NOBANIS - Invasive Alien Species Fact Sheet

Aphanomyces astaci

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Species description

Scientific names: *Aphanomyces astaci* (Schikora 1906), Saprolegniaceae, Oomycota.
Synonyms: None
Common names: crayfish plague (GB), krebsepest (DK), Krebspest, Wasserschimmel (DE), kräftpest (SE), krepsepest (NO), dżuma raków (PL), чума раков (RU), vēžu mēris (LV), vähikatk (EE), rapurutto (FI), račí mor (CZ).

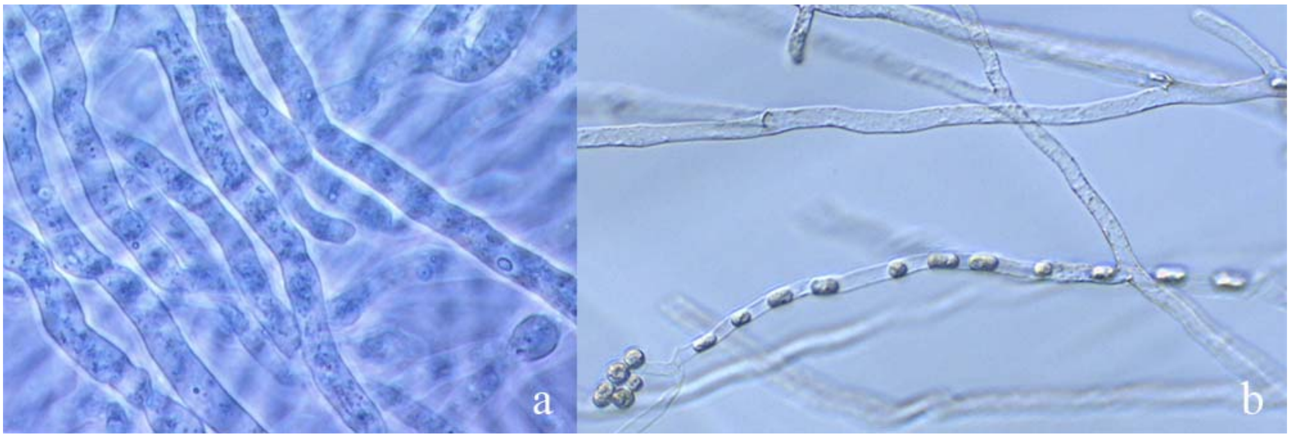

Fig. 1. Hyphae (a) and sporangium with emerging spore ball (b) of the oomycete *Aphanomyces astaci*. Photo ©: Trude Vrålstad (a) and David Strand (b), Norwegian Veterinary Institute.

Species identification

Aphanomyces astaci is an oomycete (water mould) that is not visible to eye. Using light microscope, non-septate, branching hyphae (*cf.* Fig. 1a), ca. 7-10 µm in diameter with rounded hyphal tips can be seen in the cuticle of infected crayfish (Evans & Edgerton 2002). It is impossible to identify the species based on hyphal morphology since many members of the Saprolegniaceae exhibit the same features. Confirmation of the species identity requires either classical isolation in pure culture with subsequent morphological identification (Cerenius *et al.* 1988; Viljamma-Driks & Hein, 2006) among others based in observation of classical *A. astaci* sporangia (Fig. 1b), or molecular methods including PCR and DNA-sequencing (Oidmann *et al.*, 2006; OiE 2011) or *A. astaci* specific real-time PCR (Vrålstad *et al*., 2009; Tuffs & Oidtmann, in press). During the recent years, these molecular methods have contributed to faster and more reliable diagnostics of crayfish plague in many European countries, and also shaded new light over the carrier status of North American crayfish (Oidmann *et al*., 2006; Kozubíková *et al*., 2006; 2009; 2009; Vrålstad *et al*., 2009; in press).

Native range

The origin and native range of *Aphanomyces astaci* is assumed to be North America. North American crayfish species live in a balanced host-parasite relationship with the oomycete and have evolved defence mechanisms that prevent invasive infections of *A. astaci*, which is evidence of co-evolution between *A. astaci* and the North American crayfish species on the North American continent. In contrast, European, Asian and Australian freshwater crayfish species are highly susceptible to *A. astaci* infection and exhibit no efficient immune defence mechanisms against the pathogen (Unestam 1969; 1972; Söderhäll & Cerenius, 1999; Evans & Edgerton, 2002).

Alien distribution

History of introduction and geographical spread

Crayfish plague outbreaks are characterized by mass mortalities of European crayfish without any apparent effect on other aquatic organisms. The first reports dates back to Italy in 1859 and later France in 1874. Crayfish trade and fishing activities spread the plague throughout Europe including Germany (1877; present Poland territory), Austria (1879), Czechia (~1883), Poland (1885), Latvia (1886), Russia (1892), Estonia (1894), Finland (1900), Sweden (1907) and Lithuania (1920); Norway (1971), England (1981) and Ireland (1986) to mention some of the many affected countries (Eder, 2004; Kozubíková *et al*., 2006; Souty-Grosset *et al*., 2006 and references therein). There is some uncertainty about when the plague arrived to Denmark, but probably the first outbreaks were in the period 1907-10 (Larsen 1990). The source of introduction of *A. astaci* in Europe is unknown, but is most likely due to import of infected North American crayfish. For a long period the reason for the disease referred to as crayfish plague was not understood. The oomycete *Aphanomyces astaci* was described by Shikora in 1906, and first in 1934, the Swedish researcher Nybelin isolated the agent in pure culture and demonstrated the lethal effect by re-infecting crayfish (Söderhäll & Cerenius, 1999). In recent years, molecular studies have revealed that the prevalence of *A. astaci* vary considerably between populations of North American crayfish established in Europe, but with few exceptions (e.g. Skov *et al*., 2011) the pathogen is normally detected when a reasonable number of individuals are screened (Oidtmann *et al*., 2006; Kozubíková *et al*., 2009; Vrålstad *et al*., in press). It is therefore likely that the crayfish plague infection remains viable in all countries where North American carrier crayfish are introduced and established, which practically includes close to all European countries with native freshwater crayfish (Holdich *et al*., 2009; see below).

Pathways of introduction

The initial introduction of the crayfish plague to a new watercourse mostly result from human activities, first and foremost by the spread of non-indigenous, plague-carrying crayfish species like the signal crayfish (*Pacifastacus leniusculus*), spiny-cheek crayfish (*Orconectes limosus*) or red swamp crayfish (*Procambarus clarkii*) (Alderman *et al.,* 1990, Oidtmann *et al.,* 1999; Skurdal *et al.,* 1999; Söderhäll & Cerenius, 1999; Holdich *et al*., 2009) that are the three worst American crayfish invaders in Europe at present. It can also be introduced through the transmission of infected

European crayfish and also of viable zoospores in contaminated water (moist fishing gear, water in boats, containers, etc.; Alderman *et al.,* 1987; Taugbøl *et al.,* 1993; Vrålstad et al., 2006). Crayfish predators like mink, otter, herons and other birds also have the ability to bring infected crayfish from one water body to another (Evans & Edgerton 2002).

Alien status in region

Aphanomyces astaci has been introduced to all countries in the NOBANIS region where freshwater crayfish exist (i.e. not to Iceland, Greenland and the Faroe Islands which have no freshwater crayfish species) (see also table 1.). There are a large number of populations of suitable hosts in Europe, e.g. the signal crayfish is established in 27 European countries, and the spiny-cheek crayfish in 21 European countries, and the red-swamp crayfish in 15 European countries (Holdich *et al*., 2009). Thus the crayfish plague is permanently established in these countries through a chronic infection of these populations. In Norway, with only one known population of signal crayfish permanently established (Vrålstad *et al.,* in press) and, Estonia and NW Russia where only susceptible crayfish occur, the appearance of the crayfish plague outbreaks are more incidental.

Country	Not found	Not established	Rare	Local	Common	Very common	Not known
Austria					X		
Belgium				X			
Czech republic					X		
Denmark				X			
Estonia		X					
European part of Russia		X					
Finland						X	
Faroe Islands*	X						
Germany					X		
Greenland*	X						
Iceland*	X						
Ireland		X					
Latvia			X				
Lithuania					X		
Netherlands				X			
Norway				X			
Poland					X		
Slovakia				X			
Sweden						X	

Table 1. The frequency and establishment of *Aphanomyces astaci*, please refer also to the information provided for this species at www.nobanis.org/search.asp. The frequency and establishment are directly linked to the presence of alien crayfish species suitable as hosts/carriers for *Aphanomyces astaci*. Legend for this table: **Not found** – *A. astaci* is not found in the country (*No freshwater crayfish species (hosts) are present); **Not established** - *A. astaci* is regarded as not established, because no suitable hosts are present, only the susceptible native crayfish species; **Rare** - Few sites with alien *A. astaci*-carrying crayfish species; **Local** - Locally abundant, due to populations of alien *A. astaci*-carrying crayfish species in some areas of the country; **Common** - Due to populations of alien *A. astaci*-carrying crayfish species in many parts of the country; **Very common** - Due to many populations of alien *A. astaci*-carrying crayfish species in large parts of the country; **Not known** – No information available.

Ecology

Habitat description

Aphanomyces astaci is an obligate parasite of freshwater crayfish with no known secondary hosts or resting structures, and thus occupies the same aquatic habitats as their hosts. Several North American crayfish species inhabiting almost all kind of water bodies, from ditches to clear-water lakes, have been shown to harbour *A. astaci* (Fig. 2, Evans & Edgerton, 2002). The European crayfish species are highly susceptible to the crayfish plague and cannot as far as we know act as a permanent host. Thus, a water body only inhabiting European crayfish will not represent a suitable habitat for *A. astaci* in the long run as the pathogen will die shortly after all crayfish are dead.

Fig. 2. Signal crayfish *(Pacifastacus leniusculus)* with a melanised spots (an immune system reaction) on carapax (a) and soft abdominal cuticle (b) caused by *Aphanomyces astaci* infection. Photo ©: David Strand, National Veterinary Institute, Norway.

Reproduction and life cycle

The *A. astaci* life cycle is summarized in Fig. 3. The oomycete reproduces asexually through formation of mobile zoospores. Infection of the host commences with the encystment of the zoospore in the cuticle of the crayfish. Both susceptible and more resistant crayfish are infected this way, but the subsequent host defence response determines whether the host is killed or a stable host-parasite relationship is established. After settling on the crayfish cuticle the zoospore discards the flagella and encysts. Germination proceeds, a germ tube penetrates the cuticle and hyphae ramify the cuticle. In resistant species, encapsulation/melanisation of the growing tip of the hyphae inhibits further invasion. In susceptible species, hyphae penetrate into deeper tissues and organs. This may also happen in individuals of resistant species weakened by other infections, injuries or stress. The final phase of the infection is sporulation and release of zoospores, which occurs just prior to or soon after death, when hyphae grow outwards and give rise to sporangia. The primary spores are extruded through the hyphal tip and cluster around the sporangial opening to form a typical “spore ball”. These primary spores then discharge as secondary zoospores, develop flagella and swim off in the hunt for a new host. The zoospores remain viable only for a few days, after which they either encyst in a favourable site and germinate, or, if the encystment site is not suitable, develop into a new zoospore. This process of repeated zoospore emergence can occur up to three times before the zoospore finally dies (Söderhäll & Cerenius, 1999; Evans & Edgerton, 2002)

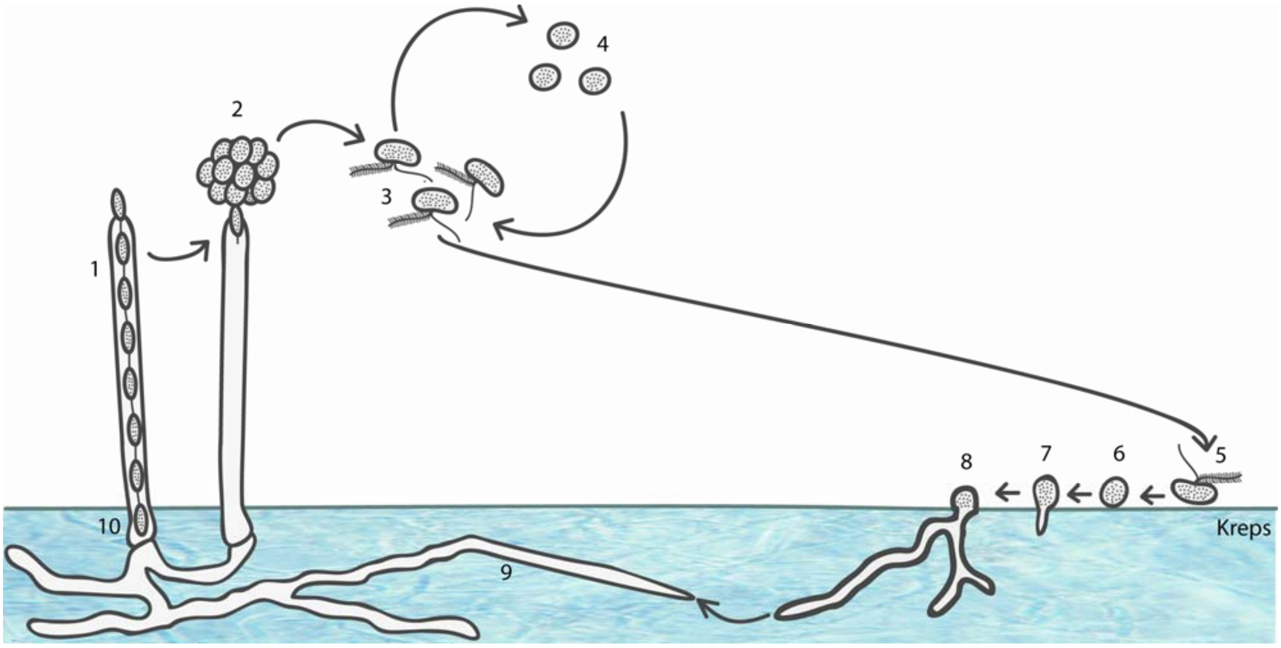

Fig. 3. Generalized life cycle of *A. astaci*. Sporangia with primary spores (1) are released as a spore ball (2) from where motile zoospores (3) are released into the water. Zoospores will either encyst (4) and repeat zoospore emergence in the absence of a suitable host, or locate a suitable host with chemotaxis (5) and encysts on the host surface (6). Aided by turgor pressure and enzymes, a developing infection spike penetrates the host (7) and non-septate hyphae ramify (8-9) within the host cuticle (exoskeleton). The immune response reaction in North American crayfish species rapidly restrict the infection to invisible or minor dark spots (hyphae encapsulated in crayfish generated melanin, se Fig. 2), while in susceptible crayfish species the infection rapidly proceed into the body cavity and nerve system, leading to host death. The host disease and death triggers the production of new spore producing hyphae/sporangia (10). Crayfish mass mortalities will therefore cause a drastic spore blooming of *A. astaci*. From Vrålstad *et al.*, 2006 with permission. © Trude Vrålstad

Dispersal and spread

Humans are the overall most important vector for the dispersal and spread, by the illegal/uncontrolled spread of plague-carrying crayfish species, first and foremost the signal crayfish (see also above).

Once introduced to a water body the crayfish plague will spread downstream through water transport of spores, while upstream spread mainly occurs through movement of infected crayfish. The rate of spread depends on factors such as crayfish density, flow rates and the presence of barriers to crayfish movements (weirs, waterfalls, etc.) (Taugbøl *et al.,* 1993; Vrålstad *et al*., 2006). However, even though fish is not a suitable host for the crayfish plague, fish may also contribute to upstream spread either by zoospores encysted on a fish that may be transported quite a distance before they develop into new swimming zoospores hunting for another host (Häll & Unestam, 1980) or by predator fishes feeding on infected crayfish. It has been shown that *A. astaci* survives within the crayfish cuticle through the fish digestive system (Oidtmann *et al*., 2002).

Impact

Affected habitats and indigenous organisms
Aphanomyces astaci is a fatal disease of the European freshwater crayfish species (OIE 2011) and the major reason why three of these species (only one in the Nordic/Baltic region, the noble crayfish *Astacus astacus*) are recognized as threatened and included in the international and national red lists, the Bern Convention and EU's Habitat Directive (Holdich *et al*., 2009).

The crayfish plague agent *A. astaci* does not directly affect other biota than the crayfish. However, since crayfish is key species in the food web structure, the crayfish pathogen may indirectly affect the abundance of different animal and plant species (Nyström, 2002). When the crayfish disappear, the sedimentation of dead organic material will increase because the crayfish as a detritus feeder play an important role in the degradation of organic matter. This might have a negative effect on the water quality (Hessen & Skurdal, 1989).

Genetic effects
No genetic effects have been reported.

Human health effects
No human health effects have been reported.

Economic and societal effects (positive/negative)
There are only negative effects connected to the introduction of the fatal crayfish disease agent *A. astaci*. The agent is a severe threat to native freshwater crayfish in Europe, some of which represents recreational and economical important species in several European countries. This particularly applies for noble crayfish. Among the broader mass of people in Europe, crayfish eating traditions started to develop first in the nineteenth century. In the period between 1853 and 1879 more than 5 million crayfish were annually consumed in Paris alone, and most of this trade came from Germany and Russia (Ackefors & Lindqvist, 1994). The demand for crayfish increased and commercial harvesting became a big industry in the nineteenth century in many European countries, including the Nordic/Baltic region. Even though *A. astaci* is not the only reason why indigenous crayfish in Europe has been drastically declining, it is undoubtedly bearing the main responsibility for the ruin of a great part of the commercial and recreational crayfish fishery. Only in Sweden and Finland, and to some extent in the other countries in the region, there are still remains of a fishery on the indigenous noble crayfish. Current harvests in the region are less than 5% compared to the situation before the crayfish plague was introduced (Skurdal *et al.,* 1999). Also this remaining fishery is at risk due to the continuous spread of the crayfish plague associated with the plague-carrying North American crayfish species.

Management approaches

Prevention methods
Prevailing evidence suggests that *A. astaci* cannot live for a long period of time in the absence of a suitable host, and only the North American crayfish species have been shown to be naturally adapted hosts. The European crayfish species are susceptible and will eventually die of crayfish plague. Thus, if there are no North American crayfish species present in an infected watercourse, crayfish plague will presumably disappear a period of time after the susceptible native crayfish are

dead. In such cases, the crayfish population can be re-established (Smith & Söderhäll, 1986; Taugbøl *et al.,* 1993). However, there are also examples indicating that the crayfish plague may remain as a chronic infection for decades also in watercourses with only native crayfish (Svärdson, 1965; Fürst, 1995). If North American crayfish species are present in the watercourse the crayfish plague is also permanently established. The only way to get rid of the crayfish plague is by eradicating the crayfish, and there is no practical way of doing this except for small, isolated water bodies (Holdich *et al.,* 1999; Hiley, 2003; Peay *et al.,* 2006; Sandodden & Johnsen, 2010).
The only effective way of preventing further spread and maintenance of the crayfish plague is to stop the spread of North American carrier crayfish. In all countries in the region it is forbidden to stock crayfish in natural waters (permission needed), and in most of the countries import of live crayfish is banned.

Viable crayfish plague spores can also be spread from an infected watercourse to new water bodies by contaminated water, biological vectors (such as fish), boats or equipment. Effective methods to avoid such spread includes to avoid the transfer of water (physical barriers), fish or other biological materials from one locality to another, and to disinfect or completely dry gear used in infected waters before use in another locality (Häll & Unestam, 1980; Direktoratet for naturforvaltning, 2009; Vrålstad *et al*, 2006; in press). This requires regulations and measures from the authorities as well as good and targeted information strategies, which undoubtedly is a great challenge.

Eradication, control and monitoring efforts

These topics are partly dealt with above. There is at present no practical way of eradicating carrier crayfish and crayfish plague from a complex watercourse, but successful chemical eradication in smaller, closed systems has been reported (Sandodden & Johnsen, 2010). Overall, the key element in controlling further spread of the crayfish plague is to control spread of the plague-carrying crayfish. Mapping and monitoring the distribution of these crayfish species is important in a management and control strategy.

Conservation of native, red-listed European crayfish species is a main objective of many countries in Europe. Preventing further spread of the crayfish plague and plague-carrying crayfish species is the most important effort. For some countries, management plans for the noble crayfish address this problem (Taugbøl & Skurdal 1998; Taugbøl *et al.* 1998; Tuusti *et al.,* 1998; Fiskeriverket/ Naturvårdsverket 1998; 2009; Taugbøl *et al.,* 2004; Johnsen & Vrålstad, 2009).

Information and awareness

The key factor in order to prevent further spread of the crayfish plague and plague-carrying crayfish species is information about the negative effects. With live American crayfish easily accessible from natural waters, it is very difficult to prevent illegal stockings unless local people understand and respect the consequences by spreading plague-carrying crayfish. Through information, it is hopefully possible to increase the knowledge and enhance the awareness of local people that play a key factor regarding the prevention of further spread of the crayfish plague. Examples of such information includes folders/brochures (Fiskeriverket/Naturvårdsverket 2009, Direktoratet for naturforvaltning 2009), media contact, education in schools, concrete projects involving relevant interest groups, see for example www.astacus.org).

Knowledge and research

Aphanomyces astaci has been the subject of many studies during the last hundred years. There is detailed knowledge of life cycle and host defence reactions (Söderhäll & Cerenius, 1999). Four different genotypes of the crayfish plague pathogen have been identified so far (Söderhäll & Cerenius 1999). Improved diagnostic methods involving specific molecular detection of *A. astaci* directly from infected crayfish tissues have been developed in recent years (Oidtmann *et al*., 2006; Vrålstad *et al*., 2009; Tuffs & Oidtmann, in press). These methods have not only enhanced crayfish plague diagnostics, but have opened up for studying the *A. astaci* carrier status of invasive American crayfish populations in Europe (Kozubíková *et al*., 2009; Skov *et al*., 2011; Vrålstad *et al*., in press). Finally, concepts for direct monitoring of *A. astaci* spores in natural waters are approaching (Strand et al., 2011), and may help to answer some of the still many questions related to the epidemiology the crayfish plague, for example on the survival of the crayfish plague after it strikes a susceptible population (Fürst 1995).

Recommendations or comments from experts and local communities

Information is crucial in order to build up the needed knowledge and respect for the fact that native European crayfish are endangered mainly as a consequence of crayfish plague and movements (often illegal) of invasive American plague-carrying crayfish. Any work that diminishes the risk and motivation of such illegal actions are important. In some countries, the endangered native European crayfish are not legal to harvest as a protective measure. In other countries, harvest is on the contrary considered as one of the most important protective factors against further spread of crayfish plague. Harvest in itself is not a threat to a well-established, reproductive population. The threat lies with the spread of crayfish plague. Increased interest to avoid the infection is therefore an important measure to protect the native crayfish species. For countries where crayfish harvest still is legal, it is imperative to convince landowners/fishermen that the indigenous crayfish is a great, harvestable resource and that spread of the crayfish plague and plague-carrying crayfish species to native crayfish localities is a biological catastrophe and a tragedy to the socioeconomic/ -cultural values that the native crayfish represents. Finally, it is illegal and regarded as an environmental crime to actively spread American crayfish. For example in Norway, those who introduce American crayfish to a new locality may risk 6 years in prison.

References and other resources

OiE reference laboratories and experts for crayfish plague:

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Links

The International Association of Astacology (IAA)
Global Invasive Species Data Base - *Aphanomyces astaci* (ISSG - Invasive Species Specialist Group)

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