximately 13 hectares. Nevertheless, many anglers reported scratches on their bait last summer. This is a good sign, which indicates a high reproduction of the crayfish. We observed a sharp weight increase in the carp […]"

Original text

"Rivierkreeften zijn de ultieme voedingsbron voor onze vriend, de karper. Ze bevatten zeer veel dierlijke eiwitten, en dit is juist waar de vissen zo goed op groeien. De moederdieren zijn opgekocht bij een beroepsvisser die ze toch regelmatig in de netten krijgen en ze anders aan een restaurant verkopen. […]. Het water waar we dit hebben gedaan is ongeveer 13 hectare groot en we hebben er maar 200 kreeften uitgezet, toch kregen we deze zomer al behoorlijk wat meldingen van vissers die krassen op de boilies hadden. Dit is dus een goed teken, want dit betekent dat ze zich goed vermeerderen. Verder zijn de gewichten goed aan het toenemen op het water, al is dit natuurlijk niet geheel hieraan te danken. Want de promotie van de diepvriesboilie heeft hier ook veel aan bijgedragen."

industry is subject to large quantities of crayfish as a by-catch. Some fisherman freeze the specimens for friends and events, while at least one individual fisherman also supplies living crayfish to (Asian) restaurants (Blokland B.V. pers. comm.). Crayfish catches by a single fisherman could be as high as 700 kg/week (ca. 17.500 specimens) for the red swamp crayfish (Verdouw 2009). As said however, the catching of large quantities of crayfish is per species highly depended on the season (for example, see fig. 7). Regular supply of the market or auction is not yet possible based on crayfish from the wild. This, combined with the low marketing price, is still a major obstacle for commercial exploitation (T. Bult/IMARES pers. comm.).

Crayfish tend to accumulate heavy metal and organic pollutants because their habit of feeding on detritus and animal matter will contribute to accumulation. Also they are bottom dwellers, which keep much of their bodies in contact with surrounding objects (Alcorlo et al., 2006; Holmqvista et al. 2007). Several heavy metals, such as lead (Pb), copper (Cu) and cadmium (Cd), have been proven to accumulate (Madigosky et al. 1991, Alcorlo et al. 2006). Also in the Meuse heavy metals have been detected in spiny-cheek crayfish (Schilderman et al. 2002). The consequences of accumulation of toxic compounds for human consumption have not yet been studied in the Netherlands, but especially in areas with heavy

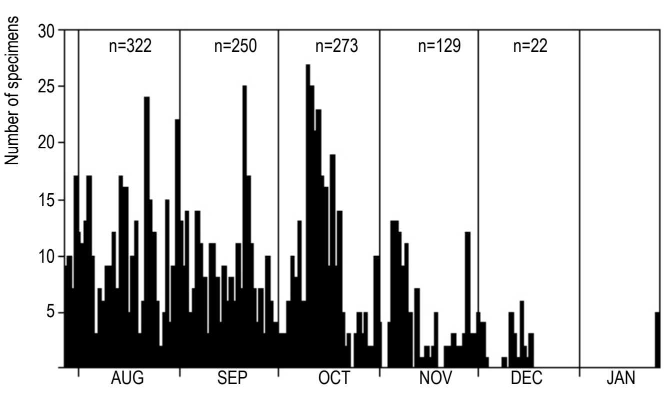


Fig. 7. Daily totals of the white river crayfish from three permanent traps in a back garden in Giessenburg (province Zuid-Holland) over a 6 month period in 2009-2010 (n=1044). Catches vary depending on weather and season. From Dec 14 - Jan 19 no controls are conducted due to ice. Source: EIS-Nederland/www.landschapsmonument.nl

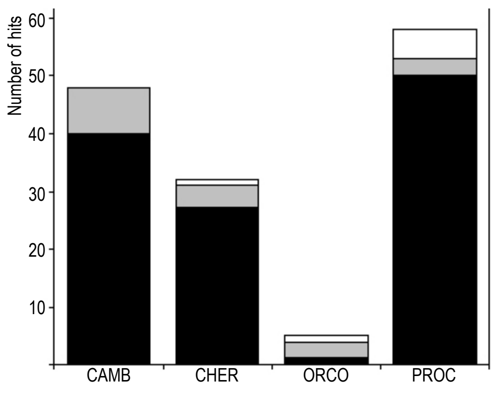


Fig. 8. Hits of some crayfish genera on popular classified sites (January 2010): black=marktplaats.nl, grey=speurders.nl, white=tweedehands.nl. CAMB=*Cambarellus*, CHER=*Cherax*, ORCO=*Orconectes*, PROC=*Procambarus*

polluted bottom sediments such accumulation is of concern for the fisheries sector.

In the aquarium trade, the tolerant genus *Procambarus* (especially the red swamp crayfish) competes in popularity with the small, aquarium friendly dwarf crayfish (*Cambarellus sp.*) (fig. 8, Ruinemans B.V. pers. comm.). From the selected species the red swamp crayfish is by far the most traded specimen on the internet (fig. 9).

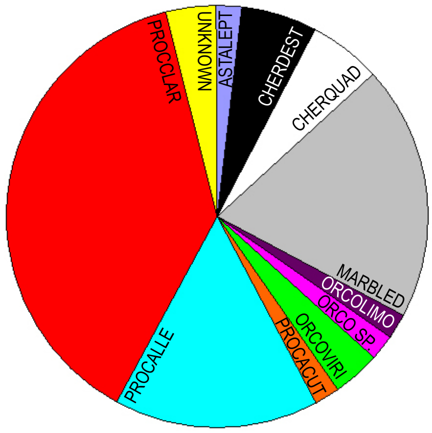


Fig. 9. Relative availability of the selected species at internet sales points (January 2010; see appendix 2 for the full list) (n=54)

4.4. Unintentional introductions

Two unintentional pathways of introduction have been identified (not quantified) in the Netherlands. The first pathway concerns the removal of crayfish with sediment after dredging, which has been observed once. Several specimens of red swamp crayfish were crawling in a sediment deposit after a discharge of mud. The individuals were collected by the employees and released alive in a nearby lake (Klinkenbergerplas, Oegstgeest) in spring 2008 (pers. comm. W. Kuijper/J. Goudzwaard).

The second pathway concerns the natural entry of invasive species from abroad.
At least two species are likely to have entered the country from abroad: the spiny-cheek crayfish and the signal crayfish. The spiny-cheek crayfish probably entered the country multiple times from different water systems in Belgium and Germany (fig. 10). The signal crayfish was first found in the Ruhenbergerbeek. In contrast to the Netherlands, the Ruhenbergerbeek is widely branched in Germany, with many fishing ponds and activities connected to it. Undoubtedly, the species crossed the border here (pers comm. Bert Knol). Although the population of the signal crayfish in Tilburg lies close to the border, there are no indications that the species immigrated from Belgium (Van Wielink & Spijkers 2008).

At least one new species, the calico crayfish, is expected to enter the Netherlands from abroad. This North American species was discovered in the Rhine near Mannheim in 1993 and colonized a stretch of more than 100 km along the Rhine in approximately 10 years (Gelmar et al. 2006). Although the species is still far away (ca. 400 km.) we expect the species to arrive in the Netherlands within two decades since the species could succesfully compete with the spiny-cheek crayfish.
Additionally, new populations of species that have already been observed elswhere in the Netherlands might enter the country on the short term. A considerable population of the narrow-clawed crayfish occurs in the Damse vaart near Damme in Belgium (pers. comm. Koen Lock/waarnemingen.be), which has a direct connection with the fortification canals of Sluis (province of Zeeland). Most likely, the species occurs here already.

4.5 Conclusion

Two interests determine the international shipping of crayfish: the aquarium trade and the consumption trade. The consumption trade is primarily focused on species that are commercially exploitable in large quantities. Therefore, the amount of species that are internationally traded for catering purposes are low and (in Europe) limited to the narrow-clawed crayfish, red swamp crayfish and signal crayfish (although we weren't able to trace any recent trades of the signal crayfish). However, some species that became established in the Netherlands are locally exploited for catering as well.
The (international) trade in living in crayfish for consumption a marginal industry, which had dropped over the last 20 years due to the low demand for living specimens and the import of prepared specimens from China. However, if the trade would become more popular the temptation to introduce crayfish

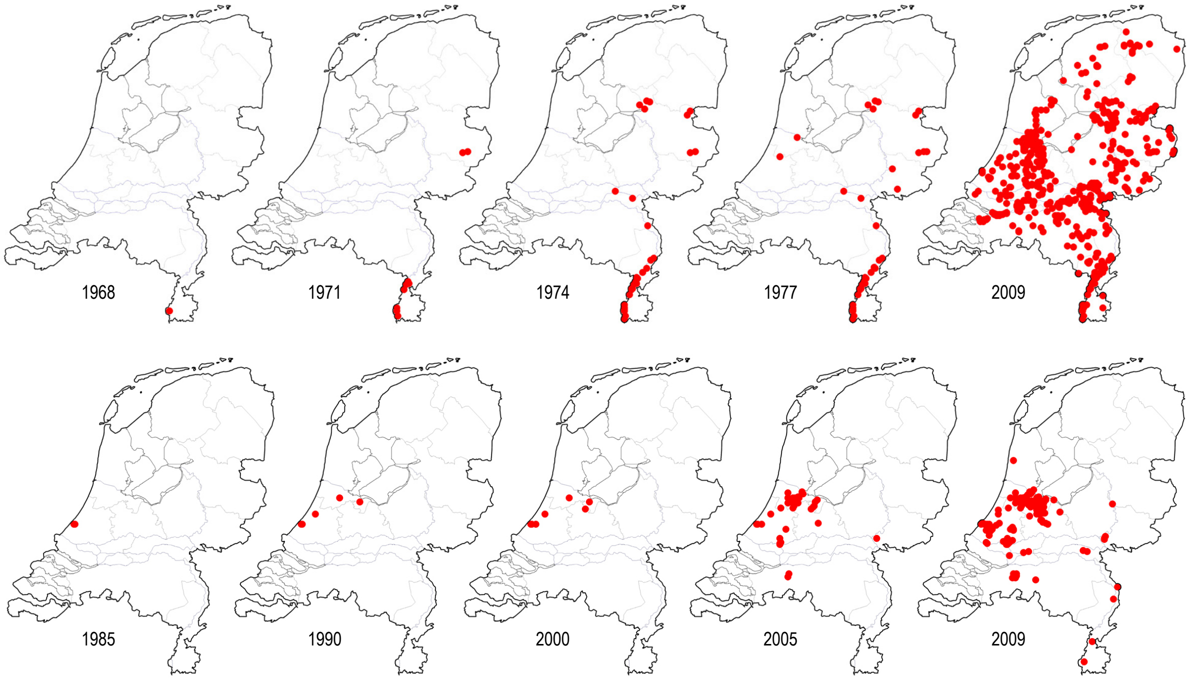


Fig. 10. Examples of introduction pathways.
Upper row: cumulative distribution maps of the spiny-cheek crayfish. The species most likely entered the Netherlands from populations in Belgium and Germany.
Lower row: cumulative distribution maps of red swamp crayfish. The distribution of the species is closely associated with urban concentrations.

elswhere in the wild might increase.

The aquarium trade sells a tremendous number of species, based on a 'trial and error' principle. Of the species considered here, the red swamp crayfish is by far the most common species in the trade. Besides, particularly *P. alleni* and the marbled crayfish are widely available. Notably, many selling points of the red swamp crayfish do not overlap with the observed distribution in the wild (appendix 2, page 65). Either the species is still not introduced in many parts of the country, or the species hasn't been succesfull so far. Certainly, the species has less chance to survive in the east, due to its habitat preferences (fig. 17b, page 52). However, we expect the species to be a succesfull invader in the lower areas in the north, where it has probably not yet been succesfully introduced.

Remarkably, some of the species that are well established in the Netherlands, such as the virile crayfish and the white river crayfish, seem to be very rare in the aquarium trade (all specimens available on classified sites are locally harvested). It illustrates that even a trade in rare species can have large consequences.

Of all observed introductions, most crayfish were obtained from the wild and many introductions were based on good (or naïve) intentions e.g. rescues. Once a species is established, humans play a large role in a further accelleration of its expansion, either by deliberate translocations or by unintended transportation such as mud translocation. The frequency of unintended displacements is entirely unknown. However, based on the intensity of mud displacements and ditch cleanings (e.g. the re-use of material in different ditches), the mechanism is expected to occur regularly.

5. Probability of establishment

Some exotic crayfish species have already established populations in the Netherlands. For some other species the probability of establishment is expected to be high (see § 2.3 and 2.4). The evaluated species have different potentials for dispersal and establishment within the Netherlands. Therefore the probability of establishment in different areas within the Netherlands is predicted.

Predicting the crayfish potential of an area is a precarious task due to the fact that species could display completely 'new' behaviours in a new situation. For example, a species renowned for its burrowing capacity in its native range, might stop burrowing in a new environment because the stimuli causing the behaviour (such as dehydration, or predators) are lacking. In this particular example, the preferred soil (for burrowing) in its native range might differ from the soil on which the species is able to survive in the new situation. As a result of this, the risk assessment for species that are already established (in the Netherlands or nearby regions) is likely to be more accurate than for 'completely new' species.

5.1 Methods

To examine the 'probability of establishment' in different regions in the Netherlands, we made a list of parameters that are both meaningful for explaining crayfish distribution as well as useful qualifications for defining geographic structure. The following physical-chemical and physical-geographical parameters were considered: soil, current, stability of the habitat (temporary versus permanent), connectivity, salinity (concentration Cl^-), and pH (see also paragraph 3.6 'Abiotic factors').

All factors were examined semi-quantitatively. Species with a particular preference (or tolerance) for a specific condition were labeled with a 2 ('preference'), species with no particular preference for a certain condition were labeled with 1 ('no preference'). Species with an obvious aversion for a condition were labeled with '0' (aversion). The average label was used to separate three different preference classes:

1: Average score between 1.5-2: optimal habitat available (coloured red on the species probability maps starting on page 42);

2 Average score between 1-1.49: suboptimal habitat available (coloured pink);

3: A score of zero for one of the parameters: sustainable populations unlikely (coloured white)

A score of zero (aversion) in one category resulted in a zero for all categories, assuming that an aversion leads to an uninhabitable habitat. Factors that might affect the probability of establishment which were not useful for discriminating preferences for particular regions (such as temperature or competitive behaviour) were used to adjust the final scores manually. Any of such adjustments were detailed in the text.

The probability maps and preference tables are presented in the species passports, starting at page 42. Probability maps are produced for six established species and one 'expected' species (the rusty crayfish). No map was made for the marbled crayfish. Until recently, this species was only known from the aquarium trade. Still, there are not enough data available to produce a reasonable probability map for this species. A map for the rusty crayfish was copied from the virile crayfish. The species are often reported from the same habitat. The other evaluated species are not considered on the map because their ability to adapt to the different regions is much harder to predict.

Table 5. Characteristics of the nine regions

	SOIL	CURRENT	TEMPORAL	CONNECTED	SALINITY	pH
dunes	sand & grit	Y/N	Y/N	N	< 300 mg Cl/l	> 5.5
marine clay	clay	N	N	Y	> 300 mg Cl/l	> 5.5
peat bog	bog	N	N	Y	< 300 mg Cl/l	> 5.5
riverine clay	clay	N	Y/N	Y	< 300 mg Cl/l	> 5.5
rivers & IJsselmeer	sand & grit	Y	N	Y	< 300 mg Cl/l	> 5.5
pleistocene bog	bog	N	Y/N	N	< 300 mg Cl/l	< 5.5
pleistocene sand	sand & grit	Y/N	Y/N	Y/N	< 300 mg Cl/l	> 5.5
lime stone	sand & grit	Y	N	Y	< 300 mg Cl/l	> 5.5
urban	sand & grit	Y/N	N	Y/N	< 300 mg Cl/l	> 5.5

5.2 Regions

Table 5 shows arrangement in nine regions based on physical-chemical or physical-geographical criteria. The classification is based on Mol (1985) and the latest topographical atlas (Wolters-Noordhoff 2007). The following regions were distinguished (from west to east) (fig. 11):

1 - Dunes

Soil sandy, water generally standing but locally running (a few natural streams and some infiltration canals). Water shallow, permanent or temporary. The connectivity between waters is low.

2) Marine clay district

Soil generally clay. Water standing and permanent. The connectivity is high. The surface water is brackish. It contains more than 300 mg Cl/l which seperates the district from all other regions.

3) Peat and impoldered peat bog area

The soil consists of peat. Water standing and permanent. The connectivity is high.

4) Riverine clay district

See 3 (marine clay districts), except that concentrations of Cl are below 300 mg Cl/l.

5) Great rivers and central lakes (IJsselmeer & Markermeer)

Soil with sand or grit. Water running and/or turbulent, permanent and connected. Water generally deeper than other regions.

6) Pleistocene sand: bog and heathland.

The soil consists of peat. The water is standing and often temporary. The surface water has a pH below 5,5 which seperates the region from all other regions.

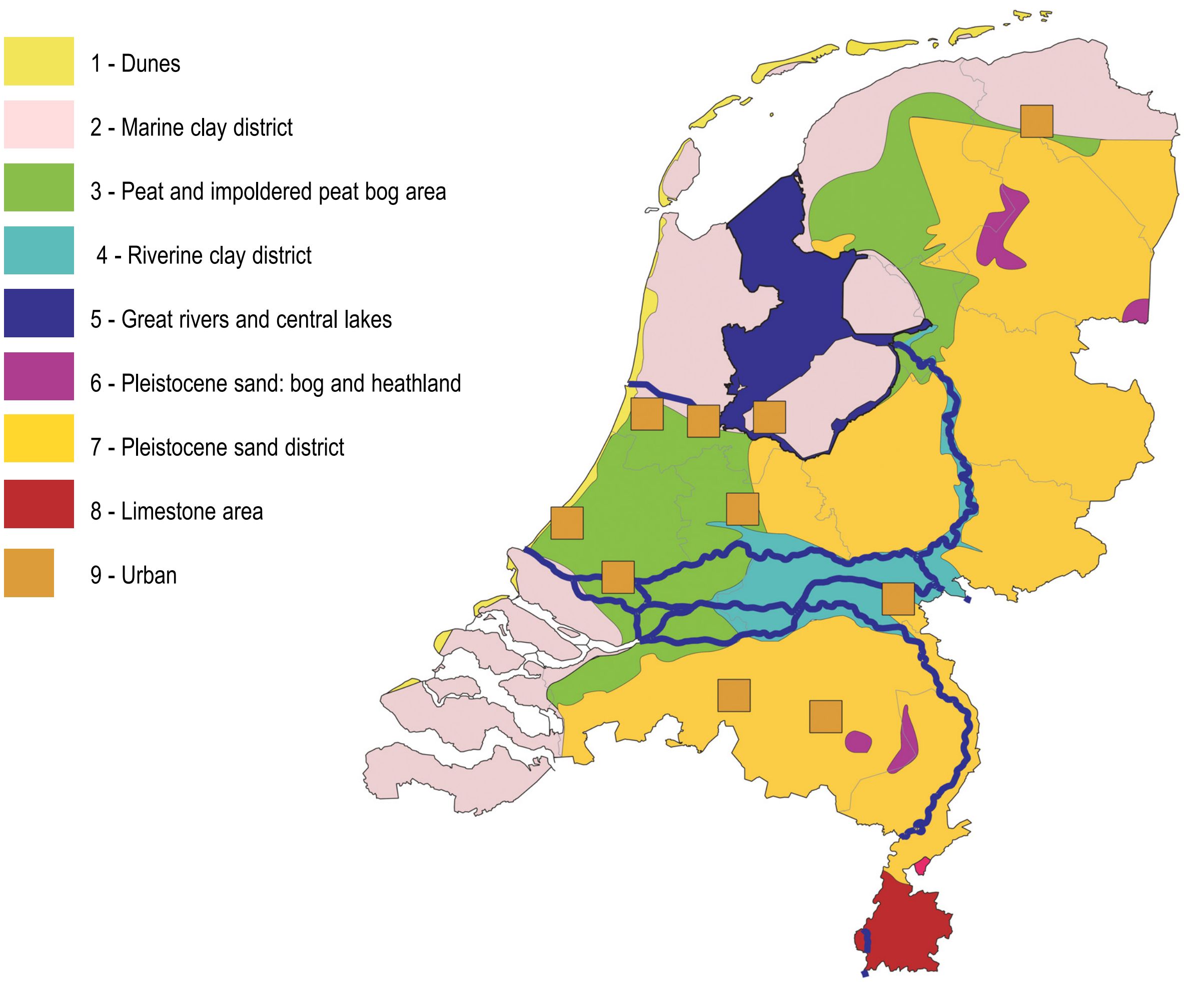


Fig 11. Classification of regions based on physical-chemical and physical-geographical parameters (see table 5).

7) Pleistocene sand district
Soil sandy. The region consists of scattered streams, canals and standing (artificial) lakes and ponds. Except for some streams, the connectivity is usually low.

8) Limestone area
Soil sandy, water running, permanent and connected.

9) Urban regions
Soil usually gravelly, with scattered shelter provided by bricks and waste. Water standing and permanent. The water temperature is relatively high. Connectivity variable. Water eutrophic with high values of pH. To conserve the overall picture, only the 10 largest cities (Amsterdam, Rotterdam, Den Haag, Utrecht, Eindhoven, Almere, Tilburg, Groningen, Nijmegen, Haarlem) are included in the map. However, the habitat can be found at almost any (larger) urban concentration.

5.3 Conclusion
Considering all species maps (see passports, page 42-58), optimal habitat for crayfish can be found almost anywhere in the country. Normally, due to their broad diet and tolerance for various environmental conditions, many crayfish are primarily (naturally) limited by biogeographical bounderies and the presence of other (crayfish) species. Since many natural boundaries are reduced due to human activities (releases) and the fact native predators and competitors are lacking, many invasive crayfish have shown to be capable of occupying a quite larger niche in the Netherlands than observed in their natural range. Only region 9 (pleistocene bog and wet heathlands) scores negative on all maps. Due to the fact that the pH is generally lower than 5.5 in these areas, no sustainable populations are expected in these regions (see also page 15, abiotic factors). Although only four large bog- and heathlands areas are indicated on the maps, many smaller patches can be found scattered within the pleistocene sand area, making the total surface of uninhabitable habitat considerably larger.
Large rivers are indicated as 'negative habitat' for two crayfish species (red swamp crayfish and white river crayfish). However, rivers can still play a role as migration corridors for such species.

6 Ecological impact

In this paragraph the impacts of exotic crayfish and the crayfish plague on ecological, economic and social aspects are discussed.

6.1 Vegetation

All crayfish species recorded from the Netherlands are known to consume plants and algae. Normally, crayfish are highly selective in their diet, preferring easy manageable macrophytes (with a short handling time) above more rigid species. As a result, submerse macrophytes and algae are generally more affected then emergent species. The size of the effect is regulated by both the intensity of the grazing and the ability of the primary producers to compensate for grazing losses (Nyström 2002).
Secondly, crayfish can affect macrophyte vegetations with non-consumptive cutting. This is for example reported from the red swamp crayfish. In microcosm experiments red swamp crayfish cut both *Elodea* sp. and *Myriophyllum* sp. (Verdonschot et al. 2009). In rice fields the red swamp crayfish is reported to damage especially seedlings although actual consumption is low (Huner 2002). In aquaria most species of crayfish have been reported to cause damage by presumably non-consumptive cutting (D.M. Soes, pers. observ.).
Lastly, crayfish might influence vegetations indirectly by effecting turbidity and water quality (Nyström 2002). Processes involved are e.g. increased turnover of nutrients due consumption and shredding of detritus and increased suspension of soil particles (bioturbation).

Both for the red swamp crayfish and the white river crayfish analysis have been performed on the relationship between vegetation cover and crayfish densities in Dutch waters (Vletter 2008b, J. Blom & D.M. Soes, unpublished data). In both studies no negative impact could be proven. Vletter (2008b) did find some correlations between (categories) of the red swamp crayfish and habitat structure, but no consistent effects

that submergsed vegetation was an important explanatory variable for presence of the red swamp crayfish. Crayfish numbers were negatively correlated with submergsed vegetation cover. However, the red swamp crayfish showed not to be an important explanatory variable for vegetation variables, therefore damage to macrophytes could not be directly related to the presence of the red swamp crayfish.

Although foreign scientific studies on the virile crayfish support negative effects, this is not published from the the Netherlands, yet. However, the same sequence of events has been observed in several Dutch waters, indicating a relation with high numbers of virile crayfish and a reduction of the submerse vegetation. Both in de Kamerikse Wetering, Wilnisse Bovenlanden and Polder Spengen, settlings of virile crayfish coincided with reductions in the cover of submerse vegetations (Emmerik & Laak 2008, Soes 2008, Soes & Spier 2006). Especially in the Kamerikse Wetering effects were strong with a total disappearance of submerse vegetations. In the Kamerikse Wetering densities have been extremely high with catches of up to 90 adult crayfish per fyke net per night (Soes & Spier 2006).
The few reports about the negative effects on vegetations in the Netherlands contradict the information that is available from outside the Netherlands. Nyström (1999) concludes in his review of the ecological impact of crayfish that most crayfish species can have strong negative effects on the biomass and species richness of aquatic macrophytes. Within Europe the best known examples are those of the red swamp crayfish affecting Mediterranean wetlands (Geiger et al. 2005). In their study of a shallow lake in North-West Spain Rodriquez et al. (2005) describe the impact of the introduction of red swamp crayfish in 1997. In 1995 the lake had a vegetation coverage of 95% consisting of 16 plant species. In 2001, four years after the introduction of the red swamp crayfish, coverage was reduced to less than 2% and only 11 species were found. Exclusion experiments using mesocosms showed recovering of the vegetation up to 95%. Comparable impact of the red swamp crayfish has been reported in several instances in- and

outside Europe (Matsuzaki et al. 2009; Geiger et al. 2005, Nyström 1999, 2002).

Within the Netherlands only the virile crayfish has been associated with significant impact on submerse vegetations (Emmerik & Laak 2008, Soes 2008, Soes & Spier 2006). The potential impact of this species is confirmed with American studies (Chambers et al. 1990, 1991). Therefore the impact of this species on aquatic vegetations is considered to be potentialy high. Both the red swamp crayfish and the signal crayfish have been reported to have high impact at least in several instances in Europe (Nyström 2002). The rusty crayfish is known to cause drastic reductions in submergsed vegetations outside its native range in the USA (Rosenthal 2006) and the calico crayfish has been successfully applied in weed control, reflecting its potential impact (Letson & Makarewicz 1994). Although actual herbivory is hard to predict due to the opportunistic behavior of freshwater crayfish and although at least in certain cases several species have not been proven to have negative impact on vegetation all four species are regarded as species with a potential high impact due to proven cases.

Other species are data deficient regarding their impact on vegetation. Both the narrow-clawed crayfish and the spiny-cheek crayfish have long a history as aliens in Western Europe (Souty-Grosset et al. 2006). To date no reports of significant damage to vegetations have yet been reported. This might indicate moderate to low impact. The white river crayfish occurs in high densities (J. Blom & D.M. Soes, unpublished data) and its ecology is comparable with the red swamp crayfish (Huner, 2002). This might indicate a potential high impact. Yabbies, redclaws, marbled crayfish and the Everglades crayfish are known to devour plants in aquaria. When these species reach high densities impact on vegetation can certainly be expected (Nyström 2002). As these species are expected to be less adapted to the Dutch climate these high densities are not expected and impact is tentatively classified as potentialy moderate-low

6.2 Fish

Crayfish can affect fish by predation, competition and habitat alteration (Degeman et al. 2006). Carpenter et al. (2005) showed that competition between crayfish species and fish species can take place, but might differ greatly between species of fish. Bottom feeders are e.g. more likely to be affected in competition then species that mainly predate on plankton.

Due to their aggressive behaviour, crayfishes are likely to compete for shelter with especially benthic fish species (Nyström 2002). For negative correlations of the bullhead (*Cottus gobio*) and the stone loach (*Barbatulus barbatulus*) with the signal crayfish in British streams it is suggested that the displacement might be the result of such competition (Guan & Wiles 1997). Hirsch & Fischer (2008) studied the interaction between spiny-cheek crayfish and burbot (*Lota lota*) in Lake Constance. Spiny-cheek crayfish successfully repelled juvenile burbot from their preferred daytime shelters into alternative, previously unselected shelters. Crayfish also affected the nocturnal behaviour of juvenile burbot by eliciting avoidance behaviour and caused an increase in the plasma cortisol levels (stress). No effect on adult animals was detected.

R. Neuteboom-Spijker (pers. comm.) reports a negative relationship between spiny-cheek crayfish and the stone loach on the Veluwe. In these streams the stone loach is very abundant. But in downstream areas the stone loach is often absent in abundance of spiny-cheek crayfish although the habitat looks suitable. Aggressive interactions might also explain these cases.

Although incidental predation might be expected, crayfish are not believed to be important predators of adult fish. They are too slow in their responses and healthy fish will in general be able to avoid and to escape crayfishes. Crayfish do however predate on fish eggs and larvae (Nyström 2002). Rene Lippmann (pers. comm.) for example observed in the Vinkeveense plassen a large red swamp crayfish who collected an egg cluster of a bullhead and started eating it. Dorn & Mittelbach (2004) described predation of the virile crayfish on eggs of the pumpkinseed (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*), reducing reproductive outcome.

Due to the different life strategies, large differences in impact are expected between fish species. For example, species with bottom dwelling eggs (e.g. bullhead, spined loach (*Cobitis taenia*)) are likely to be

more vulnerable than species who deposit their eggs on standing objects (e.g. perch (*Perca fluviatilis*)). Species with brood defence (e.g. pike perch (*Sander lucioptera*)) might also be more succesfull. Finally, the breeding season might have an impact. Most fish species breed in the (early) spring, when crayfish such as *Orconectes* sp. and *Procambarus* sp. have shown to be relatively inactive. Therefore a summer breeder (such as the tench (*Tinca tinca*)) might have a relatively disadvantageous life cycle with respect to crayfish. Comparisons of fish densities within 61 Swedish streams between years with absence and presence of crayfish (signal crayfish and noble crayfish) showed no effect of either crayfish species. A further analysis of changes in fish densities between periods without and with crayfish in low, intermediate and high densities revealed that crayfish density had no effect on fish densities (Degerman et al. 2006).
The presence of exotic crayfish clearly will influence fish population through competition and predation. These effects seem at least in the Swedish case to be moderate to low as such effects have not been detected. This might be influenced by the fact that the studied waters in Sweden are waters with natural presence of crayfish. In the Dutch lowlands crayfish are a novelty and might have different effects. But also here competition and predation might not be the most important factor affecting fish. More likely habitat alterations, especially the diminishing of vegetation, might much more influence these areas which are dominated with limnophilic species such as the bitterling (*Rhodeus amarus*), crucian carp (*Carassius carassius*), sunbleak (*Leucaspius delineates*) and European wheatherfish (*Misgurnus fossilis*).
All crayfish species are expected to have effects on fish populations. Competition and predation are likely to cause in general only moderate to low effects. Species with high impact on vegetation are expected to have more pronounced effects, especially on limnophilic fish species.

6.3 Amphibians
The introduction of predators in amphibian breeding habitats may contribute to the decline or extinction of amphibian populations (Cruz & Rebelo, 2005). Amphibians might be affected by predation and habitat alteration. Crayfish are known to predate on amphibian eggs and larvae (Nyström 2002, Hobbs 1993, Cruz & Rebelo 2005). Furthermore the signal crayfish has been observed to negatively influence a population of common frogs through causing sublethal injuries to tadpoles, which subsequently affected their ability to out-swim crayfish (Nyström 2002). Adult newts have proven to react on the aggression of crayfish and leave the water at the expense of reproduction (Gamradt et al. 1997).
Most species of amphibians make highly use of aquatic vegetation for egg laying and cover for the larvae. Species such as smooth newt (*Triturus vulgaris*) and green frogs (*Rana esculenta complex*) can reproduce in the presence of predatory fish. But for their survival they do require the cover provided by vegetation. Newts in particular, need vegetation for reproduction in which they fold their eggs. The presence of crayfish populations that greatly effect vegetation are also likely to effect amphibian populations.
In a study in the southwest Iberian Peninsula, Cruz et al. (2006) evaluated the effect of the red swamp crayfish on amphibian reproduction. In this study they assessed the effect of red swamp crayfish presence in the breeding site distribution of each of the 13 southwest Iberian amphibians, while simultaneously accounting for the effects of potentially confounding habitat variables, as well as predatory fish. After accounting for habitat variables and fish, crayfish presence was a negative predictor of the breeding probability for all newts and salamanders (*Pleurodeles* waltl, *Salamandra salamandra*, *Triturus boscai* and *T. marmoratus*) and for two toads (*Pelobates cultripes* and *Bufo bufo*).

Also in the Netherlands crayfish are known to co-exist with amphibians. The white river crayfish for example has proven to co-exist with several Nature 2000-species: great crested newt (*Triturus cristatus*), moor frog (*Rana arvalis*) and natterjack toad (*Bufo calamita*) (D.M. Soes, pers. observ.). Goverse & Janse (2008) reported an instance of the displacement of a healthy smooth newt population with red swamp crayfish in a pool in the Amstelpark, Amsterdam.

All crayfish species are expected to have affects on amphibian populations. Predation likely causes moderate to low effects in most instances. Species with high impact on vegetation and species occurring in high densities are expected to have more pronounced effects, especially when they are known to occur in standing waters: spiny-cheek crayfish, virile crayfish, red swamp crayfish, white river crayfish, calico crayfish and rusty crayfish.

6.4 Macro-invertebrates

The effects of crayfish on aquatic macro-invertebrates are reciprocal. Larger predatory macro-invertebrates such as dragonfly larvae can significantly reduce crayfish population by predation on juveniles (see paragraph 3.3 'predators', p. 12), but significant predation on macro-invertebrates by crayfish is also observed. Bjurström et al. (2008) found a considerable shift in invertebrate species composition towards less vulnerable prey species with increasing densities of the signal crayfish in a Finnish lake. Especially the species richness and abundance of (slow moving) snail species was greatly reduced in presence of crayfish. Since many crayfish species primarily consume plant organic material, especially indirect affects on macro-invertebrates are to be expected. Franck Bameul (pers. comm.) observed the disappearance of the protected Habitat Directive beetle *Graphoderus bilineatus* (and many other aquatic beetles) after the destruction of the habitat by the red swamp crayfish (see box. 3).

6.5 Birds

Negative impact of exotic crayfish on birds is reported from southern Europe. The red swamp crayfish population of Lake Chozas (Spain) has effected waterfowl considerably due to especially the large

Box 3. An email from France.

This reply was received on october 28, 2009, after a request to verify the occurence of a protected water beetle (Graphoderus bilineatus) in a 'famous' nature reserve: Marais de la Perge near Bordeaux.

From: Franck Bameul
To: Bram Koese

I waited to give you the news, which is very bad news. I am sad to tell you that *Graphoderus bilineatus* has disappeared from the Marais de la Perge and that the locality must be considered as destroyed.

I have visited La Perge last August at the begining of the month and walked all around looking for ponds. The vision was rather horrible. The place is crowded with the red legs of the Louisiana crayfish *Procambarus clarkii* (Girard). This monster has killed nearly all the macroinvertebrates of the place. While it was common to be bitten by mosquitoes and midges when collecting at La Perge, no Diptera attacked me during my visit. A bad sign. The large leeches common here have disapeared. When you take mud, one cannot find even worms in it. I visited in the past places that were polluted by paper factory effluents and even by heavy metals close to a steel factory: the ponds in such places were far more rich in invertebrates than in La Perge now!

One can have a good idea of the impact of this crayfish invasion on water beetles, because in my 1994 paper, I recorded 109 species of water beetles (one must add 5 or 6 Scirtids and semiaquatic Alticidae I collected later). During my visit in last August I managed to find only 2 species of water beetles! Yes, you read it well and it's not a mistake: only two species! That makes a loss of more than 98% of the diversity, if I count it well. The species left are: *Hydroglyphus pusillus* and *Berosus affinis*, two species that are fast collonizers of temporary ponds. Our British friends considered La Perge as one of the richest place in Europe for water beetles. Now it is just a remembrance...

The entire place is just a muddy mess now. Even the aquatic plants that were so diverse have disappeared. I met a fish specialist who observed that the invasion of the Louisiana crayfish in the area occured just after the December 1999 hurricane that made so much destructions in South West France. The overflow of the Gironde estuary during the hurricane may have contributed to spread the crayfish in the nearby marshes. [...]

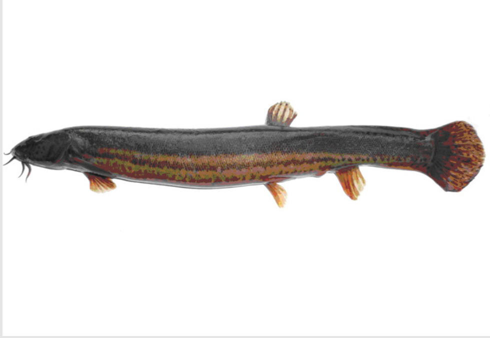
reduction in submergsed vegetation. This has effected both species that depend on marsh vegetations for breeding and species that feed on aquatic food resources. Rodriguez et al. (2005) calculated a 64% reduction of breeding bird species. Coots (*Fulica atra*) that depended on marsh vegetations for constructing their nests had for example decreased with 65% after the introduction of the red swamp crayfish. Species such as common teal (*Anas crecca*) and garganey (*Anas querquedula*) have disappeared.
Piscivore species are believed to be less affected as they are known to include exotic crayfish in their diet (Rodriguez et al., 2005, Geiger et al., 2005). In Lake Chozas species such as the cormorant (*Phalacrocorax carbo*) and the grey heron (*Ardea cinerea*) have increased (Rodriguez et al. 2005). Care should be taken in concluding that all piscivore bird species might experience no negative impact. Montesinos et al. (2008)

Box 4. Impact of crayfish in the Dutch peat bog district.
Hein van Kleef

In the past large parts of the western Netherlands were covered by extensive peat bogs. Nowadays, these bogs are drained, reclaimed and little is left of their original character. The original peat soil has decreased in thickness and is drained. The quality of many waters in the western part of the country is heavily degraded due to high nutrient concentrations. Reasons for this eutrophication are divers: nutrient leaching from agricultural areas, decomposition of peat, mobilisation of nutrients from under-water and waterlogged sediments and desiccation prevention by inlet of surface water. As a result many water bodies are turbid en important ecosystem processes such as peat accumulation and land formation by macrophytes hardly take place. Especially the latter two processes create prime habitat for characteristic and endangered flora and fauna of aquatic environments in the western Netherlands. Water and nature managers try to re-initiate these processes within national and international programs, such as Natura2000 and the Water Framework Directive.

Land formation by macrophyte is likely to be inhibited by crayfish activities. The species have shown to be able to reduce macrophyte growth by cutting, foraging, and uprooting. Moreover, the presence of crayfish has been associated with a strong water turbidity, which prevent plant growth by light limitation. Water turbidity is the result of increased suspension of soil particles, and the release of nutrient and subsequent growth of phytoplankton. Furthermore nutrients are released from the sediment due to increased fragmentation of dead plant material resulting in an increased turnover of nutrients as well as increased aeration of underwater sediments. Because decomposition rate of plant material increases in the presence of crayfish, peat accumulation is reduced or prevented. The shift of clear water lakes as a result of increased nutrient richness in combination with soil disturbing species (often carp) is a well known phenomenon in these waters. The restoration of lakes which have shifted to a turbid state has proven to require a major effort, such as removing most of the soil disturbing specimens in combination with reduction of nutrient loading.

The peat bog district is known to be important for several Natura 2000-species, four examples: moor frog (*Rana arvalis*), European weatherfish (*Misgurnus fossilis*) and the diving beetle *Graphoderus bilineatus* Photo's: D.M. Soes, G. Chernilevsky, B. Koese.


found in their study in the Doñana National Park that, although the red swamp crayfish has become very abundant, both the purple heron and the night heron didn't feed them to their chicks. Outside the colonies adult night herons were noted to feed predominantly on red swamp crayfish. Also other studies recorded less crayfish in the diet of chicks compared to that of adults (Martinez et al. 1992, Correia 2001). It is suggested that the crayfish might be too hard for the chicks to handle (Montesinos et al. 2008). Furthermore, piscivore species who depend on sight for catching their prey (such as the cormorant) can be negatively affected due to significant increase of turbidity. According to a local fisherman G. Griffioen (pers. comm.), cormorants were much less noted in the Kamerikse wetering after the colonization on the virile crayfish (Soes & Spier 2006).

6.6 Mammals

Crayfish might affect two species of indigenous aquatic mammals: European otter (*Lutra lutra*) and water shrew (*Neomys fodiens*). Water shrews are most abundant in small waterways with dense submerse vegetations. Strong degradations of such vegetations might seriously effect water shrew populations (Soes et al., 2006). The European otter is less likely to be affected. Losses in former prey species are probably compensated with crayfish consumption. Species with high impact on vegetation are expected to have effects on water shrews.

6.7 Water Framework Directive (WFD) and Natura 2000

In the WFD, goals have been identified for both the water quality and the ecological values present in different water systems. In the Natura 2000 Directive goals have been identified for habitats and birds. Ecological effects of exotic crayfish could interfere with these goals especially when high densities occur in a particular water system (see table 4). To examine the WFD objectives, so called 'WFD metrics' based on different quality elements (macrofauna, macrofytes, phytoplankton and fish) have been designed. Van der Meulen (2009) calculated that crayfish possess a serious threat for the scores of all WFD metrics.

Table 6. Examples of WFD and Natura 2000 goals that could be potentially affected by the exotic crayfish.

Goals	Possible impact of exotic crayfish
Improvement of the growth and development of aquatic plants	• Predation of plants • Reduction of the water clarity caused by bioturbation
Stimulation of the population of mussels (e.g. *Driessena* spp.) as a food source for birds	• Predation of mussels
Maintaining or stimulating the growth of populations of a specific bird species	• Predation of plants which is known to greatly effect herbivorous birds in southern Europe
Improvement of the water quality	• Release of phosphates and pollutants stored in the sediment caused by burrowing activities and detritivory
Realisation of nature-friendly banks	• Erosion of banks caused by the creation of burrows • Interference with the development of plant-, macrofauna or fish species due to predation
Improvement of the development of macrofauna and/or fish communities	• Predation of macrofauna and fish species • Habitat disturbance due to plant predation

6.8 Noble crayfish

Exotic crayfish can affect the indigenous noble crayfish by competition and as a carrier of the crayfish plague. Signal crayfish and narrow-clawed crayfish have demonstrated in several instances that they are able to outcompete noble crayfish (Souty-Grosset et al. 2006). Although no such instances have been reported from the Netherlands, this could theoretically also occur in the Netherlands. The habitat of both exotic species greatly overlaps with the habitats occupied by the noble crayfish in the Netherlands in the past (Niewold 2003, Souty-Grosset et al. 2006).

The noble crayfish is extremely sensitive for the crayfish plague. Any infection can wipe out complete populations. In 2001, the noble crayfish population in the Rozendaalse Beek was probably destroyed due to the introduction of the crayfish plague. The pathway of the introduction of the disease could not be found in this case (Niewold 2002). As the crayfish plague can exist only a few days outside its hosts colonization and introduction of exotic crayfish species are the major pathways for the introduction of the crayfish plague (Souty-Grosset et al. 2006).

Due to the almost universal presence of North American crayfish, Niewold (2003) concluded that only well isolated locations, like artificial ponds and streams with migration barriers, should be selected for introduction programs. This conclusion implies that recovery in more natural systems is very unlikely due to the presence of exotic crayfish.

The narrow-clawed crayfish, yabby and redclaw are unlikely vectors of the crayfish plague since they are sensitive for the plague themselves. The narrow-clawed crayfish has proven to be able to outcompete the noble crayfish (Souty-Grosset et al., 2006). Both the yabby and the redclaw are less likely to do so as both species are less adapted to the Dutch climate. All North American crayfish species treated in this report, including the marbled crayfish, are known or highly suspected carriers of the crayfish plague and can act as vectors (Lukhaup 2003, Souty-Grosset et al. 2006). Therefore, all North American crayfishes have a high impact on the noble crayfish, even when competition is not considered.

7. Economic & social impact

7.1 Commercial fisheries

The presence of exotic crayfish can have direct negative impacts on commercial fishermen. They can cause damage to commercial fishermen who use fish traps by:

- consuming (part of) the fish caught in traps. Fish that have partly been eaten or damaged by crayfish cannot be sold for consumption meaning loss of income for the fishermen;
- extending the handling time to sort fish from crayfish. Because of the extended handling time fishermen have to deploy less fykes than usually to be able to empty them in the same time period (Kamps 1937);
- stealing bait. When bait is removed by crayfish, fish are not attracted anymore.

Damaging fykes as reported for the Chinese mitten crab does not occur (K. Burger, pers. comm.).

So far excessive crayfish numbers have been reported in waters of relatively low value for commercial fisheries. Eel populations, the main target of commercial fisheries, in these waters are in general small. But still these waters are fished by small commercial fisheries and they experience large impact in these waters. Especially in summer fisheries with fykes can be impossible due to huge numbers of crayfish in their catch. Numbers exceeding 200 per fyke are reported. In such instances the fish is in general to damaged to be sold (G. Griffioen, pers. comm.).

7.2 Burrowing

Most crayfish species are known to create burrows in the absence of enough cover. There are several reports of damage of dikes, irrigation channels and other water works due to the intense burrowing of the red swamp crayfish, which can result in e.g. bank collapse and consequently in severe damage to both agricultural fields and natural ecosystems (Correia & Ferreira 1995, Huner 2002, Barbaresi et al. 2004). Although also in the Netherlands several species are known to create burrows, e.g. white river crayfish, spiny-cheek crayfish and red swamp crayfish (D.M. Soes, pers. observ.), no confirmed reports of substantial damage are known.

7.3 Damage to agricultural crops

Both feeding and burrowing activities of the red swamp crayfish cause considerable damage to rice crops in southern Europe. Rice fields usually consist of different sections, separated by small waterproof (clay) dikes (fig. 12). The burrowing activities cause leakage and subsequent dehydration of the rice culture Additionally, young rice shoots were eaten by crayfish. This damage has resulted in the use of pesticides to reduce its numbers (Boix, 2002). So far no reports are known from exotic crayfish causing damage to agricultural crops in the Netherlands.

7.4 Interference with recreational fishing

Exotic crayfish interfere with recreational fishermen in the Netherlands through the stealing of bait (Koopmans, 2009). This interference can occur with any type of recreational fishing as the crayfish are omnivorous and will feed on whatever sort of bait is used (e.g. fish, cheese, bread). At the moment especially fishermen trying to catch common carp are reported to be affected. Furthermore there is great concern of recreational fisheries about the possible effects of the large numbers of exotic crayfish on fish populations. In several instances angling societies have initiated research, e.g. Polder Spengen, Wilnisse Bovenlanden and Gouda (Soes, 2008; Emmerik & De Laak, 2008, Emmerik, 2010)

7.5 Crayfish in urban areas

Exotic crayfish are regularly reported walking on land in urban areas like back garden, playgrounds and even inside houses and/or apartments. In some cases this raises some concern and animal ambulances or police might get involved.

Fig. 12. An example of digging behaviour of the red swamp crayfish.
a-b) Warm, shallow rice fields provide an optimal habitat for the red swamp crayfish.
c-d) The animals burrow their holes in the bank of the small clay dikes that separate the rice fields.
e-g) Fresh clay indicates a burrow in use. Burrows vary in length. This particular female made a burrow of approximately 40 cm, at 20 cm below the surface.
All photos were taken in the Ebro delta, Spain, December 2009.

8. Risk management

In this chapter, possible measures to prevent further establishment, eradication and management of exotic crayfish and crayfish plague, are discussed.

8.1 Prevention

Obviously, the prevention of crayfish releases saves problems afterwards. Prevention seems a straight-forward tool to impede crayfish but, considering the diversity of the (un)intentional trade in crayfish, the actual implementation can be rather complicated. Different types of prevention act on different levels within an introduction pathway. Prevention consists of **communication** and **legislation** if one considers the sources of crayfish: the international trade. **Education** is the prime tool for preventing deliberate introductions whereas **practical and mechanical** solutions are (besides education) needed to prevent unintentional introductions such as the translocation of crayfish in mud. Several prevention procedures are discussed here, based on the different sources and motives that were identified in chapter 4.

International trade

Banning species from trade can be achieved either by legislation or by means of an agreement with the pet trade. Both legislation and agreements have certain (dis)advantages. The advantage of **legislation** is its stringent implication: all traders must commit to it. The disadvantage of legislation is that it can be a difficult and longlasting procedure to implement species in the law. Additionally, juridical conflicts with international trade agreements have previously shown to be a serious obstacle for legislation. Finally, if a broad social basis for legislation is lacking, the number of illegal trades might increase significantly.
The effectiveness of an **agreement** highly depends on the number of joining traders and the availabilty of alternative recourses (e.g. other species) for the company. The advantage of an agreement is that an agreement can be relatively easily achieved. The disadvantage is its informal status, creating profitable opportunities for companies who do not want to commit themselves to the agreement. Both legislation and covenants use lists of species. Lists can be either positive or negative. A positive list summarizes the species which are allowed in trade. A negative list lists the species which are not allowed.

Nowadays, the pet trade is the most important source of new and recently established crayfish species (see chapter 4). During inquiries among wholesalers for this study, we experienced a lot of willingness to support a possible agreement or a call for a ban of certain species. This commitment can be partly explained by the fact that so many species are involved in the aquarium trade. A few banned species will not harm any pet company, since many alternative freshwater crayfish (among other crustaceans and aquarium animals) are left to trade in. However, the difficulty with the large number of traded species is that its hard to formulate species lists. It is impossible to access the possible effects of all species that might show up in the trade. Due to the continuous request for 'something new', a large number of species is to be expected in near the future (pers. comm. Kreeftengarnalenshop). In other words a 'complete' positive species list is hard to assemble. A (motivated) negative species seems a better applicable starting point for an agreement with the aquarium trade.
In table 7, proposals for negative species lists are given. A drawback of such species lists is the increased risk of the import of wrongly identified specimens. Using a lists which is mainly based on genera would overcome this problem. A proposal for a genera list is also given in table 7.
As mentioned in chapter 4, the international trade in living specimens for consumption is small and nearly confined to the narrow-clawed crayfish and the red swamp crayfish. For consumption, the demand for 'new' species is negligible. Therefore, a positive species list of a few 'safe' consumable species might be a good starting point for an agreement with the consumption trade.

Local fisheries

The increase in interest for the exploitation of exotic crayfish might also increase the interest in stocking exotic crayfish. Strong and clear legislation forbidding the stocking of exotic crayfishes is an important tool for prevention. Legislation is assumed to be more succesful than an agreement due to the dimension and diversity of the inland fisheries sector. An agreement with 'all parties' is hard to achieve.

In the current legislation (Visserijwet 1963) freshwater crayfish are not included in the list of species that can be commercially exploited or freely stocked. Recently (13 November 2009) the Dutch Ministry of Agriculture, Nature and Food Quality published the intention to update policies concerning exotic crayfish.

Illegal stockings with the aim to start or to improve fisheries on crayfish have not been proven in recent time. This has been a concern of e.g. water board in relation to stimulating crayfish fisheries. As illegal stockings will be hard to prove, prevention seems to be only possible with educating the public about the impact of crayfish on the environment and about the damage crayfish cause during fishing practices.

Deliberate releases

Many motives underlying crayfish introductions have been identified (see chapter 4) such as a lack of interest (specimens too big for the aquarium or overcrowding due to reproduction), crayfish rescues (animal ambulance) or the use as crayfish as fish bait. In all cases, education is the only possible remedy for reducing the amount of such introductions. Addressed campaigns are needed to reach potential 'releasers'. Pet stores can play a role in the preventing the release of pet crayfish. Fish societies can be informed about the implications of the use of fish as bait, whereas animal-asylums can be informed about the risks of releasing animals elsewhere than they were obtained from. A drawback of public education is that it is hard to maintain. Without active maintenance, the effects of education will quickly fade away.

Unintentional introductions: neighbouring countries

Crayfishes can enter the Netherlands from neighboring countries. A population of the calico crayfish that exists near Karlsruhe spreads for example alongside the River Rhine using for almost certain also the River Rhine itself (A. Martens, pers. comm.). The signal crayfish which is now entering the Dinkel (B. Knol, pers. med.) colonized this stream from the Ruhenbergerbach which originates in Germany. With no cases of effective barriers of larger scale (Hyatt 2004) it is extremely unlikely to successfully prevent such invasions.

Table 7. Possible negative species lists.
A = List of species known to be invasive in the Netherlands, B = List of species known to be invasive in Europe, C = List of suspected species, D = List of genera including suspected species

A	B	C	D
Narrow-clawed crayfish	Narrow-clawed crayfish	Rusty crayfish	*Orconectes* sp.
Signal crayfish	Signal crayfish	Redclaw	*Procambarus* sp.
Spiny-cheek crayfish	Spiny-cheek crayfish	Everglades crayfish	*Pacifastacus* sp.
Virile crayfish	Virile crayfish		Yabby
Red swamp crayfish	Red swamp crayfish		
White river crayfish	White river crayfish		
Marbled crayfish	Marbled crayfish		
	Calico crayfish		
	Orconectes juvenilis		
	Yabby		

Unintentional introductions
Waterboards are obliged to clean their ditches and canals regularly. Often, temporal deposits are set up for larger clean-up projects. Benthic (in)vertebrates are often passively translocated to such deposits in large numbers. Crayfish have the capacity to escape the deposit overland, eventually reaching nearby water. This form of unintentional introduction is observed at least once, but is likely to occur (much) more often. Such releases can be easily diminished by modifying the design or placing of the deposits.

8.2 Eradication

Trapping
Although considerable reductions have been achieved with intensively trapping programs none of these have been able to achieve the eradication of populations, see also 8.3. Trapping is an insufficient tool for eradication of crayfish populations (Hyatt 2004).

De-watering ponds
In single cases de-watering of ponds, which is e.g. used in the Netherlands to eradicate populations of pumpkinseed (*Lepomis gibbosus*) (Bosman 2004), might be a practical method. This method might be applicable to ponds that are considered of major importance for threatened amphibians. Success of this method is hardly guaranteed for every crayfish species as some have proven to be quite resistant to even long periods of drought in winter (P.R. Wiles, in Hyatt 2004.). But at least for less winter resistant species such as the red swamp crayfish this method might be promising in certain cases.

Chemical methods
Chemical methods are the only methods that have proven to be successful in the eradication of exotic crayfish populations (Hyatt 2004, Sandodden & Johnsen 2010, D. Holdich pers. comm.). In general these methods have serious side effects due to the lack of selectivity and in certain cases also persistence in nature over longer periods. Pyrethroids seem to have the greatest potential due to their lethal effects on crayfish and their rapid breakdown (Hyatt 2004, Sandodden & Johnsen 2010). A recent experiment combining dewatering and BETAMAX VEX, a synthetic pyrethroid, in an isolated pond seems to have eradicate a signal crayfish population completely with relatively little effort. Although these result look promising the actual application to more complex systems might prove to be more difficult due to a less perfect dispersion of the chemical (Sandodden & Johnsen 2010).
The major drawback of chemical methods, their lack of selectivity, will make them hardly applicable by public opinion. This is reflected by several ecologist of water boards who uniformly rejected the consideration of chemical methods in the past.

8.3 Management

With the scale of impact being related to densities, attempts have been made to reduce population numbers (Hyatt 2004). The use of pesticides as is e.g. common practice in rice cultivation in parts of Spain, is not considered a valuable tool due its negative effects on a wide variety of wild life (Boix et al. 2002, Holdich et al. 1999). Therefore, trapping and biological control or a combination of the two are the remaining options for controlling crayfish numbers (Roessink et al. 2009).

Trapping
Trapping can be done with a wide variety of traps and fyke nets, although the actual choice can have great influences on the effectiveness of the fishing program. In the Netherlands eel fykes have proven to be very effective (A. Blokland, pers. comm.). This trapping is only effective on a limited proportion of a population, especially juveniles are much less efficiently caught. Minimum size of trappable crayfish vary between traps and fyke nets but are in general between forty and eighty millimeters total length. Due

Box 4. Legislation
Overview of most relevant Dutch legislation concerning invasive crayfish.

Fisheries law 1963 [Visserijwet 1963]
The Fisheries law regulates, among other things, which fish as well as some mollusks and crustaceans can be harvested and released. No crayfish are included on the list of the fisheries law, which became into force on January 1, 1983. This means that you are not allowed to release crayfish for commercial exploitation. It is not forbidden to harvest crayfish. However, because fishing gear is needed to harvest crayfish, it is still not allowed to harvest crayfish without a licence for using gear.

Flora and Fauna law
The Flora- and fauna law states that native species can be designated as protected species. On November 28, 2000, it was decided to include the Noble crayfish on the list of protected species. Thus, it is prohibited to catch or kill specimens of the Noble crayfish within the Netherlands, which implicates that is not allowed anymore to harvest the species. Moreover it is prohibited to initiate any activities which might disturb or damage a population of the Noble crayfish.

With respect to exotic species, Article 14 of the Flora and Fauna law is important. This article states that it is prohibited to release animals or eggs of animals in free nature. However, this article states also that the prohibition does not apply to those fish included on the list of the Fisheries law 1963.

to this especially short-term programs are hardly effective as populations can recover quickly. In fact, trapping has been proven to increase production in certain cases due to less predation of juvenile crayfish by older crayfish. Long term trapping programs are more likely to be effective, but also in these cases increase of production might lessen the reduction (Hyatt 2004).
Trapping programs offer the possibility to use the commercial value of freshwater crayfish. The major obstacle for exploitation of Dutch crayfish population is a low international market price. Presenting catches at the fish auction by Dutch fishermen is therefore unattractive (T. Bult (IMARES), pers. comm.). Some small scale exploitation for local markets have developed in recent years though. When trapping programs are considered it seems worthwhile to perform a market study using their knowledge to increase the market for freshwater crayfish and create selling points for fishermen.

Biological control
Several studies suggest that fish reduce crayfish populations and that they may consume a large proportion of crayfish production (Hyatt 2004). Svärdson (1972) found that crayfish were less abundant in Swedish lakes containing large populations of eels and vice versa. When eels were excluded by dams, the crayfish population increased in size. In a Canadian lake changing fishing regulations increased the smallmouth bass (*Micropterus dolomieu*) and decreased the numbers of the invasive rusty crayfish (Hein et al. 2006).
In the Netherlands eel and perch are probably the most effective predators (Frutiger & Müller 2002). Perch is a common species but larger perch (>25 cm) tend to become scarce in many water systems, including the area where the virile crayfish populations are booming (K. Burger & G. Griffioen, pers. comm.). Especially outside the larger rivers the eel is becoming scarce. In the last fifty years the eel population has declined by 90%. Large areas receive virtually no glass eels anymore.
Within the Water Framework Directive goals concerning the improvement of fish populations are included. Strong execution of these goals should also improve the populations of predatory fish. The Eel Management Plan is installed to save the eel from a further decline. In 2010 no eel fishing is allowed in the months September-November. Other measures are the establishment of fishery-free zones in areas that are important for eel migration and the reduction of eel mortality at pumping stations and hydro-electric stations. Although these measures are a strong implementation of the European Eel

Management Plan it is strongly debated whether this will actually give rise to an improvement of the eel stock.

As eels are becoming scarce it will be expensive to stock waters with eel. Prices for glass eel are quite variable but prices per kilo of more than 600 euro excl. BTW are realistic. Especially as poaching will be of great concern in many areas these prices will hamper the stocking of eel. A well monitored experiment to evaluate the effectiveness of such stocking is of great importance as e.g. water boards will be much more willing when stocking of eel is proven to be a successful control method.

For the management of other predatory fish habitat improvement is probably a more important component then stocking. For both perch and pike reasonably clear water with well developed submerse vegetations gives optimal conditions. But the stocking of e.g. perch in the sizes between 7- 15 centimeters have been suggested to be effective as a controlling method for bream (*Abramis brama*) and clearly such stocking should be considered in a management plan (Emmerik & De Nie 2006).

Combining trapping and biological control

Combining both methods of trapping and biological control is probably the most promising way of managing crayfish populations. Trapping removes large crayfish with a high reproductive value, whereas fish consume a greater quantity of crayfish with low reproductive value. Overall, however, fish predation is thought to decrease the population growth rate most because a greater number of crayfish (esp. juveniles) are removed (Hein et al. 2006). This implies that such programs can only be successful when populations of predatory fish are strengthened to a certain level. Also in the combined method applied in the Schübelweiher (Switzerland) predatory fish are thought to have had the greatest impact on the red swamp crayfish population (Frutiger & Müller 2002).

8.4 Crayfish plague

Prevention

As the crayfish plague is not able to establish populations without its host, the most effective prevention tools are those that prevent the establishment of exotic crayfish in new locations, see § 8.1 Furthermore, strict protocols for e.g. pond cleaning can be helpful in preventing contamination of the present noble crayfish population. Such protocols should include the disinfection of tools, boots, etc. when they have been recently used in other water systems.

Eradication

The eradication of crayfish plague populations can only be achieved with eradication of its host, see § 8.2.

Management

With the noble crayfish being at the rim of extinction it can be considered to manage the risks of the crayfish plague by establishing more populations within the Netherlands. Several possible locations have been suggested by Niewold (2003). But with exotic crayfish being widely spread also these populations will always be at risk for accidental contamination. A safer solution would be to also preserve noble crayfish originating from the Netherlands by farming them under strictly controlled circumstances, e.g. in a zoo. In Europe farming of the noble crayfish is common practice so it should be relatively easy to import the knowledge needed to start such a farm.

9. Conclusions and recommendations

- One species of native crayfish (noble crayfish) occurs in the Netherlands.
- Nine species of invasive crayfish have been observed in the Netherlands, of which:
- Six species are established
- Two species have been recorded only once (stone crayfish and redclaw)
- One species has an unclear status (marbled crayfish).
- Additionally, four species are included in the risk assessment for various reasons (widely available in trade, tolerance for the Dutch climate, observations of impact in foreign regions).
- Dozens of additional species are available in trade.
- Most of the established species occupy a larger niche than observed in their natural range.
- Therefore, the probability of establishment of 'new species' is hard to predict and can be easily underestimated.
- The distribution and number of releases (e.q. the probability of establishment) of some species is clearly related to the abundance in trade (e.g. the red swamp crayfish and the narrow-clawed crayfish).
- On the contrary, some of the established species are very rare in trade (e.g. the virile crayfish and white river crayfish), showing that incidental imports can have large consequences.
- Two factors determine the import of crayfish in the Netherlands: the aquarium trade and the consumption trade.
- Large quantities of a small number of species (mainly the narrow-clawed crayfish and the red swamp crayfish) are available in the consumption trade. The trade in living specimens declined considerably in the last two decades due to import of dead, prepared crayfish.
- Small quantities of many species are available in the aquarium trade. The aquarium trade is rapidly growing as well as the demand for 'new types' (species).
- Deliberately released crayfish are often obtained (locally) from the wild. Once a species is established, humans play a large role in further excellerating of its expansion (table 4, page 16).
- For five of the evaluated species (red swamp crayfish, the white rivier crayfish, signal crayfish, virile crayfish and rusty crayfish) overwhelming evidence of negative economic and/or ecologic impact has been observed in foreign countries.
- Little evidence of the negative impacts of crayfish is yet available from the Netherlands. Lack of information is the main reason for this deficiency.
- Crayfish may interfere with the goals of the Water Framework Directive.

- Further academic research is strongly recommended to assess the possible impact of the species.
- It is strongly recommended to limit the trade in the genera and species mentioned in table 7D.
- We experienced a lot of commitment among aquarium wholesalers to ban some species from trade.
- A negative species or genera list seems a good starting point for an agreement with the aquarium trade.
- A positive species list of some 'tasty and harmless' crayfish seems a good starting point for an agreement with the consumption trade.

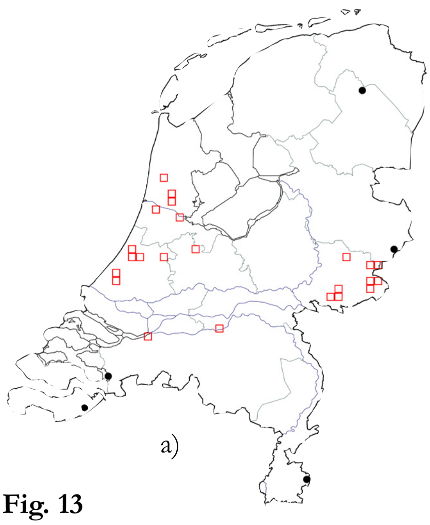
PASSPORT NARROW CLAWED CRAYFISH

Astacus leptodactylus Entscholtz 1823
English: Narrow-clawed crayfish
Dutch: Turkse rivierkreeft
First record: 1977, Rekken, Berkel (province of Gelderland)

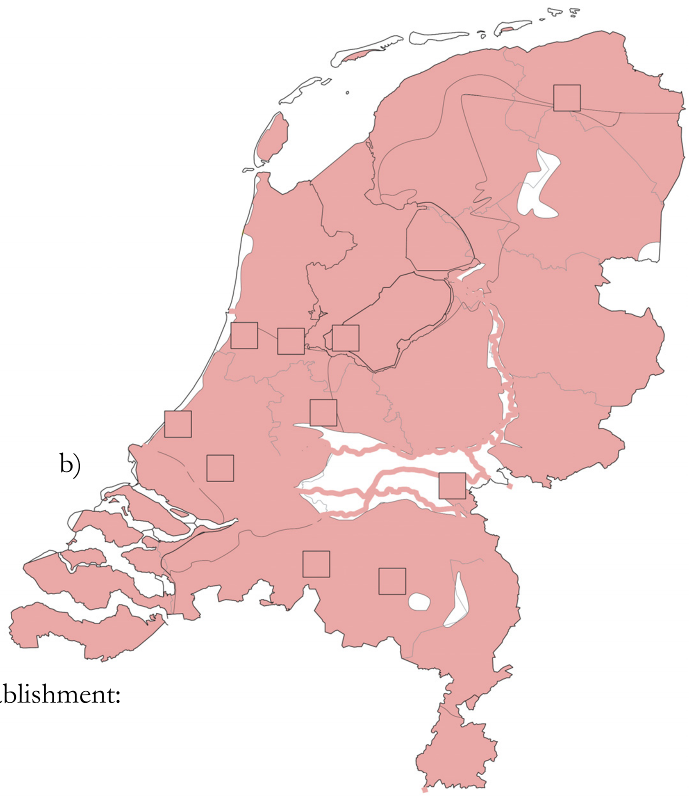
Distribution
The species is less frequently recorded than 20-30 years ago (fig. 13a) Nowadays, the species is relatively frequently found in isolated habitats (see appendix 3).

Introduction pathway
The species is almost certainly introduced by the consumption trade, although the first specimens observed in the Netherland might have entered the country indirectly from Germany. The narrow-clawed crayfish has been of high commercial value for the catering industry, especially in Eastern Europe, Turkey and Iran, although Turkish stocks severely suffered from crayfish plague and overfishing (Skurdal & Taugbøl 2002). A record of the narrow-clawed crayfish in the Brinckborsthaven in Voorburg (province Zuid Holland) in 1989 might originate from a sample that was released by an inhabitant of a houseboat shortly before the specimen was caught at the same location (Anonymus 1989). Van Laar (1984) observed two specimens in a school aquarium in the city of Amerfoort (province of Utrecht) in 1983. The specimens turned out to be leftovers from a restaurant near Haarzuilens (province of Utrecht).

Sources
Although the overall demand for living freshwater crayfish (and thus the narrow-clawed crayfish)



a)



b)

Fig. 13
a) Distribution of the narrow-clawed crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

dropped due to the rise of the Chinese supply of prepared red swamp crayfish, the narrow-clawed is still traded alive. Wholesaler Jan van As (Amsterdam) sells ‘a few hundred kilo’s a year’ of the specimen. The animals are obtained from France, but are cultivated in Turkey. The species is also cultured for fishponds (koidream.nl, Veenendaal).

Table 7. Preference table of the narrow-clawed crayfish
0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l)	pH (>5,5)	average
dunes	2	1	1	1	1	1	1.17
marine clay	1	1	2	2	2	1	1.50
peat bog	1	1	2	2	1	1	1.33
riverine clay	1	1	1	2	1	1	1.17
rivers & IJsselmeer	2	1	2	2	1	1	1.50
pleistocene bog	1	1	1	1	1	0	0.00
pleistocene sand	2	1	1	2	1	1	1.33
lime stone	2	1	2	2	1	1	1.50
urban	2	1	2	2	1	1	1.50

Probability of establishment.

Ecologically, we expect that the narrow-clawed crayfish is able to thrive in most of the inland freshwater systems. The species inhabits a wide range of habitats, mostly permanent canals, rivers and lakes of a certain depth. The narrow-clawed crayfish is highly salt tolarable and can often inhabit brackish waters (estuaries). The species might survive salinities of 28 promile over a 9-week period buth juveniles only hatch at salinities of 7 promile (20% seawater) (Holdich et al. 1997). The species is vulnerable to the crayfish plague, which might bring up severe limitations at sites where the American crayfish is present. The preference scores in table 7 were, therefore, manually lowered on the map.

Probability of spread

Due to the small but ongoing trade in living specimens of the narrow-clawed crayfish, we expect that the species will continue to show up regularly at unpredictable sites. Some of the introductions might result in local populations but, taking the last thirty years as a precedent, we don’t expect large population expansions.

Expected introductions

A considerable population of narrow-clawed crayfish occurs in the Damse vaart near Damme in Belgium (pers. comm. Koen Lock/waarnemingen.be), which has a direct connection with the fortification canals of Sluis (province of Zeeland). Most likely, the species occurs here already.

Impact

Not recorded. Large quantities of the narrow-clawed crayfish were observed in a reservoir (Craneweyer, now primary used for recreation and fishing) near Kerkrade in Limburg, 2009, which raised some concern among local fisherman.

Passport Signal crayfish

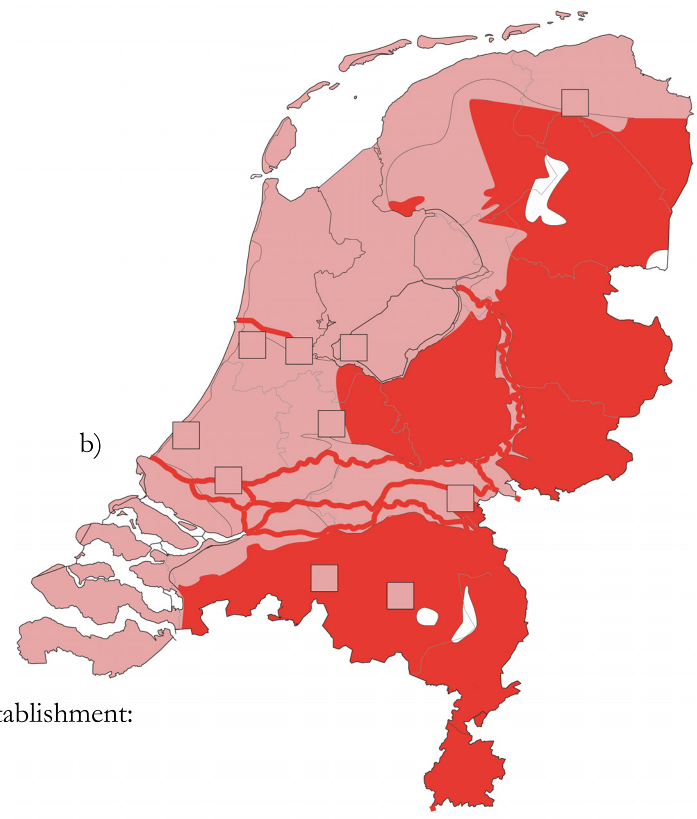
Pacifastacus leniusculus (Dana, 1852)
English: Signal crayfish
Dutch: Californische rivierkreeft
First record: 2004, Dinkel/Ruenbergerbeek (province of Overijssel)

Distribution
At present, two populations are known: one at the Oude Leij near Tilburg (province of Noord-Brabant) and one in the Ruhenbergerbeek and Dinkel near Enschede (province of Overijssel) (fig. 14a).

Introduction pathway
The population in the Dinkel/Ruhenbergerbeek most likely originates from Germany (Knol 2005). Although the population of the signal crayfish near Tilburg lies close to the border, there are no indications that the species originated from Belgium (Wielink & Spijkers 2008). Introductions to Europe started around the 1960s, primarily as a commercially attractive alternative for the plague decimated noble crayfish which occupies a similar niche (Lewis 2002). The species was experimentally cultured in Belgium around the 1980s (Adema 1989). The signal crayfish represents a high commercial value in the Scandinavian trade as it is one of the few specimens that could withstand the climate.

Sources
We weren't able to find any current trades in the Netherlands in this species, although we did noticed a description of a specimen kept in an aquarium (www.kreeftengarnalen.nl). Due to the large interest in this species for consumption, this is one of the few species that might be imported for catering rather than for aquaria

a)



b)

Fig. 14
a) Distribution of the signal crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

Probability of establishment.

Due to the ecological similarities, the signal crayfish has a high probability to become established in the former niche of the native noble crayfish (permanent lowland streams in the south and east, see preference scores in table 8).

Currently, only the spiny-cheek crayfish can be found in this habitat.

Table 8. Preference table of the signal crayfish
0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l	pH (>5,5)	average
dunes	2	1	1	1	1	1	1.17
marine clay	1	1	2	2	2	1	1.50
peat bog	1	1	2	2	1	1	1.33
riverine clay	1	1	1	2	1	1	1.17
rivers & IJsselmeer	2	2	2	2	1	1	1.67
pleistocene bog	1	1	1	1	1	0	0.00
pleistocene sand	2	2	1	2	1	1	1.50
lime stone	2	2	2	1	1	2	1.67
urban	2	1	2	1	1	1	1.33

Probability of spread

The species is known as a relatively slow natural disperser. In England, the observed downstream dispersion varied from 12 km in 17 years (=0,7 km/year) up to 2,4 km/year (Souty-Grosset et al. 2006). Wielink et al. (2010) estimated an upstream migration of 1 km over four years in Tilburg (the Netherlands) but this rate included the surpassing of one sluice. Overland movements are unusual and have not yet been observed in the Netherlands.

Impact

Since the first record of a signal crayfish in the Oude Leij near Tilburg in 2005 at least one fish species, the stone loach (*Barbatula barbatula*) showed a considerable decline (fig. 15a). It is unclear whether there is a causal relation between the two observations (Van Wielink et al. 2010).

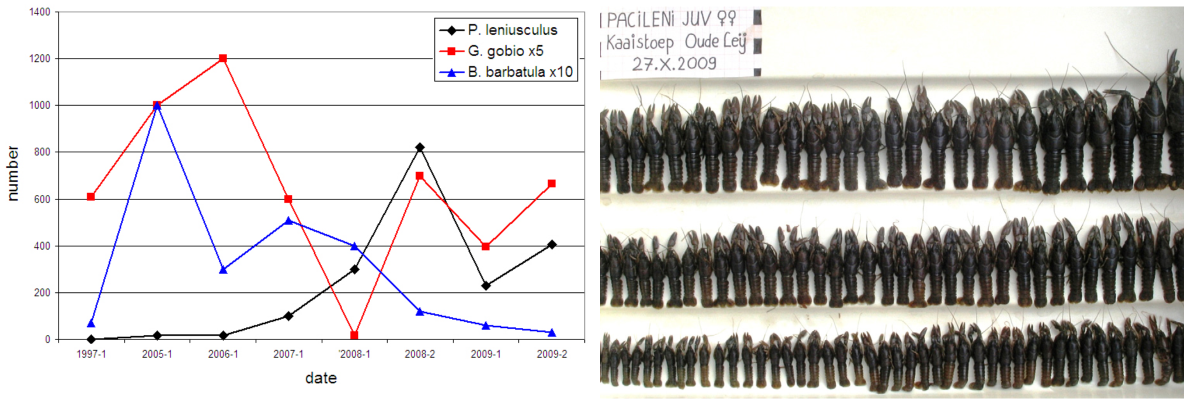


Fig. 15. a) The signal crayfish versus two fish (*G. gobio* and *B. barbatula*) Oude Leij 1997-2009; b) Juveniles in order Source: Van Wielink et. al. 2010

Passport Spiny-cheek crayfish

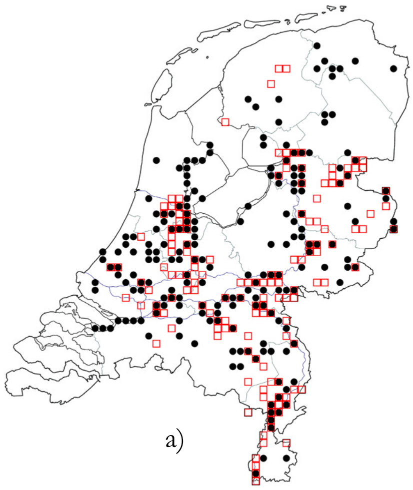
Orconectes limosus (Dana, 1852)
English: Spiny-cheek crayfish
Dutch: Gevlekte Amerikaanse rivierkreeft
First record: 1968, Maastricht, Jeker (province of Limburg)

Distribution
The spiny-cheek crayfish can be found in all provinces (fig.16a). It is a common species in rivers, larger canals and lakes. The species is scarce in shallow waters and seems quickly out competed in such habitats when other invasive crayfish (such as the white river crayfish, the red swamp crayfish and the virile crayfish) arrive.

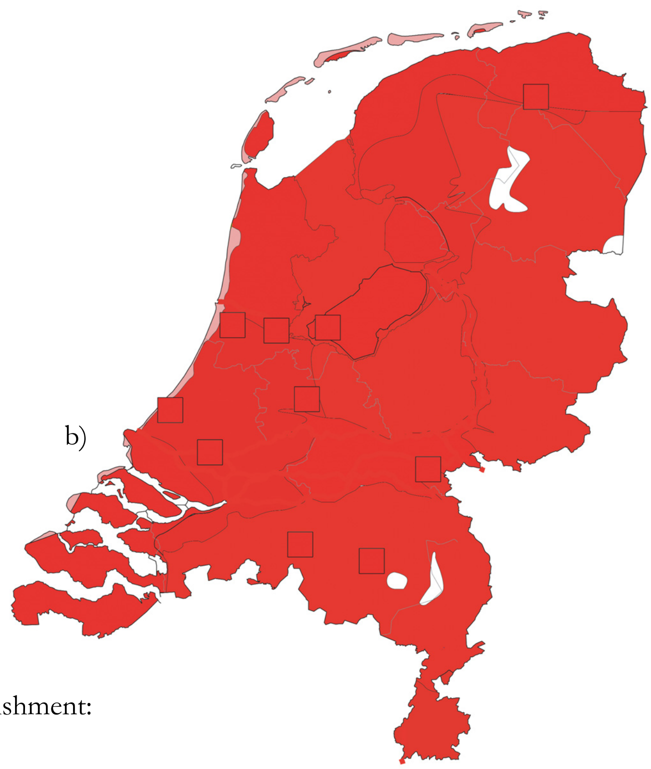
Introduction pathway
The specimen was introduced in Germany in the 19th century and arrived in the Netherlands in the 1960s. Its expansion seems largely accelerated by human displacements. The spiny-cheek crayfish is most frequently involved in the documented deliberate crayfish introductions (table 4, page 16). Additionally, the species has been recorded in at least nine isolated (fish) lakes (see appendix 3). The species has been 'rescued' several times because it was mistaken for the noble crayfish.

Sources
The species is uncommon in trade. The spiny cheeked crayfish is still the most widespread and common crayfish in the Netherlands. The species is often obtained from the wild and released elsewhere.

Probability of establishment.
The spiny-cheek crayfish is a highly tolerant species that can be expected almost everywhere (fig. 16b).



a)



b)

Fig. 16
a) Distribution of the spiny-cheek crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

Probability of spread

Pieplow (1938) estimated a natural dispersal of 5 km/year in one direction for populations of the spiny-cheek crayfish in Germany. Based on this calculation, Geelen (1978) assumed that the spiny-cheek crayfish was already present in the Netherlands 15 years prior to its recognition. The spiny-cheek crayfish has certainly often been overlooked or mistaken for the noble crayfish. It is worth mentioning however, that the species was not observed in Friesland/Groningen until 1989.

Despite its common appearance and wide distribution, the species is rarely observed on land in the Netherlands. Only four out of five land observations in the EIS database are related to specimens that were forced to walk directly after dredging or dehydrating. However, in Poland, the species has been observed several 100 meters from the water at night after rainfall (pers. comm. Paul Veenvliet).

Table 9. Preference table of the spiny-cheek crayfish 0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l	pH (>5,5)	average
dunes	2	1	1.5	1	1	2	1.42
marine clay	2	1	2	2	2	2	1.83
peat bog	1	1	2	2	1	2	1.50
riverine clay	2	1	1.5	2	1	2	1.58
rivers & IJsselmeer	2	1	2	2	1	2	1.67
pleistocene bog	1	1	1.5	1	1		0.00
pleistocene sand	2	1	2	1.5	1	2	1.58
lime stone	2	1	2	2	1	2	1.67
urban	2	2	2	2	1	2	1.83

Impact

As it was the first introduced species in Europe, the spiny-cheek crayfish is held largely ‘responsible’ for the collapse of the noble crayfish in Europe. Due to its wide distribution, the species still blocks the recovery of Astacid species in Europe (as it is a carrier of the crayfish plague). Other than that, no impact has been recorded.

Passport Virile crayfish

Orconectes virilis (Dana, 1852)
English: Virile crayfish
Dutch: Geknobbelde Amerikaanse rivierkreeft

Taxonomic notes

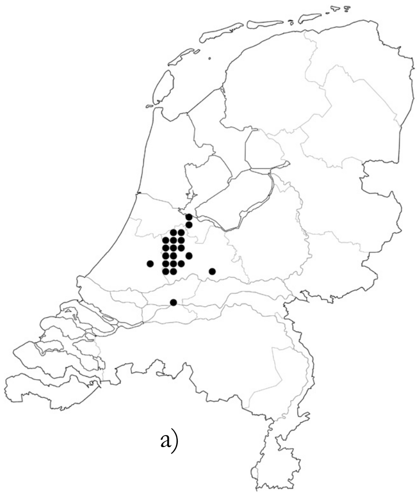
The virile crayfish represents a cryptic species complex with several lineages known in the USA, and a wide introduced range. Filipova et al. (2009) assessed the position of both known European populations within the species complex by molecular methods. Tested UK and Dutch individuals turned out not to belong to any mitochondrial lineage recorded in North America so far but formed a separate clade. This means that the original distribution area of the Dutch and English populations is actually unknown. Also it has become likely that it might be a different species, e.g. O. causeyi. Further work including more North American specimens will hopefully clarify this taxonomical issue (A. Petrusek, pers. comm.). In the present situation using *Orconectes virilis* s.l. seems to be the best temporary solution.

Distribution

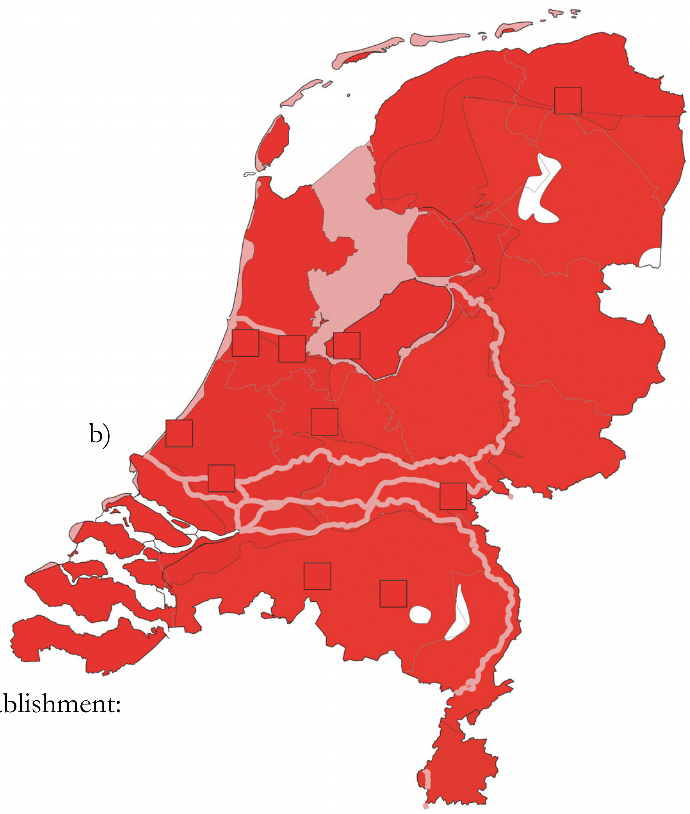
The main population is situated north of the village of Woerden (province of Utrecht) (fig. 17a).

Introduction pathway

The origin of the population is unknown. The species is offered by a garden pond wholesaler in Vinkeveen. The species was observed in a garden centre in Leeuwarden (province of Friesland) in 2003, a year before the first observation in nature (Paul Veenvliet pers. comm.). The species troubled the garden centre due to their persistent escapes. A few specimens were found dry and dead in the centre



a)



b)

Fig. 17
a) Distribution of the virile crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

later.

Sources

The species seems rather rare in the aquarium trade, although we did notice one garden centre selling the species. Aquarium wholesaler Ruinemans (pers. comm.) sold the species only once (a few specimens that were brought in by a local fisherman).

Probability of establishment.

The species preferences are quite similar to that of the spiny-cheek crayfish (table 10, fig. 17b). However, the species seems to have a competitive advantage in shallow waters (with peat soil), whereas the spiny-cheek crayfish is usually abundant at deeper sites (with sand and grit).

Table 10. Preference table of the virile crayfish
0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l	pH (>5,5)	average
dunes	2	1	1.5	1	1	2	1.42
marine clay	1	1	2	2	2	2	1.67
peat bog	1	2	2	2	1	2	1.67
riverine clay	1	1	1.5	2	1	2	1.42
rivers & IJsselmeer	1	1	2	1	1	2	1.33
pleistocene bog	1	1	1.5	1	1	0	0.00
pleistocene sand	2	1	2	1.5	1	2	1.58
lime stone	2	1	2	2	1	2	1.67
urban	2	2	2	2	1	2	1.83

Probability of spread

Occasional records in low land rivers connected to the main population (e.g. the Vecht, the Linschoten, the Kromme rijn and the Merwede) suggest a rapid spread through larger waterbodies.

Impact

The virile crayfish most likely responsible for the decline of macrophytes in a few canals in the Netherlands (Emmerik & Laak 2008, Soes 2008, Soes & Spier 2006). Also in North America, the species is known to have a marked impact on the abundance of macrophytes. Addionally extensive burrow networks in the banks of rivers have been observed in their home range (Souty-Grosset et al. 2006). The species is well adapted to low temperatures. The virile crayfish is in fact the northernmost species in Canada. The potential impact of this species is high.

Passport White river crayfish

Procambarus acutus
English: (Eastern) white rivier crayfish
Dutch: Gestreepte Amerikaanse rivierkreeft
First record: 2002, Hardinxveld (province of Zuid-Holland)

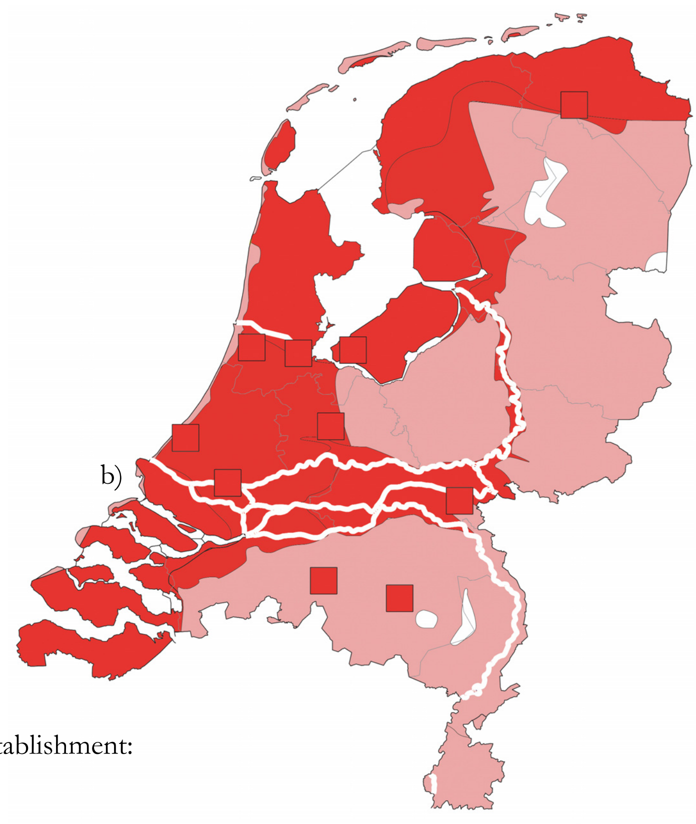
Taxonomic notes

Until recently, the identity of Dutch populations of this species was considered as not resolved. Due to uncertainties about the diagnostic characters separating *P. zonangulus* and *P. acutus* the Dutch populations were published as *P. acutus/zonangulus*. Recently Chris Taylor (Illinois Natural History Survey) identified Dutch specimens as *P. acutus*. In 2010 a project in co-operation with L. Filipova and A. Petrusek (Charles University, Prague) is started to confirm its identity also with molecular methods.

Distribution

The main population occurs on 'the isle of Hardinxveld' (province of Zuid-Holland) (fig. 18a, see also fig. 1, page 6). The habitat consists of a network of shallow ditches on stretch of land between a large river (Merwede) and a large canal (Kanaal van Steenhoek). It seems that the species managed only recently to start a succesfull setlement north of the canal (pers. comm. André Blokland). A single specimen was found in a pond in a backyard in Hoek van Holland in 2009. The species is certainly released here, although the owner didn't have any clues about the origin of this specimen.

a)



b)

Fig. 18
a) Distribution of the white river crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

Introduction pathway

Unknown. The closely related *P. zonangulus* is cultivated extensively for consumption in the U.S. (sometimes in co-occurence with the red swamp crayfish) (Huner 2002). However, we are not aware of extensive aquacultures of white river crayfish. The presence of a large aquaculture for fish on the isle of Hardinxveld is certainly suspicious.

Sources

A local fisher currently sells the species for ponds and restaurants.

Probability of establishment.

The species has a high probability to become established outside it's current range. It's habitat requirements seem to match that of the red swamp crayfish, resulting in a similar probability map. The (competitive) relationship between red swamp crayfish and *P. zonangulus* (which is considered to be similar enough to the white river crayfish (*P. acutus*) to be comparable) is complex. In the U.S., the offspring of *P. zonangulus* is normally larger than the red swamp crayfish. Therefore, the timing of the release of the offspring seems an important factor determining the population composition over time (Huner 2002). On the contrast to their native range, the red swamp crayfish grows considerably larger than the white river crayfish in the Netherlands, which might be advantageous. However, we expect *P. acutus* to be more succesfull in withstanding Dutch winters, due to the fact that its natural range reaches as north as Maine (whereas the natural range of the red swamp crayfishis situated around the Gulf of Mexico). A specimen of the white river crayfish survived a night in a nearly frozen bucket, whereas a specimen of the red swamp crayfish in the same bucket died (pers. comm. André Blokland).

Table 11. Preference table of the white river crayfish
0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l	pH (>5,5)	average
dunes	1	2	1.5	1	1	2	1.33
marine clay	2	2	1	2	2	2	1.83
peat bog	2	2	1	2	1	2	1.67
riverine clay	2	2	1.5	2	1	2	1.75
rivers & IJsselmeer	1	0	1	2	1	2	0.00
pleistocene bog	2	2	1.5	1	1	0	0.00
pleistocene sand	1	2	1	1.5	1	2	1.42
lime stone	1	1	1	2	1	2	1.33
urban	1	2	1	1	2	2	1.50

Impact

Little impact of this species has been observed. As the Dutch population is unique within Europe, no reference data for other locations are available. Similar consequences as found in the red swamp crayfish are to be expected due to its similar life strategy.

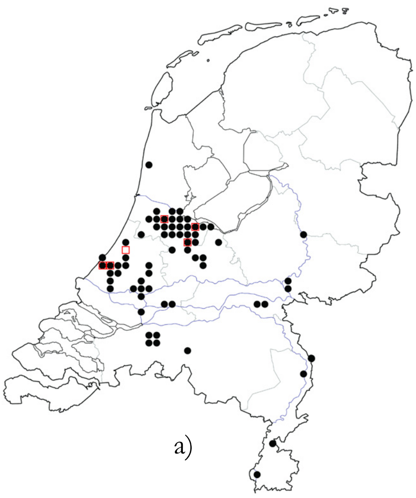
PASSPORT RED SWAMP CRAYFISH

Procambarus clarkii
English: Red Swamp Crayfish
Dutch: Rode Amerikaanse rivierkreeft
First record: 1985, Den Haag, Veenkade (province of Zuid-Holland)

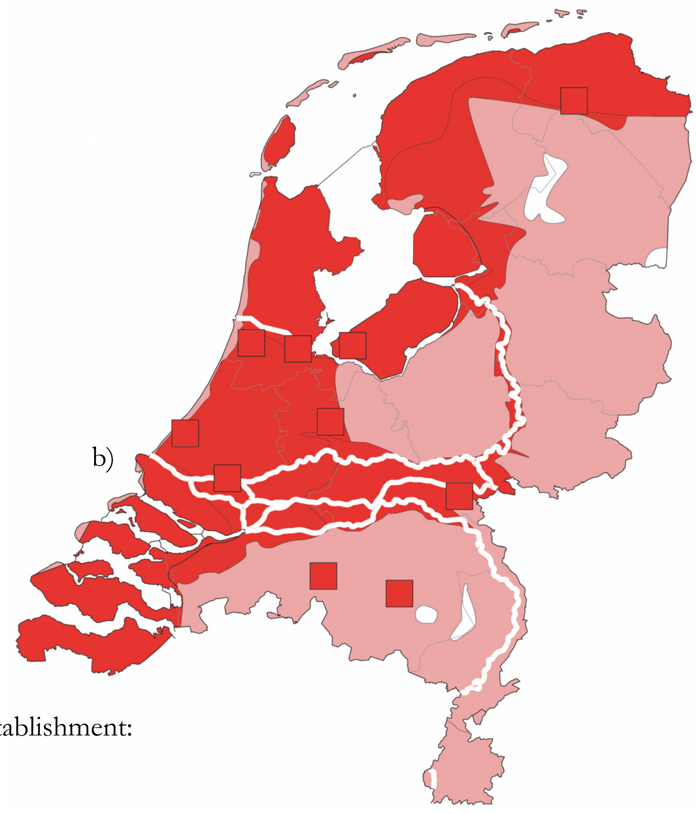
Distribution
The distribution of the red swamp crayfish is closely associated with larger urban concentrations (fig. 19a, see also fig. 1, page 6). The species occurs in seven out of ten largest municipalities of the Netherlands (Amsterdam, Rotterdam, Den Haag, Utrecht, Nijmegen, Haarlem, Tilburg), as well as a few other cities (Breda, Dordrecht, Gouda).

Introduction pathway
The species showed up simultaneously in the aquarium trade and in the consumption trade at the beginning of the 1980s. Fisheries wholesaler Roskam & Klaver B.V. (Zwartsluis) used to sell 'hundreds of specimens' imported from Kenya around 1984 (Anonymus 1984). The release of a number of specimens from Kenia in a canal in the Hague by a restaurant was described by Henny (1985). Van Laar (1984) observed 'probably a red swamp crayfish' in a school aquarium in the city of Amersfoort in 1983 , which was a leftover from a restaurant near Haarzuilens (province of Utrecht). Around 1982, the species was available through the aquarium whole saler 'Ruinemans' (pers. comm. Paul Veenvliet).

Sources
The species is one of the most popular specimens in the aquarium trade (see fig. 9, page 19). The trade in living specimens in the catering industry declined due to the import of prepared specimens from China.



a)



b)

Fig. 19a
a) Distribution of the red swamp crayfish
Red squares: records before 2000.
Black dots: from 2000

b) Predictive map of the probability of establishment:
■=optimal habitat available;
■=suboptimal habitat available
□=sustainable populations unlikely

Probability of establishment.
The red swamp crayfish is a highly adaptive species which has a high chance to become established in a variety of habitats, especially shallow, dynamic (disturbed) habitats with enough opportunities for sheltering (Gherardi 2006).

Probability of spread
The red swamp crayfish is a an active crayfish that is capable to walk many kilometers per night under favorable conditions. The species is renowned for its capacity to walk overland. Therefore, the species is hardly limited to connected waters.
Besides a natural spread, the red swamp crayfish is particularly subject to repeated releases by humans. Both in the aquariumtrade as well as in the consumption trade, the red swamp crayfish is one of the most popular species. New introductions can be expected everywhere, especially around urban areas. Fig. 20 shows the number of new localities of the red swamp crayfish per year. (new records within 5 kilometer of existing populations are not considered). On average, the species showed up at six new sites per year in the period 1999-2008, with an increasing number of sites in the last two years. Unusually, not a single new site was recorded in 2009 despite a 'normal' number of observations around existing sites. It is tempting to assume that species had suffered from the harsh winter of 2008-2009.

Table 12. Preference table of the red swamp crayfish
0=aversion, 1=no preference, 2=preference/resistence

	soil	current	stability	connectivity	salinity (>300 mg/l	pH (>5,5)	average
dunes	1	2	1.5	1	1	2	1.33
marine clay	2	2	1	2	2	2	1.83
peat bog	2	2	1	2	1	2	1.67
riverine clay	2	2	1.5	2	1	2	1.75
rivers & IJsselmeer	1	0	1	2	1	2	0.00
pleistocene bog	2	2	1.5	1	1	0	0.00
pleistocene sand	1	2	1	1.5	1	2	1.42
lime stone	1	1	1	2	1	2	1.33
urban	1	2	1	1	2	2	1.50

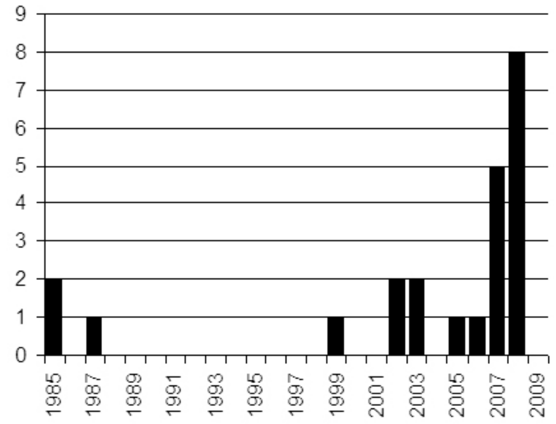


Fig. 20. Number of new localities (5x5 km squares) per year of the red swamp crayfish in the Netherlands. 'New localities' are defined as records in 5x5 squares that are at least 5 km away from excisting localities of the red swamp crayfish . Source: EIS-database.

Impact
In the Netherlands, some collapses of flowerpots have been observed in flower-cultures near Waddinxveen due to burrow activities (pers. comm. Hans v.d. Laan).
The impact of the red swamp crayfish can be substantial, both economically as well as ecologically. The observed economic impact is nearly limited to rice cultures. Leakage of the small, waterproof dikes separating each rice field, is the main economic damage in the rice industry, although predation of young rice seedlings also plays a role (Anastacio et al. 2005). Comparable damage as observed in Southern European rice fields is not expected in the Netherlands for several reasons. First, factors that stimulate digging behaviour are largely absent in the Netherlands. This includes factors such as: temporal dyhydration of the habitat and high predation rates (by birds) in relation to little available deep water for shelter. Secondly, the dimensions of hydraulic engineering works in the Netherlands (dikes, storage embankments) are considerably larger than the works in rice fields (see fig. 12, page 33).
Ecologic damage is caused by its active and aggressive behaviour. A dramatic loss of macrophytes has been observed multiple times which in turn caused important changes in the foodweb and loss of many other animal groups. Since the activity is the red swamp crayfish is greatly reduced at temperatures below 10 °C (Vletter 2008a) the species activity is, on average, extremely low in winter in the Netherlands. Therefore, the ecological impact of the red swamp crayfish is likely to be less than in southern European lakes and rice fields (where the species can be active all year round).

Passport Marbled crayfish

Procambarus sp.
Marbled crayfish
Dutch: Marmerkreeft
First record: 2004, Dordrecht, Vlij (province of Zuid-Holland)

Taxonomic notes
The origin of the marbled crayfish is unknown. It first appeared in German pet stores during 1990s. As it reproduces by self-cloning or parthogenesis, there are only females available. With procambarid taxonomy being mainly based on male gonopods, identification of a female marbled crayfish based only on morphological characters is not very reliable.

Both *P. fallax* and the Everglades crayfish have been mentioned as the parental species. Morphological analysis proofed the marbled crayfish to be most similar with *P. fallax*. Molecular analysis gave close affinity with both the Everglades crayfish and *P. fallax* (Kawai et al. 2009, Marzano et al. 2009). This is especially remarkable as both species are thought to be members of different subgenera (Hobbs, 1989). Furthermore, it is not impossible that more parthenogentic lineages exists as is shown for the red swamp crayfish (Yue et al., 2009). So far the identity of the parental species of the marbled crayfish should be considered unresolved, although it seems clear that a species from southern USA is involved.

Distribution
The species was first recorded in Dordrecht in 2004 (fig. 21). A few specimens were crawling on the land after the cleaning of a canal. They were relocated to an aquarium by a local and identified later (Lipmann 2007). Its current status is unclear.

Introduction pathway
The species entered the country through the aquarium trade.

Sources
The species is widely available through the aquarium trade. In Januari 2010, the species coud be obtained from at least ten public sources in six different provinces (see appendix 2).

Probability of establishment
Until recently, the species was only known from the aquarium-trade. Therefore, little could be said about its capacity to survive in the wild. In the aquarium, they are best cultured at temperatures between 18 °C and 25 °C. It is able to survive temperatures < 8 °C and > 30 °C for long times, but mortality increases and reproduction stops under such conditions (Souty-Grosset et al. 2006). Recently, the species has been discovered in the wild in Madagascar and Italy. In Madagascar, the species occurs in 'high numbers' in two rivers, but other than that, nothing is reported about the habitat (Kawai et al. 2009). In Italy, a single specimen was caught in a well settled population of the red swamp crayfish in a slow flowing canal in Toscana, central Italy (250 m. ASL) (Marzano et al. 2009).

Fig. 21
Distribution of the Marbled crayfish
Red squares: records before 2000.
Black dots: records: from 2000

Probability of spread
Unknown

Impact
The Marbled crayfish possibly has a similar ecology as the other *Procambarus* species in the Netherlands. Evidence for this is based on the fact that the species has shown to have a relatively large portion of plant organic material in the gut in the wild in Madagascar (Kawai et al. 2009). Additionally, the species has been found amongst red swamp crayfish in the wild. The Dutch climate might be relatively disadvantageous for the Marbled crayfish compared to the other *Procambarus* specimens. However, the fact that only a single individual can be the source of an entire population (see below) still posesses a large threat.

Passport *Orconectes juvenilis/rusticus*

Orconectes rusticus & Orconectes juvenilis
Rusty crayfish
Dutch: -

Taxonomic notes

An French population of *O. juvenilis* was first reported as *O. rustics*. *O. juvenilis* is only relatively recent elevated to the species level and formally considered as a synonym of *O. rusticus* (Chucholl & Daudey 2008, Hobbs 1989). As the distribution of the two species in North America is not well understood and as the ecology of the two species seems to be comparable, the two species are treated together in this report.

Distribution

Not recorded in the Netherlands

Sources

The rusty crayfish is not available in the regular aquarium trade (pers. comm. Kreeftengarnalenshop). It has a high chance to show up in the hobby trade due to the fact that this common species can be easy accessed. The species was banned from trade in 2003 in Sweden, after strong interest by Swedish importers to introduce the species for consumption in order to compensate for the loss of stocks of the noble crayfish (Hamr 2002, Souty-Grosset 2006) is primarily used as fishbait in North America, which is the source of many introductions outside its native range in other states in the USA and Canada. As the use of crayfish as fish bait is rather unusual in the Netherlands, this is not considered as a source of introduction. The species (*O. juvenilis*) was introduced through the consumption trade in eastern France (Chucholl & Daudey 2008). The population in France in the Dessoubre river (a part of the Rhône basin) is still very far away and not directly connected to Dutch water systems.

Probability of establishment

The rusty crayfish has a high probability to become established. Many introductions in Canada show that the species tolerates low temperatures and that the species can successfully compete with a number of crayfish species. The species displaced the virile crayfish at many locations in Canada (Hamr 2002). The fact that the virile crayfish is locally common in the Netherlands, indicates that suitable habitat is available for *O. rusticus/juvenilis* as well. Therefore, the same map for the probability of establishment is used (fig. 22).

Probability of spread

Momot (1997) observed a relatively rapid natural spread of 0,5 km/year upstream and 4,7 km/year downstream of invasive populations of the rusty crayfish in Canada (Ontario).

Impact

Besides shallow excavations under stones, the species generally does not dig burrows. Therefore, the species is expected to cause little economic impact. Due to its aggressive and active behaviour, the species possesses a serious ecological impact. Major reductions of aquatic plants due to the rusty crayfish have been observed in Canada and North America (Hamr 2002).

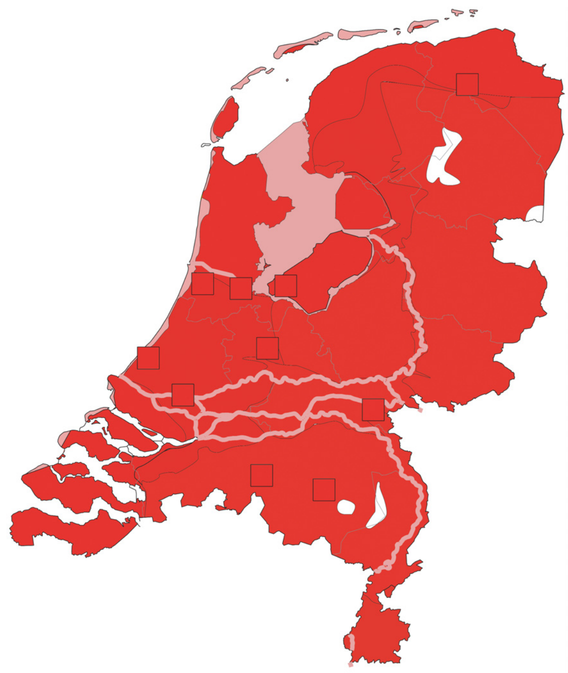


Fig. 22. Predictive map of the probability of establishment:
■ =optimal habitat available;
■ =suboptimal habitat available
□ =sustainable populations unlikely

Passport Calico crayfish

Orconectes immunis
Calico crayfish
No Dutch name

Sources

A population of the calico crayfish exists in the River Rhine Basin. The species was discovered in the Rhine near Mannheim in 1993 and colonized a stretch of more than 100 km along the Rhine in approximately 10 years (Gelmar et al. 2006).
The species was not identified in the Dutch trade.

Probability of establishment

Since the species could succesfully compete with the common spiny-cheek crayfish, we estimate the probability of establishment as high.

Probability of spread

Based on the estimated natural expension rate of the spiny-cheek crayfish (see page 47) we expect the species to arrive in the Netherlands within two decades, although the species is still far away (ca. 400 km.)

Impact

The calico crayfish has been successfully applied in weed control, reflecting its potential impact (Letson & Makarewicz 1994).

Passport Everglades crayfish

Procambarus alleni
Everglades crayfish
Dutch: Blauwe Floridakreeft

Sources

The Everglades crayfish is very popular in the aquarium trade. Of the evaluated species, the Everglades crayfish is the third most traded specimen on the internet (covering 15% of the trade in January 2010), after the red swamp crayfish and the marbled crayfish (fig. 9, page 19, appendix 2).

Probability of establishment

In its native range, the Everglade crayfish is adapted to unstable environments such as flooded marshes (Hendrix & Loftus 2000). The species tolerates high salinity levels and long periods of drought (in burrows). The species is endemic to subtropical marshes (mean temperatures: 16 °C - 27 °C) in Florida. In the aquarium trade, it's recommended to keep the species at temperatures similar to that of the Marbled crayfish (18 °C - 25 °C). The Everglades crayfish is considered to be closely related to the Marbled crayfish. Although the species is potentially ecologically adapted, it is most likely limited by the Dutch climate. Therefore, the probability of establishment is low. The species has been recorded in France (Souty-Grosset et al. 2006) but to our knowledge, no other accounts of invasive populations of the Everglade crayfish exist.

Probability of spread

Despite its resistance for the crayfish plague, the species most likely has a competitive disadvantage compared to the other (*Procambarus*-) species due to its limited tolerance for low temperatures.

Impact

The Everglade crayfish has a ecology quite similar to other *Procambarus* species. In its native range, it could live in extremely high densities (up to 28 m^2) (Jordan et al. 1996). The species can make extensive burrows, usually in response to drought. Due to a lack of reference regions, the potential impact is hard to predict, but it is considered to be low because of the climate.

Passport Yabby

Cherax destructor
Yabby
No Dutch name

Distribution

Not recorded in the Netherlands

Sources

The Yabby is a relatively common species in the aquarium trade. We identified at least three different sources (see appendix 2).

Probability of establishment

Like all *Cherax* species, the Yabby thrives best at higher temperatures. Growth stops at temperatures below 15 °C, but the species tolerates temperatures as low as 1 °C. Additionally, the species is highly tolerant towards low oxygen levels as well as increased salinity levels. Based on ecological characters, the species is potentially adapted to the Dutch environment. Due to its Australian origin, the yabby is highly susceptible to the crayfish plague. The plague was succesfully used to eradicate two exotic populations in Spain. The populations died out within 30 and 120 days after introduction of the plague respectively (Souty-Grosset et al. 2006). The species stands little chance in combination with American species. Thus, succesfull establishment is only expected in isolated areas.

Probability of spread

Due to the sensitivity for the crayfish plague it is not likely to be able to colonize larger areas.

Impact

In aquaria and aquaculture this species is a true generalist eating both plant and animal matter. Its possible impact on e.g. vegetation is data deficient, but high impact in the Netherlands is not expected as it is not likely to become widely distributed.

Passport Redclaw

Cherax quadricarinatus
Redclaw
Dutch: Australische roodklauwkreeft

Distribution

A single specimen was recorded in Wageningen, province of Gelderland in 2007 (Soes 2008).

Sources

In Europe, the species is one of the main species in the aquarist trade. Also in the Netherlands, the species can easily be obtained but the species is less popular than *Cambarellus* and *Procambarus* (see appendix 2).

Probability of establishment

In literature concerning the keeping of the redclaw it is clearly stated that this species prefers temperatures above 20 °C (Werner, 1998). According to Austin (1995) it is unable to tolerate temperatures below 10 °C for a longer period. In England, however, there is doubt about these statements and it is suggested that this species might actually be more tolerant to low temperatures. Furthermore, there is also a claim of a population in northern Germany (D. Holdich, pers. com.).
The redclaw is sensitive for the crayfish plague reducing its potential distribution dramatically. Therefore, it is only expected to form populations in isolated waters such as ponds.

Probability of spread

Due to the sensitivity for the crayfish plague, it is unlikely that the species will be able to colonize larger areas.

Impact

In aquaria and aquaculture this species is a true generalist eating both plant and animal matter. Its possible impact on e.g. vegetation is data deficient, but high impact in the Netherlands is not expected as it is not likely to become widely distributed.

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Appendix 1: Introduction survey question list

We ask your attention for the following:.
Naturalis [National Museum of Natural History] is working on an inventory of introduction routes of crayfish in the Netherlands. As an addition to the existing sources, we would like to ask you a few questions about your possible 'hidden knowledge'. We are interested in answers on the following questions:

- Have you ever released crayfish (or do you know someone who relaesed crayfish)?
- Which species was that?
- What was the origin of the species? (for example aquariumtrade, consumption trade, free nature?
- What was the motivation underlying the release (e.g. unsuitable for aquarium, fishbait, rescue of the crayfish on the street).
- Where did the species come from and where is the species released again?

Other 'hidden' information with regard to crayfish introductions in the Netherlands is welcome as well of course.
For all clarity. This inventory is NOT meant to point accusing fingers afterwards. Feel free to confess your childhood sins; we all played with aquaria once. Names will not be mentioned in the paper without your permission.

Original text:
Wij vragen uw aandacht voor het volgende:
Naturalis inventariseert de introductieroutes van kreeften in Nederland. Ter aanvulling van de bestaande bronnen zouden we graag een beroep willen doen op de verborgen kennis die mogelijk bij u aanwezig is. We zijn geinteresseerd in antwoorden op de volgende vragen:

- Heeft u wel een kreeften uitgezet (of kent u iemand die kreeften heeft uitgezet)?
- Welke soort was dat?
- Wat was de herkomst van de soort (bijv. aquariumhandel, consumptiehandel, wilde natuur?)
- Wat was de reden van uitzetting (bijv. ongeschikt worden voor aquarium, hengel-aas, redden van kreeft op straat).
- Waar kwam de soort vandaan en waar is de soort weer uitgezet?

Andere 'verborgen' informatie m.b.t. to kreeftintroducties in Nederland is uiteraard ook welkom.
Voor alle duidelijkheid. Deze inventarisatie is NIET bedoeld om achteraf met beschuldigende vingers te kunnen wijzen. Kortom, u kunt eerlijk uitkomen over uw jeugdzondes; we hebben allemaal wel eens met aquaria gespeeld. Namen zullen niet in vermeld worden zonder uw toestemming.

Appendix 2: overview of public sources

The list is meant to quantify interests and sources at a certain moment (January 2010). Due to the temporary existence of various sources, it can not be used as an accurate list of all subcontractors.

Interest	Species	Reference	Location	Origin
Aquaria	*Astacus leptodactylus*	Koidream (www.koidream.com)	(UT) Veenendaal	cultivation
Consumption	*Astacus leptodactylus*	Jan van As B.V. pers. comm.	(NH) Amsterdam	import (Turkey)
Aquaria	*Cherax destructor*	speurders.nl	(LI) Beek	cultivation
Aquaria	*Cherax destructor*	marktplaats.nl	(ZH) Den Haag	cultivation
Aquaria	*Cherax destructor*	marktplaats.nl	(FL) Swifterband	cultivation
Aquaria	*Cherax quadricarinatus*	marktplaats.nl/gdaquarium.nl	(DR) Dalen	cultivation
Aquaria	*Cherax quadricarinatus*	marktplaats.nl	(OV) Enschede	cultivation
Aquaria	*Cherax quadricarinatus*	speurders.nl	(LI) Munstergeleen	cultivation
Aquaria	Marbled crayfish	forum/dwerggarnalen.nl	(ZH) Zoetermeer	cultivation
Aquaria	Marbled crayfish	speurders.nl	(ZH) Rotterdam	cultivation
Aquaria	Marbled crayfish	speurders.nl	(NH) Zaandam	cultivation
Aquaria	Marbled crayfish	tweedehands.nl	(GL) Velp	cultivation
Aquaria	Marbled crayfish	wesp.wur.nl/forum	(GL) Wageningen?	cultivation
Aquaria	Marbled crayfish	marktplaats.nl	(ZH) Rotterdam	cultivation
Aquaria	Marbled crayfish	marktplaats.nl	(FR) Leeuwarden	cultivation
Aquaria	Marbled crayfish	marktplaats.nl	(NB) Zundert	cultivation
Aquaria	Marbled crayfish	marktplaats.nl	(NB) Landhorst	cultivation
Aquaria	Marbled crayfish	marktplaats.nl	(OV) Kampen	cultivation
Aq/Con	*Orconectes limosus*	marktplaats.nl	(ZH) Hardinxveld	wild catch
Aquaria	*Orconectes* sp. (*virilis*?)	Aquaflora (www.aquaflora.nl)	(UT) Vinkeveen	unknown
Aquaria	*Orconectes virilis*	speurders.nl	(UT) De Hoef	unknown
Aquaria	*Orconectes virilis*	marktplaza.nl	(UT) Mijdrecht	unknown
Aq/Con	*Procambarus acutus*	marktplaats.nl	(ZH) Hardinxveld	wild catch
Aquaria	*Procambarus alleni*	tweedehands.nl	(ZH) Waddinxveen	cultivation
Aquaria	*Procambarus alleni*	speurders.nl	(OV) Zwolle	cultivation
Aquaria	Procambarus alleni	tweedehands.nl	(DR) Linde	cultivation
Aquaria	*Procambarus alleni*	marktplaats.nl	(GR) Groningen	cultivation
Aquaria	*Procambarus alleni*	forum/dwerggarnalen.nl	(FR) Noordwolde	cultivation
Aquaria	*Procambarus alleni*	forum/dwerggarnalen.nl	(NH) Tuitjenhoorn	cultivation
Aquaria	*Procambarus alleni*	zooplus.nl	unknown	import (Germany)
Aquaria	*Procambarus alleni*	marktplaats.nl	(GR) Sappemeer	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(GL) Wageningen	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(DR) Beilen	cultivation
Aquaria	Procambarus clarkii	marktplaats.nl	(UT) Utrecht	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(GR) Nieuwe Pekela	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(GR) Sappemeer	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(NB) Grave	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(DR) Assen	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(GL) Almelo	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(GL) Arnhem	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(NB) Oss	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(NB) Veldhoven	cultivation
Aquaria	*Procambarus clarkii*	speurders.nl	(GE) Arnhem	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl	(UT) Woudenberg	cultivation
Aquaria	*Procambarus clarkii*	marktplaats.nl/gdaquarium.nl	(DR) Dalen	cultivation
Aquaria	*Procambarus clarkii*	deaquariumbazar.nl	(NB)	cultivation
Aquaria	Procambarus clarkii	tweedehands.nl	(DR) Linde	cultivation
Aquaria	*Procambarus clarkii*	forum/dwerggarnalen.nl	(UT) Woerdense velaat	cultivation
Aquaria	*Procambarus clarkii*	forum/dwerggarnalen.nl	(UT) Wijk bij Duurstede	cultivation
Aquaria	*Procambarus clarkii*	sandee.nl/vijversb.html	(ZE) Kamperland	cultivation
Consumption	*Procambarus clarkii*	www.eet-rivierkreeft.nl	unknown	cultivation
Consumption	*Procambarus clarkii*	marktplaats.nl	(GR) Groningen	cultivation
Consumption	unknown	www.visonline.be	België	import
Consumption	unknown	www.shop.purefoodsimport.nl	unknown	?

Appendix 3: isolated lakes and (fish) ponds with crayfish

Species	**Year**	**Location**
Astacus leptodactylus	2009	(LI) Kerkrade, Cranenweyer
Astacus leptodactylus	2009	(DR) Tynaarlo, Veenmeer
Astacus leptodactylus	2009	(OV) Enschede, Buurserstraatvijver
Orconectes limosus	?	(NB) Waalwijk, zandafgraving Drunen
Orconectes limosus	2008	(GR) Beerta, Beersterplas
Orconectes limosus	2000	(LI) Welten, vijver
Orconectes limosus	2005	(LI) Meerssen, Bunderbos, grindgroeve
Orconectes limosus	2008	(GL) Bussloo, recreatieplas
Orconectes limosus	2009	(GL) Radio Kootwijk, koelbekken
Orconectes limosus	2009	(GL) Winterswijk, kolk van Meddo
Orconectes limosus	2009	(GL) Zelhem, plas van Radstake
Orconectes limosus	2009	(GL) Deest, poolakker
Procambarus clarkii	2006	(ZH) Den Haag, westduinpark, nieuwe paddenpoel
Procambarus clarkii	2008	(LI) Maastricht, vijver langs A2.