

A review of the ever increasing threat to European crayfish from non-indigenous crayfish species

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Received October 27, 2009 / Reçu le 27 octobre 2009

Revised November 23, 2009 / Révisé le 23 novembre 2009

Accepted December 15, 2009 / Accepté le 15 décembre 2009

ABSTRACT

Key-words:
Europe,
crayfish,
indigenous,
non-indigenous,
plague,
arks,
model

Non-indigenous crayfish species (NICS) in Europe now outnumber indigenous crayfish species (ICS) 2:1, and it has been predicted that they may dominate completely in the next few decades unless something is done to protect them. Of the ten NICS introduced at least nine have become established in areas occupied by four of the five ICS. A decline in stocks of ICS has been recorded in many countries in the face of increasing populations of NICS. Most European countries retain at least one ICS but all are under threat from habitat loss, deteriorating water quality, overfishing, climate change, and most importantly from NICS and crayfish plague. The threat to ICS is so great in some countries that “ark” sanctuary sites are being established.

The three most widely-spread NICS are the North American species: *Pacifastacus leniusculus*, *Orconectes limosus* and *Procambarus clarkii*. These can be considered as “Old NICS”, which were introduced before 1975, compared with the “New NICS”, which were introduced after 1980, such as the North American species: *Orconectes immunis*, *Orconectes juvenilis*, *Orconectes virilis*, *Procambarus* sp. and *Procambarus acutus*; and the Australian species: *Cherax destructor* and *Cherax quadricarinatus*, all of which have much narrower ranges in Europe. The North American species are potentially capable of acting as vectors of crayfish plague. Outbreaks of this disease occur regularly where there are high concentrations of vectors.

In addition to the NICS currently established in the wild, a further threat exists through the aquarium trade, where many American and Australian species are available *via* the internet and in aquarist centres. Owners of such species may discard them into the freshwater environment when they grow too big as with some *Cherax* spp. and *Orconectes* spp., or multiply too frequently as with *Procambarus* sp. (a parthenogenetic species). A conceptual model is presented as a possible way forward for protecting the future survival of ICS in Europe.

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RÉSUMÉ

Une mise à jour sur la menace perpétuelle des écrevisses non indigènes pour les écrevisses européennes

Mots-clés :
Europe,
écrevisse,
indigène,
non indigène,
peste de
l'écrevisse,
sanctuaire,
modèle

Le nombre d'espèces d'écrevisses non indigènes (NICS) présentes en Europe dépasse maintenant celui des espèces indigènes (ICS) 2:1, et il est même prédit leur dominance complète si rien n'est fait pour protéger les espèces indigènes. Sur les dix espèces introduites (NICS), au moins neuf sont bien établies sur les territoires occupés par quatre des cinq espèces indigènes (ICS). Un déclin des stocks indigènes a été observé dans beaucoup de pays face au nombre croissant de populations non indigènes. La plupart des pays européens héberge au moins une espèce indigène mais toutes sont en danger à cause de la perte de l'habitat, la détérioration de la qualité de l'eau, la pêche intensive, le changement climatique et, plus important, la peste apportée par les écrevisses non indigènes. Dans certains pays, la menace est si grande pour les espèces indigènes que des sanctuaires (« ark sites ») ont été établis pour leur protection.

Les trois espèces non indigènes (NICS) les plus répandues proviennent d'Amérique du nord : *Pacifastacus leniusculus*, *Orconectes limosus* et *Procambarus clarkii*. Elles peuvent être considérées comme anciennes (« Old NICS »), car introduites avant 1975, en comparaison avec les plus récemment introduites (« New NICS »), c'est-à-dire après 1980, comme les espèces d'Amérique du nord : *Orconectes immunis*, *Orconectes juvenilis*, *Orconectes virilis*, *Procambarus* sp. et *Procambarus acutus*; ainsi que les espèces australiennes : *Cherax destructor* et *Cherax quadricarinatus*, toutes ayant une aire de répartition plus limitée en Europe. Les espèces nord américaines sont potentiellement capables d'agir comme vecteurs de la peste de l'écrevisse. Les épidémies de peste se déclarent régulièrement là où il y a une grande concentration de vecteurs.

En plus des espèces non indigènes couramment établies dans la nature, une menace supplémentaire existe à cause du marché en aquariophilie car la plupart des espèces américaines et australiennes sont disponibles sur internet et dans les magasins. Les propriétaires de telles espèces peuvent les relâcher dans les eaux douces quand elles ont une taille trop grande comme *Cherax* spp. et *Orconectes* spp., ou quand elles se reproduisent trop fréquemment comme *Procambarus* sp. (espèce parthénogénétique).

Un modèle est proposé comme moyen possible de protéger plus efficacement les écrevisses indigènes dans les années à venir.

INTRODUCTION

It has been estimated that between one-third and one-half of the world's crayfish species are threatened with population decline or extinction (Taylor, 2002). The greatest threat to crayfish biodiversity is from non-indigenous crayfish introduced for harvesting for food or unintentionally as unused bait or unwanted aquarium pets (Holdich, 1999; Taugbøl and Skurdal, 1999; Lodge *et al.*, 2000; Gherardi, 2007; Taylor *et al.*, 2007). In North America indigenous crayfish species (ICS) have been displaced by non-indigenous crayfish species (NICS) through direct competition (Taylor, 2002). This has also been the case in Europe, but the additional effect of crayfish plague has meant that the devastation amongst the small number of indigenous species has been far greater.

By comparison with North America and Australia Europe has an impoverished crayfish fauna (Taylor, 2002). The five (or six, see below) ICS in Europe are under threat from a variety of factors including habitat loss, deteriorating water quality, overfishing and climate change, as well as NICS and crayfish plague. In 1996, *Astacus astacus* (L.), *Austropotamobius palipes* (Lereboullet) and *Austropotamobius torrentium* (Schrank) were assessed as vulnerable using criterion B2bce+3bcd of the IUCN Categories and Criteria (version 2.3) (Baillie and Groombridge, 1996). Revisions to these 1996 assessments are currently underway using

the updated version of the Categories and Criteria, Version 3.1 (IUCN, 2001). Taugbøl and Skurdal (1999) predicted that if plans were not put in place, then in 100 years time it might be that all watersheds suitable for crayfish in Europe are occupied by NICS, and all ICS are critically endangered and survive in a few protected localities.

Perhaps uniquely amongst animals introduced into Europe's inland waters, crayfish have a 90% success record, *i.e.* so far ten NICS have been introduced and at least nine have become established, although other introduced crustacean groups such as North American and Ponto-Caspian amphipods and mysids may well be equally as successful in Western Europe (Holdich and Pöckl, 2007). The achievement of the NICS in Europe is largely down to their robust nature coupled with fast individual and population growth, high fecundity and invasive capabilities (Lindqvist and Huner, 1999). North American crayfish are also immune to the effects of crayfish plague unless put under stress (Cerenius and Söderhäll, 1992). The pros and cons of introducing NICS into Europe have been reviewed by Ackefors (1999), Holdich (1999) and Westman (2002). Tricarico *et al.* (2010) have developed "The Freshwater Invertebrate Invasiveness Scoring Kit (FI-ISK)" as a screening tool for identifying potentially invasive freshwater invertebrates. They deployed FI-ISK to assess the risk that a wide range of crayfish species belonging to the families Astacidae, Cambaridae and Parastacidae might pose to the Italian freshwater environment. They found that *P. clarkii* and *P. leniusculus* had high risk scores, as did *O. limosus* and *C. destructor*, whilst *A. leptodactylus*, *C. quadricarinatus* and *Procambarus* sp. were considered a medium risk. They concluded that FI-ISK will provide a useful and viable tool to aid decision- and policy-makers in assessing and classifying freshwater invertebrates according to their potential invasiveness. This has relevance to the 2007 European Union regulation regarding the introduction of alien species for aquaculture and related activities: Council Regulation No 708/2007 (28.6.2007 Official Journal of the European Union L 168/1-17).

Eight of the NICS established in Europe originate from North America and two from Australia. Three of the North American NICS have been introduced into Europe to supplement crayfish stocks, as many populations of ICS have been devastated by crayfish plague since the mid-19th century, and for aquaculture, *i.e.* *Orconectes limosus* (Rafinesque) to the German/Polish border in 1890 (Borne, 1906), *Pacifastacus leniusculus* (Dana) to Sweden in 1959 (Abrahamsson, 1973) and *Procambarus clarkii* (Girard) to Spain in 1973 (Habsburgo-Lorena, 1979). These can be considered as "Old NICS", having been introduced before 1975, compared to "New NICS", which have been introduced since 1980, mainly through the aquarium trade and for aquaculture. In general "Old NICS" are very difficult to control and virtually impossible to eliminate once they have become established (Holdich *et al.*, 1999; Peay *et al.*, 2006; Aquiloni *et al.*, 2009), although when they are found in a new area it may be possible to eliminate them before they become too well established, and the same applies to "New NICS".

In this paper the authors update distributional information and discuss the status of ICS and NICS in Europe from information in the recent literature and from personal contacts made during 2008 and 2009. We also examine the recent impact of NICS and crayfish plague on ICS in selected countries in Europe. The situation in South-west England is used to show how the balance can shift from one dominated by ICS to one dominated by NICS in a few decades. A slightly modified version of a conceptual model first introduced by Taugbøl and Skurdal (1999) is discussed as a way forward for protecting the future survival of ICS in Europe.

CRAYFISH PLAGUE

Crayfish plague, caused by the fungus-like organism *Aphanomyces astaci* Schikora, is listed in the top 100 of the "World's Worst" invaders by the International Union for Conservation of Nature (IUCN) (Lowe *et al.*, 2000). *Aphanomyces astaci* belongs to the Saprolegniales (Oomycetes); the many species of *Aphanomyces* (30–40) can be either plant or animal parasites or saprophytes and are highly specialized, with narrow host ranges (Diéguez-Uribeondo *et al.*, 2009). Unestam (1969, 1972) showed that North American crayfish species are vectors

of the disease and that Asiatic, Australasian and European crayfish were highly susceptible to its effects. Unestam and Weiss (1970) isolated *A. astaci* from *P. leniusculus* from the Sacramento River and Lake Tahoe in western North America thus proving that the pathogen originated from North America. The pathogen lives in melanized areas of the cuticle and is spread by asexual swimming zoospores, which serve as the infective units. Water is the best medium for transmission of spores, but any item that has been in contact with water containing spores can also transmit them; the spores can survive for up to 16 days under humid and cool conditions; high magnesium and low calcium levels in water are unfavourable for the spores (Oidtmann, 2000). Unestam (1969) found that North American crayfish species are highly resistant to infection by *A. astaci*, suggesting that they are largely immune to its effects and live in a balanced host-parasite relationship with the parasite probably as a result of co-evolution. However, Cerenius and Söderhäll (1992) found that the presence of the pathogen in *P. leniusculus* means that its immune system is constantly alerted and the animal is under permanent stress. If it then becomes additionally stressed by other parasites or environmental conditions it can die rapidly from crayfish plague. This can cause high mortalities in both aquaculture and the wild, and may explain some of the mortalities in *P. leniusculus* populations in Sweden (Edsman, 2009, pers. comm.) and Finland (Pursiainen, 2009, pers. comm.), as well in other North American NICS elsewhere. Cerenius and Söderhäll (1992) stress that the absence of melanised patches in *P. leniusculus* is not an indication that it is free from crayfish plague.

Although North American crayfish have the potential to carry crayfish plague, of the 360+ species living there (Taylor *et al.*, 2007) only three as far as is known have been tested and shown to be vectors of the disease as NICS in Europe (Diéguez-Uribeondo, 2006b), *i.e.* *P. leniusculus* (Unestam and Weiss, 1970), *O. limosus* (Vey *et al.*, 1983) and *P. clarkii* (Diéguez-Uribeondo and Söderhäll, 1993). The spread of these species in Europe in the 19th, 20th and 21st century is closely associated with the spread of crayfish plague.

There have been a number of reviews of the history of crayfish plague in Europe, *i.e.* Alderman and Polglase (1988), Holdich *et al.* (1995), Alderman (1996), Holdich (2003) and Diéguez-Uribeondo (2006b), and mention is made below of just the more recent outbreaks for individual countries.

CRAYFISH IN EUROPE

> BACKGROUND

The information given below updates some of the distributional data given in Holdich (2002, 2003), Holdich *et al.* (2006), Machino and Holdich (2006) and Pöckl *et al.* (2006), and has been derived from the recent literature and personal contacts with crayfish workers in Europe during 2008–2009. Recent updates on the situation in Austria (Füreder *et al.*, 2009), Eastern Europe (Maguire, 2009), Germany (Schulz *et al.*, 2009), Italy (Gherardi *et al.*, 2009) and Switzerland (Stucki *et al.*, 2009) have been published in German by Füreder (2009).

With the exception of Portugal, where *A. pallipes* has most likely been eliminated (Machino and Holdich, 2006), most European territories retain at least one ICS, although some have probably never had any indigenous crayfish species, *e.g.* Cyprus, Malta, Monaco, as well as large offshore island groups such as the Azores, Balearics, Canaries, Channel Islands (British Crown dependency), Greek and Italian islands and Madeira. Some islands in the Baltic Sea have populations of *A. astacus*, but these have been introduced. Of those countries possessing at least one ICS, only Andorra, Ireland and Liechtenstein in the west and, as far as is known, Albania, Armenia, Azerbaijan, Bosnia-Herzegovina, Bulgaria, Estonia, European Russia, European Turkey, Georgia, Kazakhstan, Macedonia, Moldova, Montenegro and the Ukraine in the east are currently free from NICS. Attempts have been made to introduce NICS into Russia but these have been unsuccessful (Holdich, 2002; Machino and Holdich, 2006), harvestable stocks of *A. astacus* are particularly prevalent in the north-west (Susloparova and Mitskevich, 2009). Note that Azerbaijan, Georgia, Kazakhstan, Russia and Turkey are

considered part of both Europe and Asia; and Armenia and Cyprus are sociopolitical European countries. Table I summarizes the occurrences of ICS and NICS in European countries and Table II quantifies this for each country.

It can be seen from Table II that some countries have a relatively high number of crayfish species, although some European ICS may well have been introduced recently, particularly *A. leptodactylus*. Austria is known to have four European ICS and three NICS, England – one ICS and six NICS, France – four ICS and five NICS, Germany – four ICS and five NICS, Italy – four ICS and five NICS, Netherlands – two ICS and six NICS, and Switzerland – four ICS and three NICS. However, when assessing the indigenous and conservation status of ICS the following ruling from the IUCN should be noted:

“To decide whether an introduced species is now considered naturalized to a region for the purposes of a Red Data Book, IUCN recommends that a preset year or event may be used (IUCN, 2003). For assessments of species in Europe, IUCN uses a cut-off date of 1500 and if a species existed in a country since that date it is considered indigenous for the purposes of the Red List assessment.”

A good example is the European ICS, *Astacus leptodactylus* Eschscholtz, which was introduced into Western Europe mainly from Eastern Europe after populations of ICS became decimated by crayfish plague (post-1860s). It was brought in for the same reasons that North American NICS were introduced, *i.e.* to supplement stocks, the main difference being that it was susceptible to crayfish plague (see below). So, in the majority of West European countries, *A. leptodactylus* would not be considered an ICS according to the IUCN ruling (see Table I). The same applies to *A. astacus* in Britain, and *A. pallipes* in Scotland (Holdich and Sibley, 2009). However, in some cases a crayfish species that was probably introduced becomes such an important part of a country's culture that it is adopted as an indigenous species (Holdich *et al.*, 2006). Another example concerns the status of *A. pallipes* in England and Wales, where there was very little evidence that it existed there before 1500 AD. Because of this it was in danger of not being included in the IUCN's next Red Data book (Dewhurst, 2009, pers. comm.). The indigenous status of *A. pallipes* had not generally been questioned by British conservationists and its current high profile has resulted in considerable efforts being made to conserve it (Holdich *et al.*, 2004). An investigation was undertaken and it was found that evidence from the palaeontology record and from genetic studies for the presence of *A. pallipes* in Britain before 1500 is inconclusive, but that there is strong evidence from historical documents and medieval recipes that *A. pallipes* has for centuries been regarded as a valued food resource in Britain. The authors concluded that there is sufficient evidence to indicate that *A. pallipes* was established in the wild in Britain prior to 1500 and that for the purposes of red listing and conservation this species should be regarded as indigenous (Holdich *et al.*, 2009). A similar situation exists with *A. pallipes* in Ireland and the suggestion is that they were introduced by monastic orders from France as early as the 12th century (Gouin *et al.*, 2003). These views have now been formally recognised by the IUCN (Dewhurst, 2009, pers. comm.). Interestingly, a similar situation exists for *A. astacus* in Sweden, with no evidence in the literature for its existence in the country prior to 1504 (Swahn, 2004).

Populations of ICS and North American NICS occurring in the same waterbody have been reported from many countries, *e.g.* Austria (Pöckl and Pekny, 2002), Belgium (Cammaerts, 2009, pers. comm.), England (Dunn *et al.*, 2009), Finland (Westman *et al.*, 2002), France (see below), Germany (Hirsch, 2009), Italy (see below), Poland (Śmietana *et al.*, 2004), Switzerland (Hefti and Stucki, 2006), although this does not necessarily mean the NICS are free from crayfish plague (Diéguez-Uribeondo, 2009, pers. comm.). Crayfish plague was found to be present in some populations of *O. limosus*, *P. leniusculus* and *P. clarkii* in Switzerland but not in others (Oidtmann *et al.*, 2004). In Latium (Italy), *O. limosus* and *A. leptodactylus* co-occur in Lago del Salto, and *P. clarkii* and *A. leptodactylus* in the lakes of Bracciano and Bolsena (Gherardi, 2009, pers. comm.). Out of 3208 riverine and lacustrine sites sampled in Switzerland, 1578 contained ICS, 499 contained NICS, and 62 contained both ICS and NICS (Hefti and Stucki, 2006).

Table 1

European territories possessing wild populations of ICS and NICS. Grey highlights are new NICS records and/or confirmations since Souty-Grosset et al. (2006). Azerbaijan, Georgia, Kazakhstan, Russia and Turkey are considered part of both Europe and Asia. Armenia and Cyprus are sociopolitical European countries. Turkmenistan (*A. leptodactylus* and *A. pachypus*) and Uzbekistan (introduced *A. leptodactylus*) have not been included.

Tableau 1

Populations de ICS et NICS présentes dans les pays européens. Les nouveaux signalements de NICS et/ou confirmés depuis Souty-Grosset et al. (2006) sont surlignés en gris. Azerbaïdjan, Georgia, Kazakhstan, Russie et Turquie sont considérés à la fois comme Europe et Asie. Arménie et Chypre sont des pays européens. Turkmenistan (*A. leptodactylus* and *A. pachypus*) et Uzbekistan (*A. leptodactylus* introduite) ne sont pas inclus.

Territories	European ICS					North American and Australian NICS								
	ASA	ASL	ASP	APP	APT	OCL	OCI	OCV	OCJ	PCC	PA	PCsp	PFL	CXD/Q
Albania	+				+									
Andorra	+													
Armenia		l												
Austria	+	+		lp	+	+				+			+	
Azerbaijan		+	+											
Azores (Pt)										+				
Belarus	+	+				+								
Belgium	+	l				+							+	
Bosnia-Herz.	+	+		+	+									
Bulgaria	+	+		+										
Corsica (Fr)				l		+								
Croatia	+	+		+	+	+							+	
Cyprus	l									+				
Czech Republic	+	l			lp	+							+	
Denmark	+	l											+	
England	l	l		+		+		+		+			+	/?
Estonia	+													
Finland	+	lx											+	
France	+	l		+	+	+	+		+	+			+	
Germany	+	l		+	+	+	+		+	+		+	+	/?
Georgia	+	+												
Greece	+	+			+								+	
Hungary	+	+			+	+							+	
Irish Republic				+										
Italy	+	l		+	+	+				+		+	+	+/?
Kaliningrad (Ru)	+	l				+							+	
Kazakhstan		+	+											
Latvia	+	l				+							+	
Liechtenstein	+			l										
Lithuania	+	l				+							+	
Luxembourg	l	l			lp	+							+	
Macedonia	+				+									
Majorca (Sp)										+				
Moldova	+	+												
Montenegro	+			+	+									
Netherlands	+	l				+		+		+	+	+	+	/?
Northern Ireland				+										
Norway	+												+	
Poland	+	l				+							+	
Portugal				lx						+			+	
Romania	+	+			+	+								
Russia (Eur)	+	+	+											
Sardinia (It)										+				
Scotland				l									+	
Serbia	+	+			+	+								
Sicily (It)										+				
Slovakia	+	+			+	+							+	
Slovenia	+			+	+								+	
Spain				+	+					+			+	+/?
Sweden	+												+	
Switzerland	+	l		+	+	+				+			+	/?
Tenerife (Sp)										+				
Turkey (Eur)		+			+									
Ukraine	+	+	+											
Wales				+									+	
Totals	39	32	4	17	20	21	2	2	1	15	1	3	27	2/?

Abbreviations: ASA – *Astacus astacus*, ASL – *Astacus leptodactylus*, ASP – *Astacus pachypus*, APP – *Austropotamobius pallipes/italicus*, APT – *Austropotamobius torrentium*, OCL – *Orconectes limosus*, OCI – *Orconectes immunis*, OCV – *Orconectes virilis*, PCC – *Procambarus clarkii*, *Procambarus juvenilis*, PA – *Procambarus acutus*, PCsp – *Procambarus* sp. (marmorkrebs), PFL – *Pacifastacus leniusculus*, CXD – *Cherax destructor*, CXQ – *Cherax quadricarinatus*. x = probably no longer present, l = introduced relatively recently, lp = possibly introduced.
 Abréviations: ASA – *Astacus astacus*, ASL – *Astacus leptodactylus*, ASP – *Astacus pachypus*, APP – *Austropotamobius pallipes/italicus*, APT – *Austropotamobius torrentium*, OCL – *Orconectes limosus*, OCI – *Orconectes immunis*, OCV – *Orconectes virilis*, PCC – *Procambarus clarkii*, *Procambarus juvenilis*, PA – *Procambarus acutus*, PCsp – *Procambarus* sp. (marmorkrebs), PFL – *Pacifastacus leniusculus*, CXD – *Cherax destructor*, CXQ – *Cherax quadricarinatus*. x = probablement absente aujourd'hui, l = introduite relativement récemment, lp = probablement introduite.

Table II

Number of European ICS and NICS by territory. Records with ? marks in Table I are not included. Introduced (I) or probably introduced (Ip) ICS shown in Table I are included under ICS except for England, where *A. astacus* and *A. leptodactylus* are considered as NICS under the Wildlife & Countryside Act.

Tableau II

Nombre d'ICS et NICS européennes par pays. Les signalements marqués ? dans le tableau I ne sont pas inclus. Les ICS indiquées comme introduites (I) ou probablement introduites (Ip) dans le tableau I sont considérées comme ICS sauf pour l'Angleterre, où *A. astacus* et *A. leptodactylus* sont considérées comme NICS par le Wildlife & Countryside Act.

Territory	ICS	NICS	Territory	ICS	NICS
Albania	2	0	Latvia	2	2
Andorra	1	0	Liechtenstein	2	0
Armenia	1	0	Lithuania	2	2
Austria	4	3	Luxembourg	2	2
Azerbaijan	2	0	Macedonia	2	0
Azores (Pt)	0	1	Majorca (Sp)	0	1
Belarus	2	1	Moldova	2	0
Belgium	2	2	Montenegro	3	0
Bosnia-Herz.	4	0	Netherlands	2	6
Bulgaria	3	0	Northern Ireland	1	0
Corsica (Fr)	1	1	Norway	1	1
Croatia	4	2	Poland	2	2
Cyprus	1	1	Portugal	0	2
Czech Republic	3	2	Romania	3	1
Denmark	2	1	Russia (Eur)	3	0
England	1	6	Sardinia (It)	0	1
Estonia	1	0	Scotland	0	2
Finland	1	1	Serbia	3	1
France	4	5	Sicily (It)	0	1
Germany	4	5	Slovakia	3	2
Georgia	2	0	Slovenia	3	1
Greece	3	1	Spain	1	3
Hungary	3	2	Sweden	1	1
Irish Republic	1	0	Switzerland	4	3
Italy	4	5	Tenerife (Sp)	0	1
Kaliningrad (Ru)	2	2	Turkey (Eur)	2	0
Kazakhstan	2	0	Ukraine	3	0
			Wales	1	1

> ICS

Little has changed in the occurrence of ICS in Europe since the publication of the crayfish atlas (Souty-Grosset *et al.*, 2006). However, some additional information is added below for each species. Although species are listed as being indigenous in Table I, this indicates they are indigenous to Europe rather than to individual countries, where they may have been introduced from other parts of Europe relatively recently (see above). To indicate these situations "I" or "Ip" have been inserted in the table following Machino and Holdich (2006). The decline of ICS is dealt with in more detail for selected countries, *i.e.* England, France, Italy, Spain and Portugal, and Sweden in another section. The maps shown in Figures 1, 3, 5 and 7 are taken from the CRAYNET Atlas (Souty-Grosset *et al.*, 2006) and represent data collected up until the end of 2005.

Astacus astacus (Linnaeus, 1758) (noble crayfish) (Figure 2): Currently found in 39 territories across most of northern and central Europe, although its range was greater before the onset

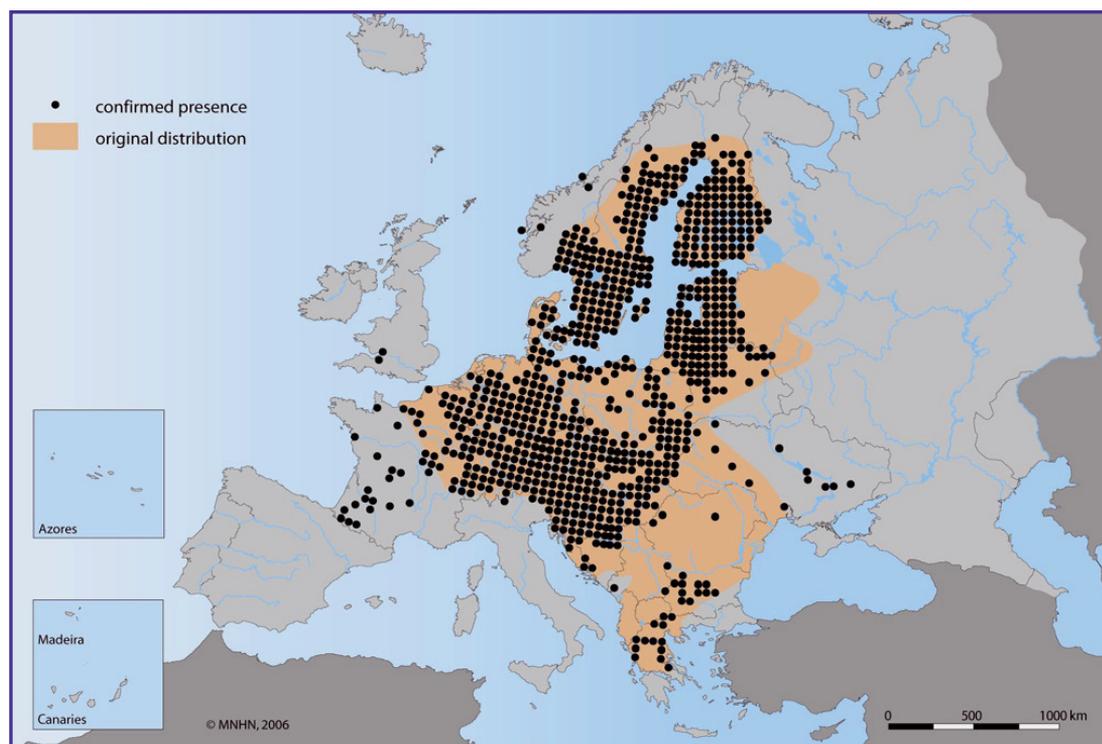


Figure 1

Map showing the distribution of *Astacus astacus* (CRAYNET atlas).

Figure 1

Carte de distribution d'*Astacus astacus* (CRAYNET atlas).

of crayfish plague (Figure 1). It is widely harvested and many countries have national and federal regulations governing catching seasons and size restrictions (Skurdal and Taugbøl, 2002). The most abundant populations exist in Nordic and Baltic countries, e.g. it is the dominant crayfish in Latvian waters, having been found in 220 out of 258 crayfish localities (Taugbøl et al., 2004; Arens and Taugbøl, 2005). *Astacus astacus* was introduced to Cyprus from Denmark in the 1970s and although the original stock has disappeared it apparently occurs in the Lefkara dam (Stephanou, 1987). According to Schmidt (2009, pers. comm.) it has disappeared from Luxembourg. However, it was reintroduced into the R. Our (Troschel, 1999) and a specimen was found at an introduction site at Weiswampach in 2002 (Machino and Holdich, 2006), so it is listed as being still present in Table 1.

Astacus leptodactylus Eschscholtz, 1823 (narrow-clawed crayfish) – species complex (Figure 4): Currently found in 32 territories across most of Europe with the exception of Scandinavia and the Baltic Peninsula, although its range was probably greater before the onset of crayfish plague (Figure 3). The systematics of this species complex is in a state of flux with those in Western and Central Europe referring just to *A. leptodactylus*, whilst in Eastern Europe a number of species are recognized within a genus *Pontastacus* (Starobogatov, 1995; Śmietana et al., 2006). The most abundant populations are found in Eastern Europe and the Near East. Large commercial stocks of *A. leptodactylus* exist in Belarus (Alekhovich, 2006), but between 2004–2005 there have been large-scale mortalities in some shallow and deep water lakes with nothing else affected (Alekhovich, 2009, pers. comm.). However, a lake similarly affected in the 1990s had shown some recovery by 2004–2005. Crayfish plague is thought to be the cause of these mortalities but this has not been proven. This species is prone to the effects of crayfish plague and in recent times there have been reports of introduced populations being affected, e.g. England (Environment Agency, 2007), Switzerland



Figure 2
The noble crayfish, *Astacus astacus* (C. Lukhaup).

Figure 2
L'écrevisse à pieds rouges, *Astacus astacus* (C. Lukhaup).

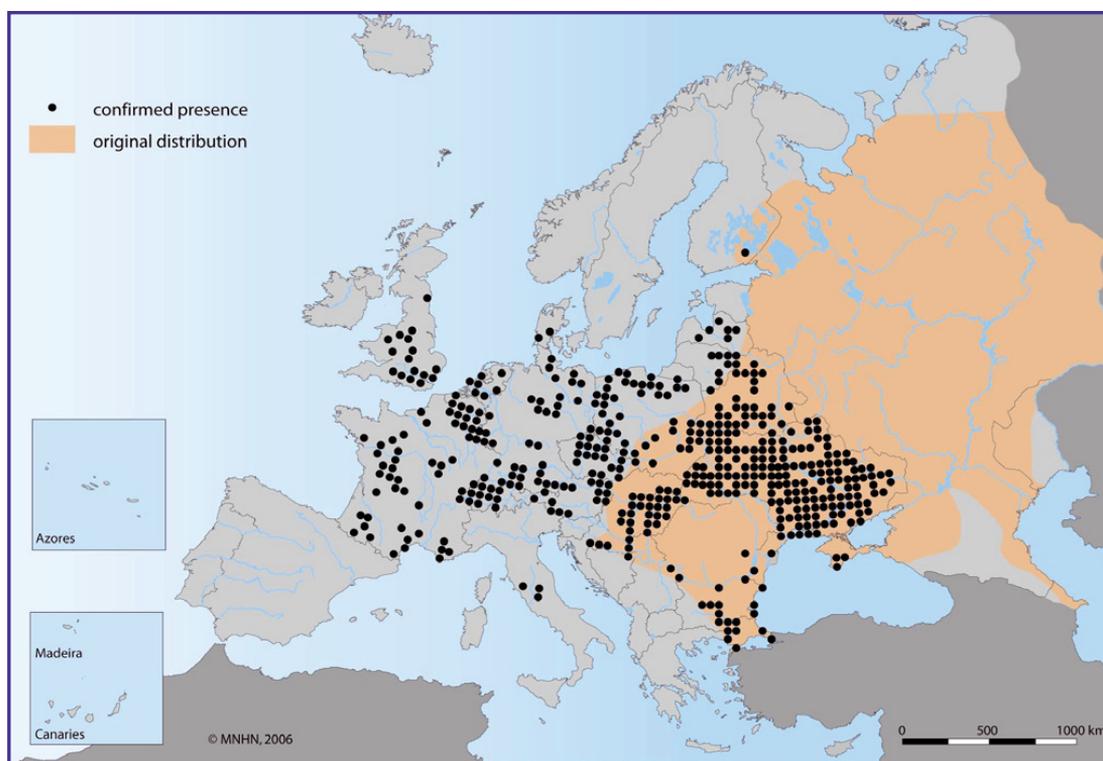


Figure 3
Map showing the distribution of *Astacus leptodactylus* (CRAYNET atlas).

Figure 3
Carte de distribution d'*Astacus leptodactylus* (CRAYNET atlas).



Figure 4
The narrow-clawed crayfish, *Astacus leptodactylus* (C. Lukhaup).

Figure 4
L'écrevisse à pattes grêles, *Astacus leptodactylus* (C. Lukhaup).

(Hefti and Stucki, 2006). Simić *et al.* (2008) report that although *A. leptodactylus* is spreading in some regions of Serbia in others numbers are being reduced by the presence of *O. limosus*. Although crayfish plague devastated populations in Turkey in the 1980s resulting in very low harvests (down from 5000 tonnes in 1984 to 320 tonnes in 1991) a partial recovery has been recorded in the 2000s, *i.e.* 2317 tonnes in 2004, and previously plague-infected lakes are productive again (Harlioğlu, 2008). Perdikaris (2009, pers. comm.) has also reported *A. leptodactylus* from the R. Nestos in Greece, where it was probably deliberately introduced. Tertyshny and Panchishny (2009) have reported large-scale mortalities amongst the industrial stocks of *A. leptodactylus* in the Ukraine, which are partly attributable to disease. Pöckl (2009, pers. comm.) during a recent visit to the Lower Bug River in the Crimean region of the Ukraine found that virtually every house in the village of Rakove was advertising crayfish for sale, and in their cellars they had many containers full with assorted live crayfish according to size, quality, and price.

Astacus pachypus Rathke, 1837 (thick-clawed crayfish): Known from only four countries bordering the Black and Caspian Seas (see map and photo in Holdich *et al.*, 2006). Some astacologists believe that this species should belong to a separate genus *Caspiastacus* (see Starobogatov, 1995).

Austropotamobius pallipes (Lereboullet, 1858) (white-clawed crayfish) – species complex (Figure 6): Currently found in 17 territories. This species has a narrower range than those of *A. astacus* and *A. leptodactylus* and is more centred in Western, Central and Southern Europe (Figure 5). Machino *et al.* (2004) have catalogued the many introductions of *A. pallipes* that have been made throughout Europe. If the division of the species into *A. italicus* (Faxon, 1814) and *A. pallipes* is accepted then the distribution map will have to be redrawn (Fratini *et al.*, 2005; Bertocchi *et al.*, 2008a).

Austropotamobius torrentium (Schrank, 1803) (stone crayfish) (Figure 8): Currently known from 20 countries but with a restricted range in Central and South-eastern Europe, where it was most likely more widely spread in the past (Figure 7). It is the most southerly of the European ICS extending as far as Bulgaria and Romania, and has recently been found in Turkey (Harlioğlu, 2007). Perdikaris *et al.* (2007) have confirmed the presence of *A. torrentium* in the R. Evros in Greece for the first time in 112 years. Trontelj *et al.* (2005) discuss the distribution of the sub-species of this species.

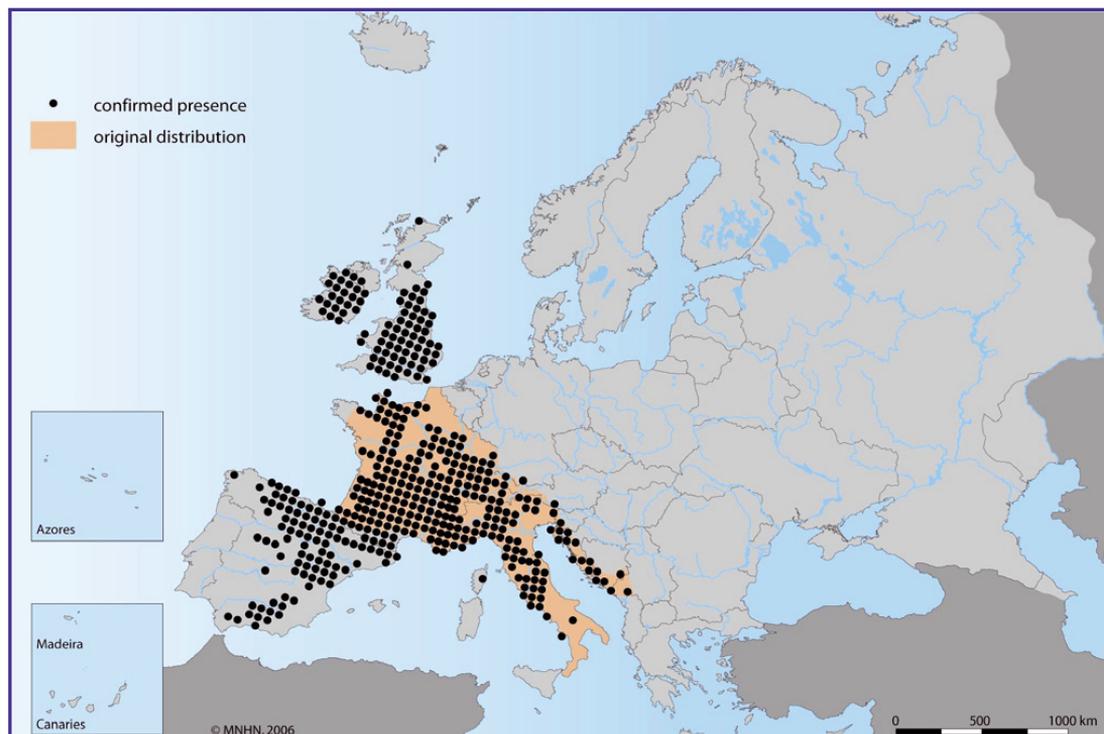


Figure 5
Map showing the distribution of *Austropotamobius pallipes* (CRAYNET atlas).

Figure 5
Carte de distribution d'*Austropotamobius pallipes* (CRAYNET atlas).



Figure 6
The white-clawed crayfish, *Austropotamobius pallipes* (C. Lukhaup).

Figure 6
L'écrevisse à pattes blanches, *Austropotamobius pallipes* (C. Lukhaup).

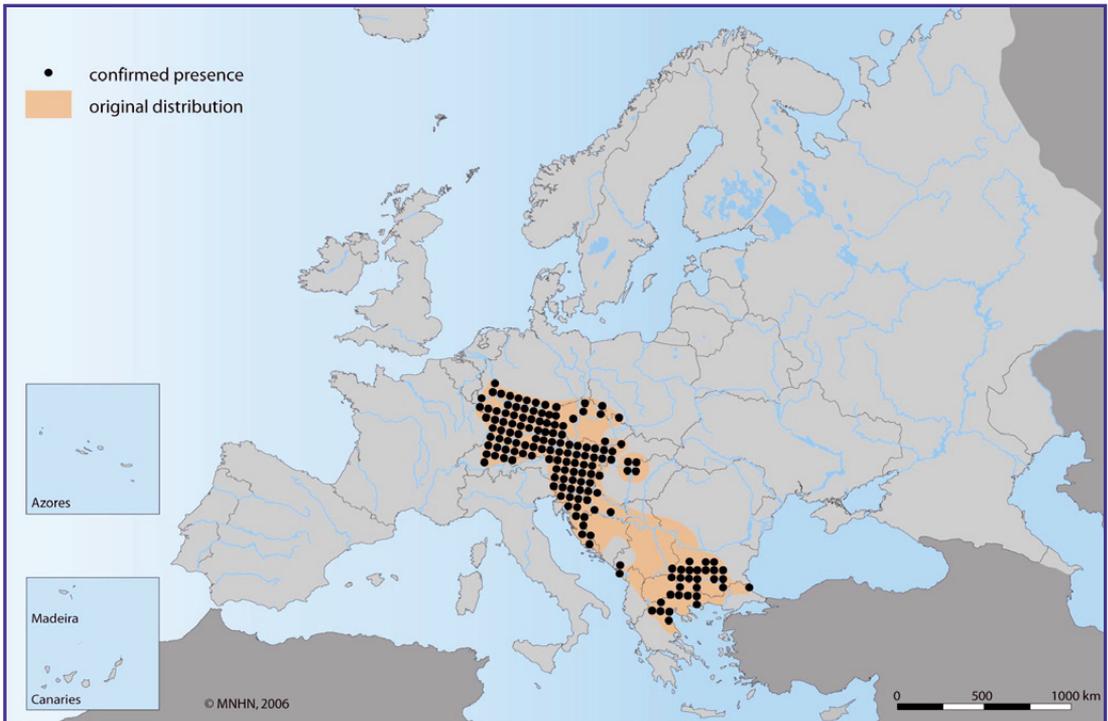


Figure 7
Map showing the distribution of *Austropotamobius torrentium* (CRAYNET atlas).

Figure 7
Carte de distribution d'*Austropotamobius torrentium* (CRAYNET atlas).



Figure 8
The stone crayfish, *Austropotamobius torrentium* (C. Lukhaup).

Figure 8
L'écrevisse des torrents, *Austropotamobius torrentium* (C. Lukhaup).

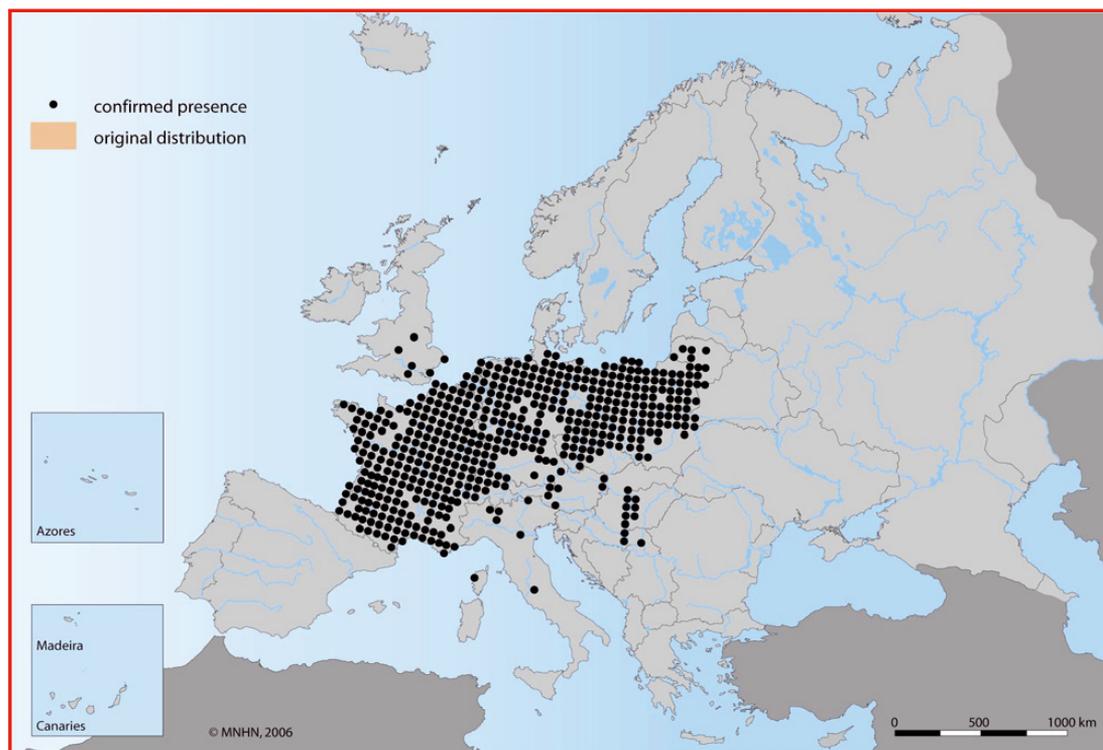


Figure 9
Map showing the distribution of *Orconectes limosus* (CRAYNET atlas).

Figure 9
Carte de distribution d'*Orconectes limosus* (CRAYNET atlas).

> OLD NICS AND THEIR CONTINUED SPREAD

It can be seen from Table I that since the publication of the crayfish atlas (Souty-Grosset *et al.*, 2006) the range of “Old NICS” has expanded in Europe. Most notable is the presence of *O. limosus* in Latvia (Arens, 2009, pers. comm.) and Romania (Pârvolescu *et al.*, 2009); *P. leniusculus* in Croatia (Maguire *et al.*, 2008), Norway (Johnsen *et al.*, 2007) and Slovakia (Petrušek and Petruskova, 2007); and *P. clarkii* in Austria (Strasser and Patzner, 2005). The presence of *P. clarkii* in Cyprus is also confirmed (Stephanou, 1987; Perdikaris, 2009, pers. comm.). The maps shown in Figures 9, 11 and 13 are taken from the CRAYNET Atlas (Souty-Grosset *et al.* 2006) and represent data collected up until the end of 2005.

Orconectes limosus (Rafinesque, 1817) (spiny-cheek crayfish) (Figure 10): Introduced to Europe in 1890, this species is currently recorded from 21 territories (Figure 9) including the island of Corsica. It is particularly common in Western, Central and Eastern Europe as far east as Belarus, e.g. out of 300 lakes examined in north-east Germany, 214 were found to have populations of *O. limosus*, and in Poland populations of *O. limosus* have increased from 57 in 1959 to 1383 in 2004 (Holdich *et al.*, 2006). A proven vector of crayfish plague, this species is thought to have been responsible for the demise of many populations of ICS in Europe (Holdich *et al.*, 2006). In Belgium, *O. limosus* is the most successful crayfish species, especially in Flanders where it occurs in virtually every water course and many ponds (Cammaerts, 2009, pers. comm.). According to Puky and Schád (2006) it tends to inhabit the lower stretches of rivers and their tributaries and as a consequence populations of ICS in the upper stretches may be protected from it. *Orconectes limosus* appears not to be so sensitive to land use changes and human activities as the ICS (Schulz *et al.*, 2002), and it can withstand habitats unfavourable to the ICS such as soft substrates, turbid and muddy



Figure 10

The spiny-cheek crayfish, *Orconectes limosus* (C. Lukhaup).

Figure 10

L'écrevisse américaine, *Orconectes limosus* (C. Lukhaup).

waters, polluted canals and organically enriched ponds and lakes (Puky, 2009). *Orconectes limosus* is common in the western half of the Czech Republic, particularly in the R. Elbe catchment (Petrušek *et al.*, 2006), where it has been identified as a vector of crayfish plague (see below); it was recently found in the Bohemian Forest, which is the most southerly record for the country (Beran and Petrušek, 2006). In Poland, where *O. limosus* is very common, Krzywosz and Ulikowski (2009) have reported a number of crashes in populations across the country, although the cause is unknown. Burba (2009) gives details of the recent (1998–2004) rapid expansion of *O. limosus* in Lithuania, where it has spread throughout the entire country since the mid-1990s, mainly inhabiting the R. Nemunas and the R. Venta, the latter flowing from Lithuania through Latvia to the Baltic Sea. It has also been recorded from the Baltic Sea coast in Lithuania (Burba, 2008). In Belarus, *O. limosus* was found in 1997 in rivers bordering Poland and Lithuania, and now mainly occurs in the R. Neman. In 2009, *O. limosus* was found in large quantities in the Lesnya Levaya River, which belongs to the R. Narev basin (Baitchorov and Giginiaik, 2009). The invasion in Belarus appears to be upstream. It is now in rivers close to the R. Yaselda, which is in the Black Sea basin.

Stloukal and Harváneková (2005) reported no NICS from Slovakia, but Jansky and Kautman (2007) reported the presence of *O. limosus* in the R. Ipeľ and Váh close to the R. Danube in 2007 and this was confirmed by Puky (2009). *Orconectes limosus* was introduced to Hungary from Germany in the 1950s for farming but the venture was unsuccessful, and it was not found in the country until it appeared in the R. Danube in 1985 (Puky and Schád, 2006). The main catch in the river in the 1990s consisted of *A. astacus* but this is now dominated by *O. limosus*. It has now colonized the complete Hungarian stretch of the R. Danube south to Budapest since 1985, and has also been spreading fast along the R. Tisza and its tributaries (Sallai and Puky, 2008). Its downstream colonization rate over 20 years has been estimated to be 13 km·yr⁻¹ (Puky and Schád, 2006). If one takes into account its recent occurrence in Croatia then this increases to 16 km·yr⁻¹ (Puky and Schád, 2006). *Orconectes limosus* has entered Croatia through the R. Danube from Hungary. It has entered the R. Drava in Croatia and is spreading upstream some 1.5 km·yr⁻¹ affecting populations of *A. leptodactylus* (Maguire and Klobučar, 2003; Faller *et al.*, 2009). *Orconectes limosus* has recently spread down the Danube to Serbia (Karaman and Machino, 2004; Pavolić *et al.*, 2006; Simić *et al.*, 2008) and Romania (Pârvulescu *et al.*, 2009). It seems likely that rapid spread of this species

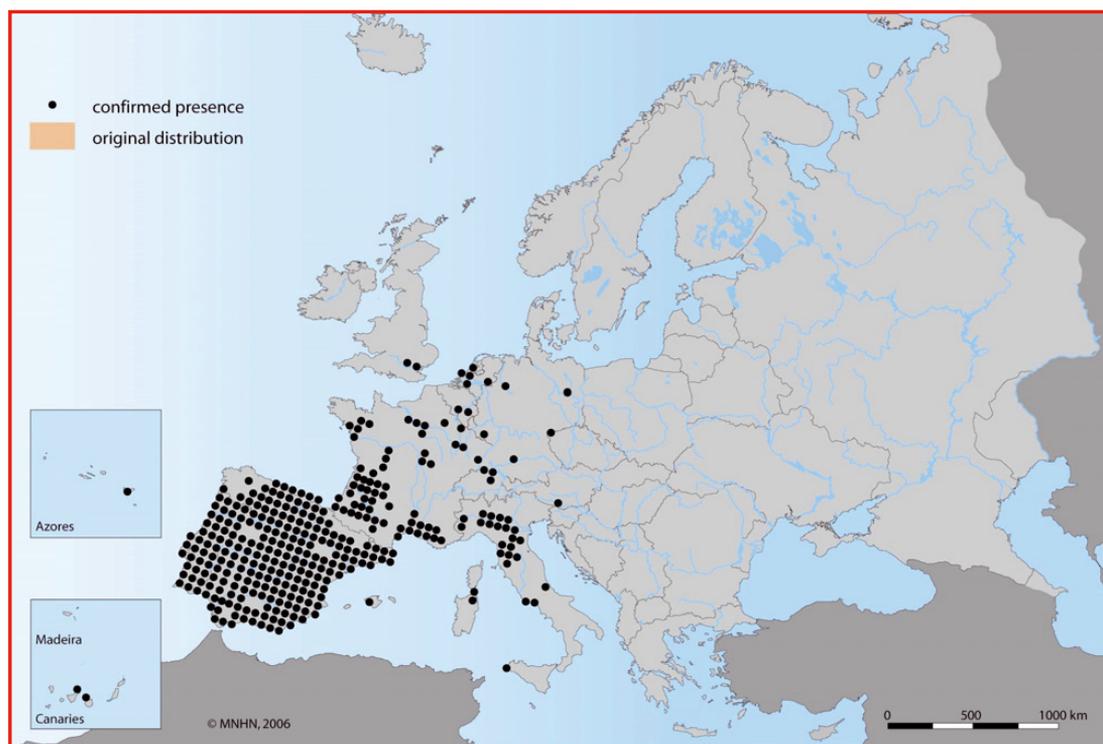


Figure 11

Map showing the distribution of *Procambarus clarkii* (CRAYNET atlas).

Figure 11

Carte de distribution de *Procambarus clarkii* (CRAYNET atlas).

in the R. Danube may well be partly due to deliberate introductions. Kozubíková *et al.* (2009) found that a high percentage, but not all individuals, of *O. limosus* carried crayfish plague in the Czech Republic, and were responsible for recent mortalities of indigenous species. Petrussek *et al.* (2006) found that *O. limosus* was mainly restricted to the R. Elbe catchment in the eastern half of the Czech Republic, but was likely to spread naturally upstream from the R. Danube into the R. Morava catchment, or by human translocations from the R. Oder and R. Vistula in Poland (Kozák *et al.*, 2004).

ICS have been found co-existing with *O. limosus* in large rivers in Austria (Pöckl and Pekny, 2002), in a quarry lake in Belgium (Cammaerts, 2009, pers. comm.), in a lake in Italy (Gherardi, 2009, pers. comm.), and in Lake Constance (Germany), where *O. limosus* co-exists with *A. leptodactylus* (Hirsch, 2009), as apparently it does in many other lakes in southern Germany (Hirsch, 2009, pers. comm.). Hirsch and Fischer (2008) have shown that in Lake Constance, *O. limosus* may have a negative impact on juvenile of burbot (*Lota lota*). Schulz *et al.* (2006) have recorded the occurrence of *A. astacus* and *O. limosus* in a number of lakes in Poland, and suggest that *O. limosus* is gradually displacing *A. astacus* by direct competition rather than disease. Keller and Stucki (2008) have recently reviewed the distribution of *O. limosus* in some European countries.

Procambarus clarkii (Girard, 1852) (red swamp crayfish) (Figure 12): Currently recorded from 15 territories, including a number of islands, *i.e.* São Miguel (Azores), Cyprus, Majorca, Sardinia, Sicily and Tenerife (Figure 11). The most recent expansion to its range is to Austria (Strasser and Patzner, 2005; Petutschnig, 2008). It had apparently been introduced to Cyprus some time ago, where it flourished in the Athalassa dam, and was also introduced into two other dams, but the reference has only come to light recently (Stephanou, 1987). Perdikaris (2009, pers. comm.) has confirmed its presence on the island through



Figure 12
The red swamp crayfish, *Procambarus clarkii* (C. Lukhaup).

Figure 12
L'écrevisse de Louisiane, *Procambarus clarkii* (C. Lukhaup).

a third party. Populations are most prevalent in Italy (see below), Portugal, Spain (see below) and The Netherlands. In the Azores it is present in three lakes on São Miguel but does not occur on any of the other islands (Costas, 2009, pers. comm.). Although outside the geographical range of this paper it is worth noting that a reproducing population of *P. clarkii* has recently been found in Israel (Wizen *et al.*, 2008). In Spain, Alcorlo *et al.* (2006) have shown how *P. clarkii* can be used as an indicator of the bioavailability of heavy metals. In addition to being a vector of crayfish plague, due its short life-history, rapid growth, burrowing activities and high population density it can impact adversely on the aquatic environment (Rodriguez *et al.*, 2003, 2005; Gherardi, 2006; Gherardi and Acquistapace, 2007). Further details of *P. clarkii* in Spain and Italy are given below.

Pacifastacus leniusculus (Dana, 1852) (signal crayfish) (Figure 13): Currently known from 27 territories. This is the most widespread of the NICS (Figure 14). Most populations have been derived from implants made into Sweden in 1959 and subsequently. These were mainly derived from Lake Tahoe in California. However, as well as obtaining *P. leniusculus* from Sweden, Finland imported stock directly from North America in 1967–1968. The species was illegally introduced into Austria from California and into France from Oregon. It is most widespread in Sweden (some 4000 populations in 2008; Edsman, 2009, pers. comm.), Finland and England (see below). In 2006 plague-carrying *P. leniusculus* were found for the first time in Norway, although the population is now thought to have been eradicated (Johnsen *et al.*, 2007). In 2008 they were found in the Halden watercourse, which had previously been struck with crayfish plague (Johnsen and Vrålstad, 2009). In 2003 it was found in Slovenia having moved down the R. Mura in Austria and subsequently into the R. Ščavnica (Bertok *et al.*, 2003; Govedič, 2003); and 2005 in the R. Morava in Slovakia, having either been introduced by Austrian fishermen or invaded from waterbodies in Austria (Petrušek and Petruskova, 2007). In north-west Italy, *P. leniusculus* was introduced into Brugneto Lake in 2002 and poses a threat to the R. Po watershed (Capurro *et al.*, 2007); records for north-east Italy have been noted by Machino (1997) and Füreder and Machino (1999) in the Adige River basin. *Pacifastacus leniusculus* is having an impact on the macrophyte beds and aquatic snails in Lake Geneva, but an unexpected consequence of this is a reduction in the prevalence of swimmer's itch, caused by a snail-borne trematode (Dubois *et al.*, 2006). It is present in the R. Gyöngyös in Hungary, and specimens have proved positive for crayfish plague (Kiszely, 2006). In the northern part of Croatia, *P. leniusculus* has been recorded for the first time coming down the R. Mura from

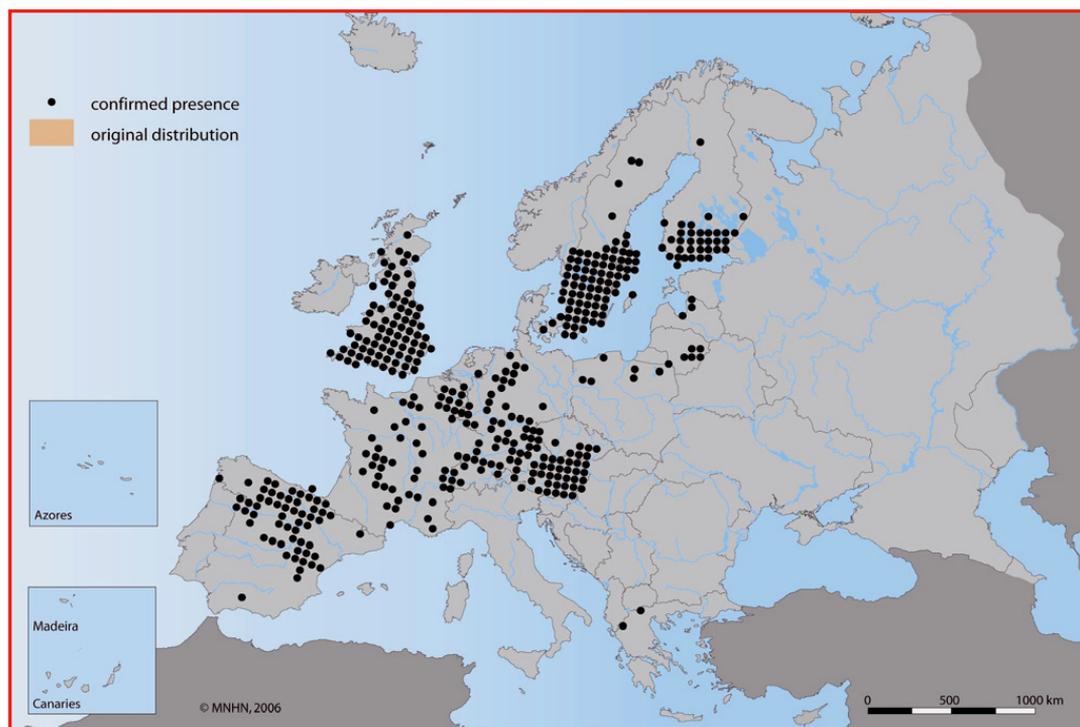


Figure 13
Map showing the distribution of *Pacifastacus leniusculus* (CRAYNET atlas).

Figure 13
Carte de distribution de *Pacifastacus leniusculus* (CRAYNET atlas).

Slovenia and will probably enter the R. Drava (Maguire *et al.*, 2008). From the first record in Slovenia in 2003 it has been calculated that *P. leniusculus* has moved at $13.8 \text{ km}\cdot\text{yr}^{-1}$ down the R. Mura by 2009 (Hudina and Lucić, 2009). The rapid spread of *P. leniusculus* can also be illustrated by the situation in Scotland, where it was first discovered in 1995 (Maitland, 1996) and in just over 10 years it has spread to eight locations, including 58 km of river (Gladman *et al.*, 2009). Its impact on *A. pallipes* in South-West England is dealt with below. In addition to being a vector of crayfish plague, due to its rapid growth, burrowing activities and high population density it can impact adversely on the aquatic environment (Guan, 1994; Guan and Wiles, 1996, 1997). It has been estimated that in some stretches the banks of the River Lark in England are being eroded by $1 \text{ m}\cdot\text{yr}^{-1}$ due the burrowing activity of *P. leniusculus* (Stancliffe-Vaughan, 2009). The impact that *P. leniusculus* is having on the resident biota in parts of England is such that in some cases it is thought to be preventing waterbodies from attaining good ecological status as prescribed under the Water Framework Directive. Further details of *P. leniusculus* are given below.

> NEW NICS

(For photos and maps of the species below see Holdich *et al.*, 2006; Pöckl *et al.*, 2006; except for *O. juvenilis* – see Chucholl and Daudey, 2008.)

It can be seen from Table 1 that since the publication of the CRAYNET atlas (Souty-Grosset *et al.*, 2006) a number of “New NICS” have appeared in Europe, and others have expanded their range.

Orconectes immunis (Hagen, 1870) (calico crayfish): This species was introduced through the aquarium trade in Germany and is kept as a pet in aquaria and garden ponds. A single individual was originally found in a small canal in the upper Rhine valley in southern Germany



Figure 14
The signal crayfish, *Pacifastacus leniusculus* (C. Lukhaup).

Figure 14
L'écrevisse signal, *Pacifastacus leniusculus* (C. Lukhaup).

in 1997 (Dehus *et al.*, 1999), although according to Gelmar *et al.* (2006) the first reliable record is from 1993. A breeding population was subsequently discovered and this has spread down the R. Rhine to Karlsruhe, a distance of 45 km from the original site, and possibly further to Speyer some 35 km downstream (Dehus *et al.*, 1999). Gelmar *et al.* (2006) have since recorded it from 28 localities in the Upper Rhine region, in Baden-Württemberg, as well as in France and Rheinland-Palatinate, and Martens (2009, pers. comm.) states that this has increased to 35 localities in 2009 and that the species is entering the Black Forest region. According to Chucholl *et al.* (2008) and Chucholl (2009) it is displacing another NICS, *O. limosus*, which has been present in the upper Rhine system for at least five decades. *Orconectes immunis* digs deep burrows, which allow it to occupy shallow and temporary water bodies (Chucholl, 2009).

Orconectes virilis (Hagen, 1870) (virile crayfish): First recorded in The Netherlands in 2004 (Soes and van Eekelen, 2006), but it is thought to have been present before that as it was already widespread. It is now known from numerous sites and had colonized several hundred kilometres of waterway by 2006 (Koesse and Blokland, 2008; Soes, 2008, pers. comm.). In some sites it has displaced *O. limosus*. It is thought to be having a negative impact on the freshwater environment in The Netherlands (Soes, 2008, pers. comm.). *Orconectes virilis* was originally identified as *O. limosus* from a pond near the River Lee in north London in 2004 (see Holdich and Black, 2007); however, Ahern *et al.* (2008) re-identified it as *O. virilis*, and recorded it in watercourses adjacent to the pond within a 7 km radius, a dispersal rate of more than 2 km·yr⁻¹. It is thought that the original population was derived from the dumping of the contents of an aquarium. Apparently, although densities are fairly low, this species is still spreading downstream in the Lee Navigation and connecting streams and ditches (Ellis, 2009, pers. comm.). Filipová *et al.* (2009) studied the molecular genetics of specimens from England (R. Lee) and The Netherlands, finding them to be of the same lineage, but different from American specimens analysed.

Orconectes juvenilis (Hagen, 1870): In the CRAYNET atlas this species was referred to as *Orconectes rusticus* (Girard, 1852), but it has since been re-identified as the closely-related species *O. juvenilis* (Hagen) by Chucholl and Daudey (2008). It escaped from a breeding population in ponds at a restaurant advertising crayfish as a delicacy into the R. Dessoubre in eastern France where it was discovered in 2005, and has since become established; in 2006 it was found to have colonized at least a 700 m stretch of the river.

***Procambarus* sp.** (marbled crayfish/marmorkrebs): This unique species is currently only known from a small number of sites in three European countries. It was first recorded from The Netherlands in 2004 (Soes and van Eekelen, 2006). In Germany, *Procambarus* sp. is known from at least two sites (Marten *et al.*, 2004; Schulz *et al.*, 2009), including a gravel pit near Karlsruhe and a waste treatment pond near Braunschweig (Schulz *et al.*, 2009). An egg-bearing specimen and juveniles have recently been recorded from a natural lake near Freiburg in the Black Forest (Schulz, 2009, pers. comm.). Recently, a single specimen of *Procambarus* sp. was found amongst a population of *P. clarkii* in Tuscany, Italy (Marzano *et al.*, 2009). It is widely available through the aquarium trade and on the internet and is a popular pet in many countries in Western and Eastern Europe. It has recently been shown to be capable of harbouring crayfish plague (Environment News Service, 2008). In addition, due to its parthenogenetic properties it is being highlighted as a useful laboratory animal (Vogt, 2008). The only country where it has become widely established is Madagascar (Jones *et al.*, 2009).

Procambarus acutus (Girard, 1852): So far has only been recorded from The Netherlands, where it has been present since 2005 (Soes and van Eekelen, 2006), a fact not known when the atlas was compiled. *Procambarus acutus* is closely related to *P. zonangulus* Hobbs & Hobbs, 1990, and it was known for sure which of the two species was present; however, Soes (2009, pers. comm.) has recently confirmed that it is *P. acutus*. *Procambarus acutus* was thought to have been originally introduced into Spain along with *P. clarkii* in the 1970s (Henttonen and Huner, 1999), but did not become established. The taxonomy of *P. acutus* and *P. zonangulus* is discussed by Huner (2002). The only record for *P. zonangulus* outside of North America or possibly Europe is from the R. Nile in Egypt, where it co-occurs with *P. clarkii* (Ibrahim *et al.*, 1997).

Cherax destructor Clark, 1936 (yabby): This Australian species is farmed in Italy (D'Agaro *et al.*, 1999) and has recently been recorded from the wild in central Italy (Scalici *et al.*, 2009). It was introduced into Northern Spain from a crayfish farm in California in 1983, and further introductions were carried out in 1984 and 1985 (Bolea, 1996). Some Spanish populations in ponds were eradicated by using crayfish plague in 2005 (Holdich *et al.*, 2006), but other populations still exist (Camargo and Gonzalo, 2009). *Cherax destructor* is available from fish markets in some European countries, e.g. Germany and Switzerland. It has been found in the wild in Switzerland, where it can be legally imported for human consumption, but there have been no reports of it becoming established (Stucki and Jean-Richard, 2000; Hefti and Stucki, 2006). It is also kept as an aquarium pet in Switzerland and could be released into the wild by owners or escape from ponds (Wittenberg, 2005).

Cherax quadricarinatus (von Martens, 1868) (redclaw): There are no confirmed wild populations of this Australian species in Europe, although it is widely available through the aquarium trade and live food trade. It is the only species from outside of Europe to be legally allowed into Britain, but only for aquarium purposes (Holdich *et al.*, 2004). There has been one report of a breeding pond population in Germany (Lukhaup, 2007, pers. comm.), but confirmation of this has not been forthcoming, although one of us (DMH) has seen a photograph clearly indicating that it is this species. It was found by divers in a gravel pit near Cologne (Germany) in 2005, but an intense survey the following year did not reveal any specimens (Schulz *et al.*, 2009). *Cherax quadricarinatus* is apparently being abandoned by owners and they have been found in the wild in the Netherlands (Soes, 2008) and England (Holdich and Sibley, 2009), but there have been no reports of populations developing. *Cherax quadricarinatus* is farmed in Italy (D'Agaro *et al.*, 1999). Perdikaris (2009, pers. comm.) has found specimens of *C. quadricarinatus* imported from Italy in pet shops and restaurant aquaria in Greece. Control of illegal imports of exotic species is apparently practically absent in Greece.

> POTENTIAL INTRODUCTIONS

In addition to the above, many species of crayfish from the Americas and Australia are advertised for sale on the internet and in some aquarist catalogues in Europe, e.g. *Procambarus alleni*, *P. clarkii*, *P. sp.*, *P. spiculifer*, *P. tolteca*, *Orconectes durelli*, *O. luteus*, *Cambarus*

coosae, *C. manningi*, *C. rusticiformis*, *C. speciosus*, *Gambarellus chapalanus*, *C. montezumae*, *C. patzcuarensis*, *C. puer*, *C. shufeldtii*, *Cherax destructor*, *C. holthuisi*, *C. lorentzi*, *C. quadricarinatus*, *Cherax* spp. of various colour varieties, and *Samastacus spinifrons*. The potential exists for any of these species to be released into the inland waters of Europe. Stloukal and Vitázková (2009) mention the fact that in Slovakia *P. clarkii* and *P. sp.* occur in garden ponds and present a high invasion risk.

CASE STUDIES OF THE DECLINE OF ICS IN EUROPE

The IUCN has recently been reviewing data concerning the population decline of *A. astacus*, *A. pallipes* and *A. torrentium* in Europe (see below). We show below that the decline for these species is serious and use the situation in England, Italy, France, the Iberian Peninsula, Sweden and Finland in particular to illustrate this. In addition, information is given about the situation in some other countries.

> ENGLAND

As highlighted by Sibley *et al.* (2009) and Holdich and Sibley (2009), the situation in England concerning the decline of *A. pallipes* is serious. A 95% reduction in *A. pallipes* populations at the 2 km square level in the county of Hampshire has occurred since the 1970s. A likely loss of > 95% has been recorded by the Thames Environment Agency since the 1970s; four NICS occur in the sub-catchments of the Thames Basin and whereas *A. pallipes* once occurred in all the major tributaries it has only been recorded in eight of the 55 sub-catchments since 2004 (Ellis, 2009). In the counties of East and West Sussex a 100% loss of *A. pallipes* is likely since the 1970s, while only a few small populations exist in Kent. Pugh (2008) and Pugh *et al.* (2008) have documented the severe decline of *A. pallipes* in Essex and Suffolk, thought mainly to be due to NICS and crayfish plague. An estimated 77% decline in populations in Eastern England has occurred over the last 30–40 years. The prediction that *A. pallipes* will disappear from all 10 km squares nationally by the 2030s (Sibley, 2004) looks like becoming a reality, although only for South-West England is the data available to make a more informative estimate, *i.e.* 2038, if *P. leniusculus* continues to spread.

The situation concerning *A. pallipes* is considered critical in South-West England (Sibley *et al.*, 2009). Figure 15a shows its approximate distribution in 1975 before the introduction of NICS. Its range is wide, although somewhat restricted by unsuitable water quality and geology. Figure 15b shows the situation in 2009 following more than three decades of deliberate introductions, escapes and continued colonization by NICS. Three NICS are now present (Figure 15c), *i.e.* *A. astacus*, *A. leptodactylus* and *P. leniusculus*. Of these only *P. leniusculus* has become widespread and this has been at the expense of *A. pallipes*, mainly through outbreaks of crayfish plague since the 1980s. It has also colonized waters not suitable for *A. pallipes*. Since 1990–1996 there has been a 28% decline in *A. pallipes* distribution by 10 km squares in South-West England and an increase of 71% in NICS. However, if one looks at this from a sub-catchment point of view the decline is more dramatic. Pre-1975, 87 sub-catchments in South-West England were occupied by *A. pallipes*, but at the end of 1999, this had declined to 48, and by the end of 2008 to 26. This represents a decline by sub-catchment of 45.8% from the end of 1999 to the end of 2008, and a decline of 70.1% from 1975 to the end of 2008.

Faced with this decline the need for a strategic approach to crayfish conservation through translocations to isolated “ark” sites has become more urgent if the future of *A. pallipes* is to be secured (Peay, 2009). “An ark site is a new refuge site where populations of ICS can be established, safe from NICS and crayfish plague. It is an isolated, self-contained site with running water, still water, or both, which can support a healthy, self-sustaining population with little need for ongoing management” (www.buglife.org.uk). In England the South West Crayfish Project was conceived in response to the chronic decline in *A. pallipes* outlined above

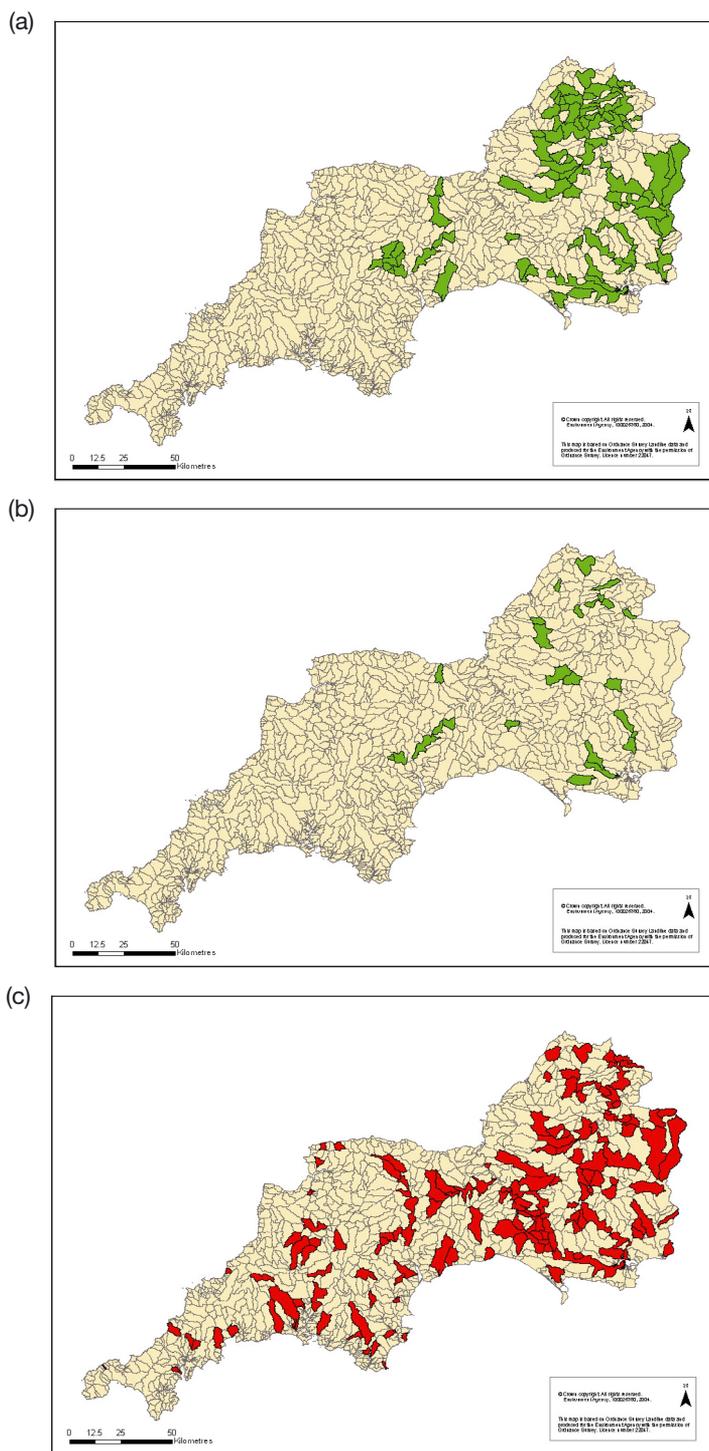


Figure 15
Crayfish distribution in waterbody catchments in South-West England. a – Approximate distribution of *Austropotamobius pallipes* in 1975. b – Distribution of *Austropotamobius pallipes* in 2009 (excluding recently translocated populations). c – Distribution of NICS, mainly *Pacifastacus leniusculus*, in 2009.

Figure 15
Distribution des écrevisses dans les bassins versants du sud-ouest de l'Angleterre. a – Distribution approximative d'*Austropotamobius pallipes* en 1975. b – Distribution d'*Austropotamobius pallipes* en 2009 (excluant les populations déplacées récemment). c – Distribution de NICS, principalement *Pacifastacus leniusculus*, en 2009.

specifically including the loss of some of the most historically and numerically important populations in the region in the early/mid 2000s. Bristol Conservation and Science Foundation based at Bristol Zoo Gardens are leading this partnership, which works at a landscape scale across the region (Nightingale *et al.*, 2009). This builds on work undertaken by Avon Wildlife Trust and the Environment Agency and has thus far resulted in the translocation of crayfish from two threatened populations to five new ark sites (one stillwater and four streams). These ark sites now hold more than one fifth of the remaining populations of *A. pallipes* in the whole of South-West England. The first of these was set up in 2006 (Sibley *et al.*, 2007). Further locations across the region are currently under consideration. The invertebrate conservation trust Buglife (www.buglife.org.uk) are providing guidance on the use of aggregate sites (Kindemba and Whitehouse, 2009) that will be examined using the criteria of Peay (2009) as to their suitability for crayfish introductions. Many quarry sites in other regions of Britain are also being considered as ark sites.

> FRANCE

According to Changeux (2003), the national surveys of crayfish species distribution performed in France since 1977 by the *Conseil Supérieur de la Pêche*, show that the indigenous species (*A. pallipes*, *A. astacus*, *A. torrentium*) are either rare, or in decline; while the introduced species (*O. limosus*, *P. leniusculus*, *P. clarkii*, *A. leptodactylus*), are increasing. The banning of the transport of live introduced species, except for *A. leptodactylus*, has not stopped this process, especially the rapid propagation of *P. leniusculus*, which has been responsible for a number of crayfish plague outbreaks. Legal protection has been provided for a range of indigenous species and habitats in France, with the setting up of 55 habitat decrees and 154 Natura 2000 zones with their management plans.

At the regional level Bramard *et al.* (2006) analysed surveys carried out in the Poitou-Charentes Region (Departments of Deux-Sèvres, Vienne, Charente, Charente-Maritime) from 1978 to 2003 and revealed a large-scale disappearance of *A. pallipes* populations and the alarming spread of non-indigenous species such as *P. clarkii* and *P. leniusculus*. In the past *A. pallipes* was widely distributed in the Deux-Sèvres department and well represented throughout the departments of Vienne and Charentes. By 2003, they were mostly found in the Deux-Sèvres department, with only a few isolated populations in the other parts of the region. In 1978, 137 populations of *A. pallipes* were recorded in the region. In 1988, 120 populations were found and by 1995 only 81 populations existed in the region, a loss of more than 30% of crayfish populations in just seven years. In 2003, only 45 populations were recorded, representing only 32% of the 1978 number. Most of the disappearances of crayfish are unexplained. The main known causes for the loss of crayfish populations in the region are crayfish plague, the introduction of NICS, habitat degradation and pollution. Pesticides have been implicated in the loss of a few populations, including one in the Crochet stream (Vienne), where the chemicals lambda cyanlochtrine and isoproturon were identified. Organic pollution (farm waste) was also found to be the cause for the loss of at least two populations. At least two populations in the Deux-Sèvres department disappeared following the creation or the maintenance of a pond. The occurrence of crayfish plague was confirmed in the St Christophe river (Deux-Sèvres) (Neveu and Bachelier, 2002) and suspected in three other rivers in 2001. Drought can also cause the loss of a population. During summer 2003, an unprecedented heat wave hit France and two crayfish sites in the Vonne catchment (Poitou-Charentes) completely dried out. Introduced in 1978 to the Vienne department, *P. leniusculus* now occurs in 28 locations, which are situated in the headwaters of rivers and result from human translocations and natural colonization. The first record of *P. clarkii* was in 1988 in Charente-Maritime department; since then it has spread through most of the hydrographic basin of this department. *Orconectes limosus* has been widely distributed in the main rivers of the region for almost a century (Arrignon, 1997). One example of cohabitation between *O. limosus* (dam brook) and *A. pallipes* occurs in Rourie Brook, where a strong population of *A. pallipes* exists. At a regional scale, a second good example is the Burgundy where Lerat *et al.* (2006) provide

detailed information about the geographical distribution of *A. pallipes* since 2000; 893 stations have been sampled, from 593 streams and *A. pallipes* has been found in 128 small rivers, and *A. astacus* in only two streams and two ponds. Four non-indigenous species have also been recorded, *i.e.* *A. leptodactylus*, *O. limosus*, *P. leniusculus*, and *P. clarkii*. In half of the stations where *A. pallipes* was recorded during the last 30 years it is no longer present. In Burgundy, the *A. pallipes* populations are not very rare but very isolated as in Poitou-Charentes.

According to Collas *et al.* (2007) the last national survey conducted in 2006 shows the same trend and the situation of the three indigenous species is considered alarming: *A. torrentium* and *A. astacus* are close to extinction, and *A. pallipes*, with mortalities observed in 47 departments, can now only be found in the uppermost parts of the watersheds. These mortalities are due not only to disease, but also to the first signs of climatic changes, *i.e.* heat-waves and droughts observed in 2003 and 2008, the consequences of which have been analyzed by Renai *et al.* (2008); and the pressure of non-indigenous species, which are still expanding their range. Both *P. leniusculus* and *P. clarkii* showed their strongest geographical expansion during the 2001–2006 period. Everywhere they appear to be very strong competitors; being more aggressive; resistant to disease, although there are outbreaks of disease at times associated with either a chronic or epizootic mortality (Edgerton *et al.*, 2004); and are able to colonize varied environments. They are in the process of colonizing new departments, new watersheds, and eliminating indigenous species.

> ITALY

The complexities of the taxonomy and nomenclature of the Italian white-clawed crayfish have been reviewed by Manganelli *et al.* (2006). There is a general consensus to define the taxon as a species complex. By molecular studies, Fratini *et al.* (2005) were the first to clearly show that in Italy *A. pallipes* was comprised of two species *i.e.* *italicus* and *pallipes*, with *italicus* having four subspecies, *i.e.* *A. i. carinthiacus*, *A. i. italicus*, *A. i. meridionalis* and *A. i. carsicus*. Therefore, Italy may be considered a “hot-spot” for the genetic diversity of the European crayfish *Austropotamobius*. The occurrence of five taxonomic units of this threatened crayfish in Italy clearly suggests that any conservation programme and re-introduction plan should refer to the geographic distribution of each unit to ensure the preservation of independent genetic pools. Bertocchi *et al.* (2008a) have attempted to characterize *A. pallipes* and *A. italicus* by morphometric means, but they state that the issue surrounding their taxonomic status has not yet been resolved and that the confused taxonomy may hamper attempts to conserve indigenous crayfish in Italy.

Fragmentation of populations is due to continuous effects of habitat destruction and degradation, but other threats to the survival of *A. pallipes* complex populations include diseases, notably crayfish plague carried by *P. leniusculus* and *P. clarkii*, interspecific competition with NICS and with the indigenous river crab (*Potamon fluviatile* Savigny), water pollution, overexploitation, and poaching. In Italy, the decline is about 74% over the last 10 years based on data from Nardi *et al.* (2005), Füreder *et al.* (2003), and Renai *et al.* (2006).

In addition to those mentioned above there have been many surveys of the distribution, or population biology and/or impact of the Italian ICS *A. pallipes/italicus* and NICS, *O. limosus* and *P. clarkii*, particularly in central, north-east and north-west provinces, *e.g.* by Nardi *et al.* (2005), Chiesa *et al.* (2006), Fea *et al.* (2006), Ferri *et al.* (2006), Gherardi (2006), Gherardi and Lazzara (2006), Gherardi and Acquistapace (2007), Scalici and Gherardi (2007), Ligas (2008), Bertocchi *et al.* (2008b), Polloni and Ghezzi (2008) and Scalici *et al.* (2008).

Figure 16a shows that except in the south *A. pallipes/italicus* occurs in most Italian provinces. Figure 16b clearly shows how the distribution by province of *P. clarkii* is now almost as great as that of *A. pallipes/italicus*, and that it even occupies provinces in Sicily and Sardinia not occupied by the ICS.

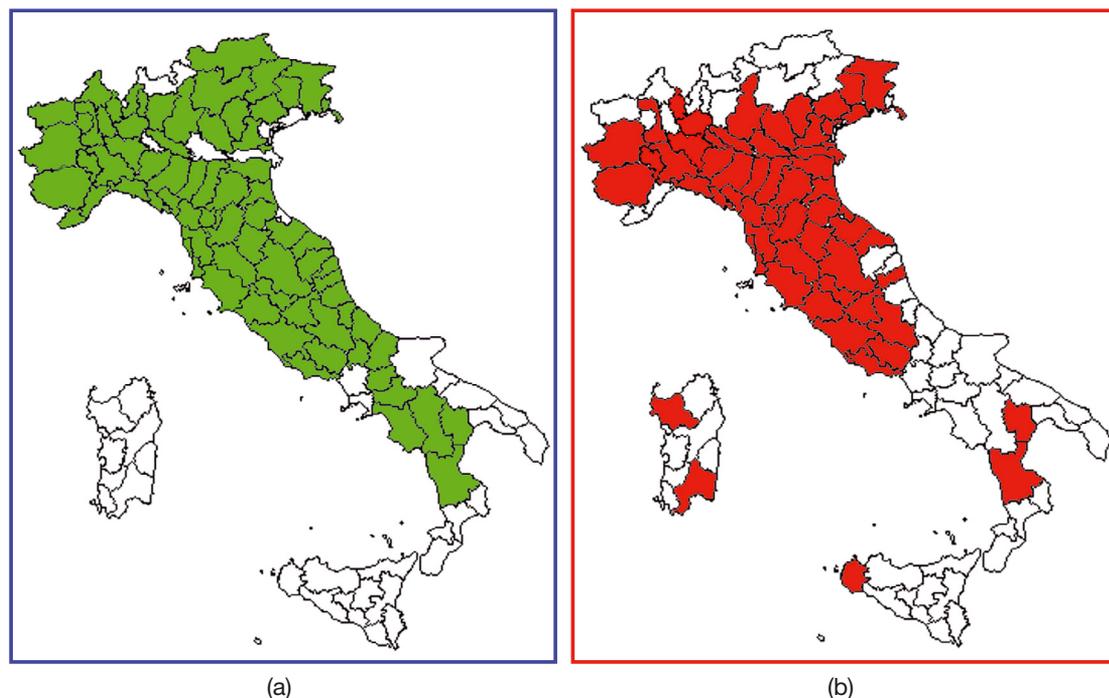


Figure 16

a – Distribution of the *Austropotamobius pallipes* species complex in Italian provinces. b – Distribution of *Procambarus clarkii* in Italian provinces. Reproduced with permission from Füreder (2009).

Figure 16

a – Distribution du complexe d'espèces d'*Austropotamobius pallipes* dans les provinces italiennes. b – Distribution de *Procambarus clarkii* dans les provinces italiennes. Reproduction autorisée d'après Füreder (2009).

> IBERIAN PENINSULA

Austropotamobius pallipes was at one time widespread and quite common in the Iberian peninsula, particularly in the north and north-east (Asturias to Leon) and highlands of the south (Holdich *et al.*, 2006). Its origin is in dispute, largely due to differences in interpretation of different genetic techniques. Examination of mtDNA by RFLP found that Spanish white-clawed crayfish share a haplotype with those from northern Italy, suggesting that they were originally translocated from Italy (Grandjean *et al.*, 2001). More detailed work confirmed this hypothesis (Diéguez-Urbeondo *et al.*, 2008). However, using RAPD analysis Beroiz *et al.* (2008) refute this, finding genetic variability as high in Spain as in other European regions. The southern populations are also morphologically distinct (Gil-Sanchez and Alba-Tercedor, 2006). Some publications therefore refer to Spanish populations as *A. italicus* (e.g. Martinez *et al.*, 2003). Here they will be considered as part of the *A. pallipes* species complex.

With the introduction of two North American species into the Iberian peninsula, first, *P. clarkii* in 1973, and then *P. leniusculus* in 1974 (Habsburgo-Lorena, 1979), the fate of white-clawed crayfish was effectively sealed. Today this crayfish is believed extinct in Portugal (Holdich *et al.*, 2006; Machino and Holdich, 2006) and only remnant populations remain in Spain, chiefly in Atlantic regions of Asturias, Girona and Pais Vasco, Navarra, Castilla and Leon, Cuenca and Granada. As elsewhere when NICS have ousted ICS from the majority of their habitat, *A. pallipes* is now restricted in Spain to small headwater streams and springs (Martinez *et al.*, 2003).

In Cuenca, in the south midlands and enjoying a Mediterranean climate, white-clawed crayfish were formerly quite common in limestone and dolomitic catchments, supporting one of

the most important crayfisheries in Spain (Torre and Rodriguez, 1964). However, most of the populations in Cuenca had disappeared by 1985 (Martinez *et al.*, 2003), as evidenced from surveys carried out in 1984, 1986, 1990, 1994 and 1998. The number of populations has decreased slightly since 1990, with an annual loss of 1.5%, but some of the most important populations have disappeared since then. *Pacifastacus leniusculus* was first stocked in Cuenca in 1986, but no new populations were seen until 1994, about the time when this species was opened to fisheries in some Spanish rivers (Alonso *et al.*, 2000). In 2000 a new province-wide survey detected *A. pallipes* in two areas, comprising just 35 sites out of 259; the rest had no crayfish and of these, 27 were dry. Martinez *et al.* (2003) analyse the underlying environmental situation.

A similar picture has been seen in other Spanish regions. A 3-year programme of conservation and management was developed for *A. pallipes* in Andalucia (southern Spain) in 2002, where the species was formerly widely distributed (Alonso *et al.*, 2000) but from the 1980s a strong decline in the area occupied was noted, related to expansion of *P. clarkii*, drought and other causes (Gil-Sanchez and Alba-Tercedor, 2006). The management programme encompassed first surveys to delimit the extant populations and their mapping using GIS, then controls against disturbance and habitat degradation, and finally restocking in suitable sites.

In Castilla-Leon *A. pallipes* was described as close to extinction by the early 1990s (Carral *et al.*, 1993), while its decline in Navarra has been attributed to human dispersal of plague-carrying *P. leniusculus* (Diéguez-Urbeondo, 2006a). The emphasis since then was on conserving the remaining indigenous stocks and restocking suitable sites through captive breeding and other measures, while concurrently developing an acceptable astacid harvest with introduced *P. leniusculus* (Reynolds *et al.*, 1992).

As a result of its decline, *A. pallipes* is now listed as threatened in different regions, and was protected in National legislation in 2003 (Martinez *et al.*, 2003).

> SWEDEN

The Swedish example is significant, as Sweden leads Europe in seasonal consumption of crayfish, and the associated trade and commerce is important to the economy.

Starting in 1907 there were unexplained mortalities and declines in Swedish populations of *A. astacus*. The cause eventually turned out to be crayfish plague and up to the present more than 7000 mortalities have been registered showing the hallmarks of crayfish plague (Bohman *et al.*, 2006). An involved and interested public looked for solutions. By the 1950s the search was on for a gastronomically comparable species that would be an “ecological homologue”, which would bolster up the declining indigenous stocks, that were down to 50% at the end of the 1950s. Another desired feature of the replacement species was that it should be “immune” to the crayfish plague. The answer seemed to have been found in the signal crayfish *P. leniusculus* from Western USA; probably without realizing that it was a chronic carrier of crayfish plague. First introductions to Sweden were made from California in 1959 and then juveniles were released from captive breeding stock into wild in the 1960s (Holdich *et al.*, 2006). Secondary introductions were made from Swedish stocks across Europe. However, by 1998 an estimated 95% of populations of *A. astacus* in Sweden had been lost to plague and pollution over the last 100 years and it was now indisputable that *P. leniusculus* carry and spread the plague. In 2007 alone there were 439 outbreaks of crayfish plague, and in 2008 there were at least 4000 populations of *P. leniusculus* compared to less than 1000 of *A. astacus*, a decrease of more than 500 in only eight years (Edsman and Schröder, 2009) (Figures 17a and 17b).

Economically, *A. astacus* today still fetch more than twice the price compared to *P. leniusculus*, although they make up a declining percentage of the catch in southern Sweden. Public and official attitudes are changing, and the continued spread of *P. leniusculus* across Sweden is viewed with alarm, although today it is entirely the work of illegal translocations by local people who misleadingly believe in the superiority of *P. leniusculus* despite lower prices being

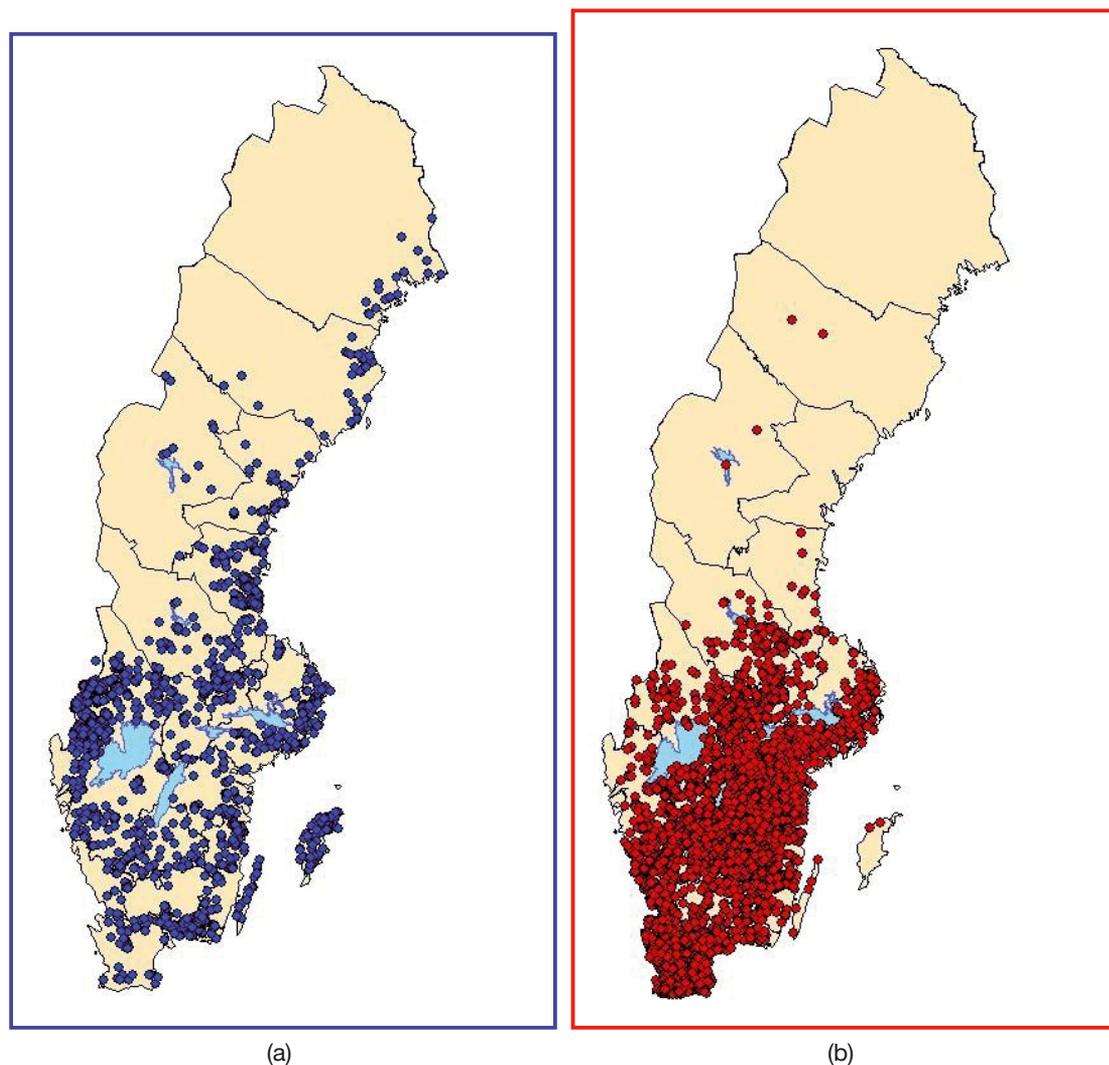


Figure 17
a – Distribution of *Astacus astacus* in Sweden in 2008 (1000 localities, a decrease of more than 500 in eight years). b – Distribution of *Pacifastacus leniusculus* in Sweden in 2008 (> 4000 localities). Reproduced with permission from Edsman and Schröder (2009).

Figure 17
a – Distribution d'*Astacus astacus* en Suède en 2008 (1000 localités, un déclin de plus de 500 en huit ans). b – Distribution de *Pacifastacus leniusculus* en Suède en 2008 (> 4000 localités). Reproduit avec la permission d'Edsman et Schröder (2009).

fetched. In northern Sweden at least, *A. astacus* survive and reproduce better than *P. leniusculus* (Edsman, pers. comm.) as has also been found in Finland by Heinimaa and Pursiainen (2008). In a continuing attempt to protect stocks of *A. astacus* Swedish legislation has now reverted to banning all live imports of crayfish (see below). This decision was long in gestation, but when it came it reflected the reality that even in a free-trade Europe, environmental legislation was now seen as stronger than trade legislation.

> FINLAND

Jussila and Mannonen (2004) have described the crayfish situation in Finland. Two commercially valuable species are present, *i.e.* *A. astacus* and *P. leniusculus*. *Astacus leptodactylus* also occurred in some eastern lakes; however, Mannonen (2009, pers. comm.) believes that these no longer exist. *Astacus astacus* is widespread in the lower half of the country and has traditionally been stocked into most of the suitable water bodies since the discovery of its commercial value 150 years ago. Originally the species distribution reached the level of 62°N, but has until now been introduced up to the level of 67°N (Westman, 1973). There is a tradition for moving crayfish from one place to another so that the distribution of *A. astacus* has mainly been created by man in the last 100 years (Mannonen, 2009, pers. comm.). In the past 20 years there have been around 10–15 crayfish plague outbreaks in *A. astacus* populations annually, but in the past years only about 30% of them have been caused by *Pacifastacus*-type plague, most of the outbreaks still represent the original old type of plague, which was present before the introduction of *P. leniusculus* and which caused devastation throughout populations of ICS in Europe from the 1860s onwards (Alderman, 1996; Diéguez-Urbeondo, 2006b). Due to mass mortalities caused by crayfish plague and other factors many water bodies have been restocked a number of times. As in Sweden, *P. leniusculus* was introduced from the 1960s into the 1990s to supplement stocks. The official crayfish strategy was to try and confine *P. leniusculus* to waters in southern Finland and discourage farming of the species outside this region. Due to many unsuccessful re-introductions of *A. astacus* after the plague, the popularity of *P. leniusculus* has increased, and there have been many unlicensed stockings resulting in a spreading of the species northwards, which increases the number of plague outbreaks in the country. Most of the introduced *P. leniusculus* populations have shown signs of infections or really are infected by the plague, although some stocks in the south are thought to be plague-free, some having co-existed with *A. astacus* for many years (Westman *et al.*, 2002). Heinimaa and Pursiainen (2008) examine the factors that determine the northerly distribution limits to *P. leniusculus* introductions in Finland with a view to avoiding any non-viable stocking attempts and for the protection of the indigenous *A. astacus* populations. Due to the adverse impact that *P. leniusculus* is having on *A. astacus* a worst-case scenario is that there will not be any commercially viable *A. astacus* populations in Finland 30 years from now.

> COMMENTS ON SOME OTHER COUNTRIES

In **Belgium**, *A. astacus* is absent from Flanders (Cammaerts, 2009, pers. comm.) but is present in 41 still water sites in Wallonia, although the numbers have been declining (20%) since the 1990s; they are also present in six small brooks (9% decline). *Astacus leptodactylus* and *P. leniusculus* are slowly extending their ranges and eliminating *A. astacus* in Wallonia.

The **Netherlands** have two ICS, *A. astacus* and *A. leptodactylus* (introduced in 1977), and six NICS – all from outside of Europe, a number greater than any other European country (Tables I and II; Soes and van Eekelen, 2006). According to Koese (2008, 2009, pers. comm.), there appears to be only one population of *A. astacus* left, although it was formerly widespread in the south-east of the country, and those of *A. leptodactylus* are few. *Pacifastacus leniusculus* was not recorded until 2004 (Soes and van Eekelen, 2006) and three populations exist in the south and one in the east (Koese, 2009, pers. comm.). *Procambarus* sp., first recorded in 2004 (Soes and van Eekelen, 2006), was still present in 2008 but difficult to catch as numbers were low. *Orconectes limosus*, first recorded in 1968 (Soes and van Eekelen, 2006), is widespread but rarely occurs at high densities. *Orconectes virilis*, first recorded in 2004 (Soes and van Eekelen, 2006), is expanding its range rapidly and could become one of the commonest crayfish in the Netherlands (Soes and Spier, 2006). *Procambarus clarkii*, first recorded in 1985 (Soes and van Eekelen, 2006), is spreading rapidly with many new records in 2008. *Procambarus acutus* still has a local distribution, but at very high densities.

In **Germany**, on the basis of occurrences in 10 × 10 km squares, *A. astacus* and *O. limosus* are the most wide-spread and common species; *A. leptodactylus* is known from 67 squares, *P. clarkii* from 15, *O. immunis* from 11, *Procambarus* sp. from at least two (calculated from maps supplied by H. Schulz, 2009).

In the Carinthia region of **Austria** there are three ICS, i.e. *A. astacus*, *A. pallipes* and *A. torrentium*, and three NICS, i.e. *O. limosus*, *P. clarkii* and *P. leniusculus* (Weinländer and Füreder, 2009). Besides habitat loss caused by human activities it is displacement by *P. leniusculus* that is the reason for the rapid decline of ICS, particularly *A. astacus* and *A. torrentium*, in this region. This situation also appears to be occurring in other parts of Austria (Pöckl and Pekny, 2002; Füreder et al., 2009). Wittenberg (2005) provides an inventory of NICS and their threat to biodiversity and the economy in **Switzerland**.

The current crayfish situation in the Baltic countries of **Lithuania**, **Latvia** and **Estonia** is worthy of comment. There has been some re-establishment of *A. astacus* populations in large mesotrophic lakes in Lithuania, partly due to a decrease in eels and an improvement in water quality. However, *O. limosus* is spreading at a rapid rate through the country and is a major threat to *A. astacus* (Burba, 2009; Burba, 2009, pers. comm.). Although known from an isolated lake in the north in 1994, *O. limosus* entered the south and south-west of Lithuania from Belarus and the Russian enclave of Kaliningrad in 1995 and took only 10 years to invade almost the whole country. *Astacus leptodactylus* is distributed in the north-east of the country and can be found for sale in shops. *Pacifastacus leniusculus* was introduced illegally into a river in the east of the country in 2002. There have been many mass mortalities of crayfish in Lithuania since 2002, involving *A. astacus*, *A. leptodactylus* and *O. limosus*, although it is not known if these were due to crayfish plague due to a lack of testing facilities. *Procambarus* sp. is popular in the aquarium trade. In Latvia to the north of Lithuania, work is underway to develop aquaculture facilities for *A. astacus* (Arens, 2009, pers. comm.). Three non-indigenous species occur in the country, i.e. *A. leptodactylus* from Russia, Belarus and Lithuania; *P. leniusculus* from Lithuania; and most recently *O. limosus* from Lithuania. In 2004, *A. astacus* was the dominant crayfish species in Latvia, it was found in 220 out of 258 localities (Taugbøl et al., 2004). Most of these localities are lakes (175), but many crayfish populations were also found in rivers and streams (66). A few populations were found in reservoirs, ponds and gravel-pits. In 26 localities *A. leptodactylus* was the only species, and *P. leniusculus* was found as the only species in four localities. *Astacus astacus* and *A. leptodactylus* were reported to coexist in eight localities. The arrival of *O. limosus* in Latvia may change the balance in the future. *Astacus astacus* is the only crayfish inhabiting Estonian waters, although a single specimen of *P. leniusculus* was caught in one river in the north in 2008 (Paaver, 2009, pers. comm.). *Astacus leptodactylus* from **Armenia** are sold live in shops and there is the potential for them to be released into the wild. There is no commercial fishing for *A. astacus* and recreational catches are low compared to the early 1900s and the onset of crayfish plague; a lot of restocking for recreational purposes is being undertaken, and there are around 20 crayfish farms, five of which produce crayfish for consumption (Paaver and Hurt, 2009a). There are many threats to *A. astacus* in Estonia including NICS from surrounding countries, habitat deterioration, pollution, and predation by eels and mink (Paaver and Hurt, 2009b).

In the **Czech Republic**, Vlach et al. (2009) state that *A. torrentium*, which is considered critically endangered and is protected by national law (Kozák et al., 2002), is known from 30 localities (21 in Kozák et al., 2002). *Astacus astacus* appears to be declining as many historical records have not been confirmed in recent surveys, while *A. leptodactylus* has a scattered distribution, but may be less frequent than previously assumed due to misidentification with *A. astacus*. *Astacus leptodactylus* was introduced from the Dniester watershed for aquaculture purposes and despite being a relatively new addition it is protected as an endangered species. All three have been affected by crayfish plague outbreaks in recent years. Although there were only two suspected mortalities due to crayfish plague in the second half of the 20th century, there were five between 2004 and 2007, and it is thought that *O. limosus* (introduced in 1989) is the primary reservoir of crayfish plague in the Czech Republic (Kozák

et al., 2000a, 2000b; Kozubíková et al., 2006, 2007, 2008, 2009). Populations of ICS are also being affected by localized pollution events and habitat alteration, especially watercourse regulation, mink predation and competition with NICS (*O. limosus* and *P. leniusculus*). *Pacifastacus leniusculus* was introduced for aquacultural purposes in 1980 and now mainly occurs in south-western Moravia near the original site of introduction (Filipová et al., 2006a, 2006b). However, a new population has been found at the border with Germany (Petrušek, 2009). *Orconectes limosus* is the most widespread invasive species in the Czech Republic, especially in the western part, and is found in a wide variety of habitats. Its presence in the region was first confirmed in 1988 close to the border with Germany, but actually earlier than this in the 1960s it was reported from pools adjacent to the R. Elbe. It invaded the Czech Republic by upstream migration through the R. Elbe (Filipová et al., 2006a; Petrušek et al., 2006). It has been found close to the border with Poland in the north-east, from where it migrated. It has recently been found in south-eastern Moravia close to the border with Slovakia, an area assumed to be devoid of NICS (Petrušek, 2009). As with many other Central and East European countries, *Procambarus* sp. is popular with hobbyists.

Between 1999 and 2001 a large scale restocking programme for *A. astacus* and *A. leptodactylus* took place in **Poland** to try and counteract the decline of these two species; a 60.8% success rate was recorded (Śmietana et al., 2004). However, Śmietana (2009, pers. comm.) predicts that due to the impact of *O. limosus*, *A. astacus* may be eradicated within the next 2–5 years. The spread of *O. limosus* is being facilitated by recreational angling where it is used as bait, and by owners of new lakes who put anything into their lakes that will survive, especially crayfish, which are considered as a bioindicator of clean water. Where *O. limosus* is absent then *A. astacus* survives in small rivers and streams in southern Poland. There were 98 wild and 42 restocked populations of *A. astacus* in 1999, and 89 wild and 12 restocked populations in 2008. There have been two mass mortalities of *A. astacus* in the last five years due to unknown reasons. *Astacus astacus* is listed as VU (vulnerable) in the Polish Red Data Book of Animals. *Astacus leptodactylus* is less abundant than *A. astacus* in Poland and is disappearing faster. It is not included in the Red Data Book but is considered as vulnerable. There were an estimated 64 populations in 1999 and this has decreased to 47 at present. *Pacifastacus leniusculus* was introduced from Sweden between 1972 and 1979 but the attempt failed; between 1991 and 1992 further introductions were made and now *P. leniusculus* is an important aquaculture species in the country (Schulz and Śmietana, 2001).

In **Croatia** the rapid spread of *O. limosus* through the R. Danube catchment is having adverse effects on the populations of *A. leptodactylus* (Faller et al., 2009), as is *P. leniusculus* on *A. astacus* populations in the R. Mura, where they have disappeared from many sites (Hudina and Lucić, 2009). *Pacifastacus leniusculus* entered Croatia in 2008 via the R. Mura, which borders Hungary and Slovenia and is expected to spread downstream toward the R. Drava (Maguire et al., 2008).

Pârvulescu et al. (2009) have recently recorded the presence of *O. limosus* in the R. Danube from **Romania**, and there is little to stop it continuing down-river to **Bulgaria** and the Black Sea. Zaikov and Hubenova (2007) report that there are no NICS in Bulgaria. Three ICS are present, *A. leptodactylus*, *A. astacus* and *A. torrentium* and there are laws to protect each of them. About 20 tonnes per annum of *A. leptodactylus* are harvested, but there is no strong tradition for eating them except on the Black Sea coast.

In **Greece**, populations of *A. astacus* occur in north-west, north and central parts of the country and *A. torrentium* occurs in northern and north-eastern parts, with a degree of overlapping in its distribution with *A. astacus* in Thessaly and Central Macedonia. *Astacus leptodactylus* has been recently verified in the River Evros close to the Greco-Turkish border, suggesting that the species should be regarded as indigenous in Greece. *Pacifastacus leniusculus* forms a well established population in Lake Agras and co-occurs with *A. torrentium*. A mass mortality of *A. astacus* occurred in August 2005 over a 15-km stretch of the main R. Kalamas and its tributaries in north-western Greece (Savvidis, 2005a, 2005b). Despite many signs that it was caused by crayfish plague this could not be verified in the laboratory by Cefas (Centre for the Environment, Fisheries and Aquaculture Science) in the UK. Previous mortalities, thought

to be due to crayfish plague occurred after the introduction of *P. leniusculus* from Sweden in 1982, and also occurred in the R. Kalamas (1986) as well as in the R. Louros (1987) (Theocharis, 1986).

Šanda and Petrusek (2009) have confirmed the presence of *A. astacus*, *A. pallipes* and *A. torrentium* in **Bosnia-Herzegovina**, where a number of mass mortalities have been reported despite there apparently being no NICS present. A detailed study of the habitat preferences and level of endangerment to ICS in **Serbia** and **Montenegro** based on a 60-year period has been given by Simić *et al.* (2008). *Astacus astacus* is the most endangered species in both countries due to pollution, habitat fragmentation, diseases, competition from *A. leptodactylus*, as well as isolation of populations. Populations of *A. astacus* are also endangered by overfishing in Serbia, but not in Montenegro.

LEGISLATION AND CONSERVATION MEASURES

The three ICS in Western Europe, *A. astacus*, *A. pallipes* and *A. torrentium*, are listed as protected in Appendix III of the Bern Convention. The EC's Habitat Directive, part of Europe's response to the Convention on Biological Diversity at the 1992 Earth Summit in Rio de Janeiro, lists *A. pallipes* under Appendix II and *A. astacus*, *A. pallipes* and *A. torrentium* under Appendix V. Species listed under Appendix II of the Habitats Directive (Directive for the Conservation of Natural Habitats and Wild Flora and Fauna (92/43/EEC and 97/62/EU)), are those that require the designation of protective sites or special areas of conservation (SACs) that are overseen by the European network – Natura 2000. *Austropotamobius torrentium* has recently been included in Appendix II. Species listed under Appendix V of the Habitats Directive and Appendix III of the Bern Convention are those whose exploitation or harvesting should be subject to appropriate control in member states.

As mentioned in the introduction to this paper, in 1996 *A. astacus*, *A. pallipes* and *A. torrentium* were assessed as vulnerable using criterion B2bce+3bcd by the IUCN (Baillie and Groombridge, 1996). These assessments still stand at present (IUCN, 2009), although with the caveat “needs updating”. This is in progress (Dewhurst, 2009, pers. com.) and current population estimates indicate that some of these species are likely to change category, however any change in category cannot be interpreted as a decline or increase in abundance since the 1996 assessments. These previous assessments of vulnerable were made on the basis that these species had an extent of occurrence (EOO) of less than 20 000 km²; recent calculations of the EOO for each species indicate that they far exceed 20 000 km² and so no longer qualify for listing under criterion B. Both *A. astacus* and *A. pallipes* now qualify for a listing under criterion A, which utilizes population data to infer rates of decline over a 10 year period or three generation lengths, whichever is greater. Trends in abundance have been calculated using both presence/absence data, and harvest data. It is, however, acknowledged that calculations of these trends are based on the assumption that rates of decline for parts of a country can be translated into what is happening in the whole country, that the population is equally distributed across the country or has been in the last 10 years, and that the rates of decline that have been obtained from presence/absence data are reasonably indicative or at least conservative estimates, of changes in population numbers. Preliminary results suggest that *A. pallipes* has declined by ~60% in the UK, ~50% in France, and ~75% in Italy over the last 10 years. Population estimates for *A. astacus* indicate declines of ~87% for Sweden and ~15% for Finland over the last 10 years. Data on population trends for *A. torrentium* is greatly lacking and so it is unlikely to qualify for a listing under criterion A. As declines are known to be occurring, this species may be listed as Data Deficient with a caveat acknowledging that it is likely to be threatened but data to assess it under the criteria is not available. Based on the available data, the authors of this paper, along with others who took part in discussion of the issue, suggest a revised listing of endangered for *A. pallipes* and to maintain a listing of vulnerable for *A. astacus*.

Legislative controls are one way to protect indigenous crayfish (Reynolds *et al.*, 2006). Legislation may relate to controls on imports and exports, or to protection of indigenous stocks

and habitats. Fishing regulations may relate to ICS, NICS or both. The relevant legislation relating to freshwater crayfish varies across Europe (Vigneux *et al.*, 2002, Edsman and Šmietana, 2004) and within states (Puky *et al.*, 2005), and its efficacy has been questioned (Holdich and Pöckl, 2005). Variable controls in trans-national catchments, notably the Danube system, are particularly problematic in regard to the spread of species (Puky *et al.*, 2005; Pârvulescu *et al.*, 2009), and European legislation is not strong enough in this regard. There are also problems of enforcement, particularly in internet based trade. Given below are a series of examples of the type of legislation in force in Europe regarding ICS and NICS; space does not permit every country to be dealt with. Further details of the situation in Britain and of that in Austria can be found in Holdich and Pöckl (2005).

In the past decade the situation has changed markedly in Northern Europe, where the ICS *A. astacus* is in decline as NICS (largely *P. leniusculus*) expand their range. Swedish legislation with restrictions on live crayfish imports was lifted in 1997, but a ban on live imports both from EU and third countries was reinstated in 2003. The Swedish example indicates the new importance at the European level of environmental and conservation legislation over the previously dominant free trade agreements (Edsman, 2004). A revised national action plan for the conservation of *A. astacus* was launched in 2009 and county administrations can now assign special protected areas for *A. astacus* with restrictions on moving live crayfish, fish and gear in and out of the area to avoid spreading the disease crayfish plague. In addition, a budget of 1.5 million € has been allocated for actions such as information, inventories, extermination of illegally introduced *P. leniusculus* populations, reintroduction of *A. astacus* after crayfish plague and habitat improvements. The action plan also states that with NICS readily available, the largest threat is not over-fishing but illegal introductions of plague-carrying *P. leniusculus* by man. Local people that are allowed to catch and benefit from *A. astacus* are also the best protection against illegal stocking of non-indigenous crayfish. The possibility to exploit the crayfish is of major importance in underpinning the will to protect and will involve more people in the task. In Sweden, exploitation, in the form of a sustainable fishery, is considered to be the key to successful conservation of *A. astacus*. Consequently the major part of the budgeted funds will be allocated locally, directly to the fishing rights owners of the lakes and running waters (Edsman and Schröder, 2009).

In Norway, lacking NICS until recently (see above), a law forbids stocking of any freshwater organism without permission from environmental authorities. There is central regulation of crayfish harvesting, involving legal periods, minimum size ICS and legal mesh size on traps. Another law forbids live imports of NICS. In watersheds with crayfish plague local regulations forbid fishing for crayfish and restrict other uses of or activities in the watershed. There are no major changes since 2005, apart from a local regulation made after the finding of *P. leniusculus* in Telemark.

The Finnish fisheries legislation has notified crayfish since 1920s, and it has been renewed several times. To catch crayfish one needs a governmental fishing licence, and the licence of the water owner. There is no minimum legal size of catchable crayfish. The crayfish season is limited to be from 21st June at noon until the end of October. The legislation is currently being reviewed, but as far as known, no radical changes concerning crayfish will be made. Local Finnish fisheries authorities' crayfish policy is based on the national crayfisheries strategy published in 2000, which includes both *A. astacus* and *P. leniusculus*.

Since 2005 German federal law has not been improved and Germany remains a major hole in the defences against NICS. The ICS *A. astacus* and *A. pallipes* are protected under the Federal Nature Conservation & Protection Act (NCPA) and Federal Species Protection Ordinance. According to NCPA, the introduction of NICS is not allowed, but all species naturally reproducing over several generations are defined as native or indigenous. Thus, NICS like *O. limosus*, *P. leniusculus* and other species already established in natural habitats are not specially controlled. The state fisheries laws of some federal states include additional restrictions on stocking of crayfish, e.g. in Bavaria only *A. astacus* is allowed to be stocked in all kinds of waters.

United Kingdom and Irish legislation differs (Holdich *et al.*, 1999), although the EU Habitats Directive provides some protection in both jurisdictions for the indigenous white-clawed crayfish, *A. pallipes*. British legislation provides “no-go” areas where NICS may not be introduced, but still allows some importation and movement of non-indigenous stocks, for example the sale of live crayfish over the counter for human consumption, except in Scotland (Bean *et al.*, 2006). In Ireland, fisheries legislation prohibits importation of NICS (Gibson, 1979; Reynolds *et al.*, 2002), to protect the valuable salmonid stocks. Northern Ireland, while being part of the UK, cooperates with the Irish Republic on this. However, UK citizens may assume that all British legislation applies there, and social influences such as some media programmes, which have given a false impression that NICS are already present in the province, further endanger the Irish white-clawed crayfish stocks.

DISCUSSION

Recent evidence that Europe may be home to 11 000 alien species has spurred the European Commission to release its first ever Communication on invasive species (European Commission, 2008). The European Environment Commissioner, Stavros Dimas, noted at the launch of the Communication that “the ecological, economic and social consequences of the spread of invasive species for EU countries are serious and need a harmonised response”. The Communication, which is currently open for consultation, proposes the development of a European Strategy on Invasive Species. It outlines three potential ways forward, each representing a different level of legislative cost and complexity. The first, and least complex, involves making better use of existing legislation; the second would adapt existing legislation to address invasive species, while the third, and most complex, would develop a dedicated legal instrument. But is this the best way forward? A recent paper published in the journal *Science* by Hulme *et al.* (2009) suggests legislation is only part of the answer and that what Europe lacks is appropriate governance and institutional coordination across Member States to tackle the problem of invasions effectively. They state that: “Currently, responsibility for invasive species management sits within too many different European Institutions. These are organizations such as the European Environment Agency (EEA), European and Mediterranean Plant Protection Organisation (EPPO), European Food Safety Authority (EFSA) that rarely communicate with each other and where the topic of invasions is only one of many areas of activity”, and “This system is not effective. For example EPPO and EFSA have not seen eye to eye when it comes to assessing the risks to Europe of different alien species, while funding for research and management is often prioritised separately by the different Directorates-General in Brussels. The political, cultural and geographic complexity of Europe makes a single coordinating body a necessity”. The authors of the paper, who recently edited the Handbook of Alien Species in Europe (Daisie, 2009; European Invasive Alien Species Gateway, <http://www.europe-aliens.org/>) recommend that the European Parliament and Council give serious consideration to the establishment of a single body to bring together invasive species related resources and activities currently dispersed amongst the various European institutions. This body, which they call the European Centre for Invasive Species Management (ECISM), would have a mission to identify, assess and communicate current and emerging threats to the economy and environment posed by invasive species. ECISM would coordinate activities across Member States, building a Europe-wide surveillance system, which could monitor emerging threats, support rapid response and raise public awareness around the issues of invasive species. The idea is sound, but such a Centre would face considerable challenges. For example, the major policy driver of a single EU market for goods and people favours the spread of invasive species, the number of alien species introductions continues to increase year on year, and public awareness of the impact of those species is little more than 2%. Unfortunately, these factors make the formation of such a body all the more challenging and only time will tell if Europe is able to meet that challenge.

It is clear from the above that the development of a trans-national strategy on biological invasions in freshwater is needed; however, as Genovesi (2007) has pointed out the main

obstacles to this are: lack of transboundary cooperation, limited ability to detect species early enough, ineffectual or delayed responses to the early stages of invasions, limited tools for eradicating or controlling invasive species in freshwater, the deficiencies and inconsistency of legal provisions and the difficulty of trade regulation – all of which is very relevant to the NICS situation. The EU strategy on invasive species highlights the ever-growing problem of invasive alien species in Europe and emphasises the importance of early detection of potentially invasive species and rapid action to eradicate them while it is still economically and environmentally effective (European Commission, 2008). This is very relevant to the “New NICS” situation and also to the expansion of “Old NICS”. Perhaps most worrying in the context of the survival of ICS in Europe is the rapid spread of *O. limosus* and *P. leniusculus* through the rivers in Eastern Europe. *Orconectes limosus* has reached Romania through the R. Danube (Pârvulescu *et al.*, 2009) and *P. leniusculus* has reached the R. Mura in Croatia (Hudina and Lucić, 2009). This does not bode well for stocks of *A. astacus* and *A. leptodactylus* in these regions and further east, although because of its habitat preferences *A. torrentium* may be protected to some extent. As of yet there have been no reports of mortalities caused by crayfish plague in these easterly regions, but there have been many unexplained mortalities. The rapid spread of a “New NICS” is well illustrated by that of *O. immunis* in the upper R. Rhine in Germany, even to the extent of displacing an established “Old NICS”, *O. limosus* (Chucholl *et al.*, 2008; Chucholl, 2009). Another worrying fact is the popularity of *Procambarus* sp. amongst hobbyists, particularly in Central and Eastern Europe.

In their discussion on the future of ICS in Europe, Taugbøl and Skurdal (1999) predicted that if effective conservation plans were not put in place, then in 100 years time it might be that all watersheds suitable for crayfish in Europe are occupied by NICS, and all ICS are critically endangered and survive only in a few protected localities. To avoid this scenario and to ensure that some countries remain free from NICS and retain extensive populations of ICS they suggested the following actions: restoration of aquatic habitats; protection of ICS as a national aim; obtaining a good knowledge of the status and distribution of crayfish; identifying and establishing “native crayfish areas”, preventing the further spread of NICS, implementing effective legislation, fostering cooperation and coordination, re-establishing ICS where they have been eradicated, informing the public, and exploiting ICS – these actions were displayed in a conceptual model similar to that in Figure 18. Whilst most of the actions are commendable the last one is contentious. Taugbøl and Skurdal (1999) and Taugbøl (2004) maintain that exploitation and protection are closely linked, as those who exploit are usually concerned about the resources and will protect them (see Sweden under Legislation). This may be the case for countries where there is a strong tradition of harvesting and consuming crayfish, but not where the ICS are protected from harvesting by law, as in the British Isles. In light of what was happening in Europe in the 1990s, Taugbøl and Skurdal (1999) suggested that the setting up of “native crayfish areas” (NCAs) was of prime importance for ensuring the future of ICS. These could be as large as a country, a region, a watershed, or even a single watercourse or waterbody. They highlighted Ireland and Norway as being suitable NCAs for *A. pallipes* and *A. astacus* respectively as both countries were at the time free of NICS. Unfortunately, Norway has since had a number of incursions of *P. leniusculus* into its waters, although in one case they have may have been eradicated (Johnsen *et al.*, 2007; Johnsen and Vrålstad, 2009). Ireland retains its status as the only country solely occupied by *A. pallipes* and with no NICS (Gallagher *et al.*, 2005; Reynolds, to appear). In the 2000s this suggestion has become a reality, albeit only at the level of single populations so far. As mentioned above, in South-West England (Sibley *et al.*, 2007) and also elsewhere in Britain (Peay, 2009), secure locations or “ark sites” are being developed into which threatened populations of ICS are being moved. The concept of “ark sites” is also being taken forward in Northern Ireland (Horton, 2009; Reynolds, to appear). Sweden is in the process of setting up protected areas for *A. astacus*, including the whole of the island of Gotland (Edsman, 2009, pers. comm.).

The conceptual model shown in Figure 18, shows the different actions necessary for protection of ICS in Europe, under two main groupings: **general management**, including implementing legislation, developing public education strategies and coordination, and **specific**



Figure 18

Conceptual model showing paths that could be taken to try and protect ICS. Modified from Taugbøl and Skurdal (1999).

Figure 18

Modèle conceptuel montrant les solutions qui peuvent être choisies pour protéger les ICS. Modifié d'après Taugbøl et Skurdal (1999).

actions – distribution surveys, site protection and habitat restoration, fisheries controls for ICS and NICS, and actions to restrict NICS and the spread of plague. This model can be applied to the actions being carried out in South-West England (see above), with the exception that the ICS are not exploited but are protected. The model has also been suggested as a basis for conserving ICS in Austria (Pöckl and Pekny, 2002). In the decade since Taugbøl and Skurdal published their guidelines, a number of things have changed, thanks to greater activity in Europe (e.g. EU Habitats Directive, CRAYNET) and in EU member states, particularly the UK (meetings, initiatives such as no-go areas and ark sites). Legislation has been tightened, and the attitudes of EU and member states to international treaties dealing with the environment and with free trade have changed somewhat. In Scandinavia, the Swedish story, involving relaxation of legislation in 1997 to permit live crayfish imports and their eventual reimposition in 2003, is described by Edsman (2004), while the value of exploitation as a conservation tool is emphasized by Taugbøl (2004). A number of countries have set up national plans for their ICS and NICS, e.g. Austria (Pöckl and Pekny, 2002) and Switzerland (Stucki *et al.*, 2005; Hefti and Stucki, 2006). In France, during the recent World Wetlands Day (2nd February 2009, the anniversary of the signing of the Ramsar Convention on Wetlands in 1971) an opportunity for governments, organizations, and citizens to undertake large and small actions intended to raise public awareness of wetland values, a motion was raised about an action plan against *P. clarkii* and other NICS. This motion was signed by scientists, managers and stakeholders calling for national action for effective legislation, a network of managers to detect the arrival of new NICS, and a network of scientists and managers

to evaluate the resulting disequilibrium of ecosystems and control the populations; finally, it demanded greater information for the public.

Public education into the dangers of spreading NICS is increasing at a national and local level. Directed surveys have established the distribution of ICS and NICS in Europe up to 2006 (Souty-Grosset *et al.*, 2006), and research in the UK has shown the difficulty of eradicating NICS stocks (Peay *et al.*, 2006). An attempt to eradicate them from the River Clyde in Scotland cost over £100 000 but was unsuccessful (Collins, 2006). Prophylactic measures to prevent the spread of plague, already promoted in Scandinavia (*e.g.* Taugbøl *et al.*, 1993) are now better and more widely established as transmission of the plague organism has become better understood (Diéguez-Urbeondo, 2006b). The real problem is in the persistent power of myths about the superiority of the signal crayfish, *P. leniusculus*, and the main culprit remains the illegal transfer of NICS into waters containing indigenous crayfish stocks particularly in Scandinavia and Britain.

Whether or not European ICS survive the next 100 years is up to each country and the action it takes, but it should be born in mind that **no action** may well impinge on the survival of ICS in neighbouring countries. Territories without invading populations of NICS, or in early stages of the problems could do well to look at the mixed experiences of Britain in trying to protect its single ICS, *A. pallipes*, in the face of an ever growing number of NICS (Holdich and Sibley, 2009; Sibley *et al.*, 2009; Peay *et al.*, to appear).

ACKNOWLEDGEMENTS

Special thanks goes to Chris Lukhaup (Germany) for allowing us to use his excellent photographs, to Lennart Edsman (Sweden) and Leopold Füreder (Austria) and for permission to use their maps, and to Nadia Dewhurst (UK) for information on the IUCN's position. The authors also wish to thank the following for their help in providing information on crayfish distribution: Anatoly Alekhovich (Belarus), Augusts Arens (Latvia), Aloyzas Burba (Lithuania), Roger Cammaerts (Belgium), Chris Chucholl (Germany), Ana Costa (Portugal), Javier Diéguez-Urbeondo (Spain), Christoph Dümpelmann (Germany), Adam Ellis (UK), Lennart Edsman (Sweden), Gianiuca Fea (Italy), Leopold Füreder (Austria), Francesca Gherardi (Italy), Fernando Alonso Gutierrez (Spain), Daniel Hefti (Switzerland), Philipp Hirsch (Germany), Stein Ivar Johnsen (Norway), Emmanuil Koutrakis (Greece), Pavel Kozák (Czech Republic), Chris Lukhaup (Germany), Yoichi Machino (Japan), Ivana Maguire (Croatia), Alexandra Marçal (Portugal), Andreas Martens (Germany), Tiit Paaver (Estonia), Lucian Pârvulescu (Romania), Stephanie Peay (UK), Costas Perdikaris (Greece), Adam Petrussek (Czech Republic), Manfred Pöckl (Austria), Miklós Puky (Hungary), Markku Pursiainen (Finland), Gérard Schmidt (Luxembourg), Holger Schulz (Germany), Christian Skov (Denmark), Przemek Śmietana (Poland), Mikhail Son (Ukraine), Eduard Stloukal (Slovakia), Thomas Stucki (Switzerland), Trond Taugbøl (Norway), and Angel Zaikov (Bulgaria). Finally, thanks are due to two anonymous referees for their input.

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