Rev Fish Biol Fisheries (2006) 16:171–181
DOI 10.1007/s11160-006-9010-1

ORIGINAL PAPER

Threat of non-native crayfish introductions into Turkey: global lessons

Muzaffer Mustafa Harlioğlu · Ayse Gül Harlioğlu

Received: 21 February 2006 / Accepted: 2 June 2006 / Published online: 26 August 2006

Abstract Introductions of crayfish species from their home range to new environments have been carried out in many parts of the world. The most important introduced crayfish species are *Procambarus clarkii, Pacifastacus leniusculus, Cherax destructor, C. quadricarinatus, Orconectes limosus, O. rusticus* and *Astacus leptodactylus*. The environmental impact of crayfish introductions can be positive, negative or neutral. However, native crayfish populations in Europe have been negatively affected by introductions of non-indigenous crayfish species from America. Negative effects of non-native crayfish introductions included displacement of native crayfish species, transfer of disease (crayfish plague), consumption of fish eggs, reduction of fish stocks, consumption of large amounts of macrophytes, indirect and direct effects on other invertebrates and upsetting production in rice fields. As a result of non-native crayfish introductions, the natural harvest and crayfish industry in Europe have been severely affected. Large quantities of Turkish *A. leptodactylus* were harvested (approximately 7,000 tonnes annually) and exported to Europe before the crayfish plague was observed in these populations. The total harvest of *A. leptodactylus* in Turkey reduced dramatically to 320 in 1991 after the plague. Therefore, although Turkey currently has no known non-native crayfish species, there is a threat of non-native crayfish introduction in order to increase crayfish productions and subsequent harvest. The North American spiny-cheek crayfish, *O. limosus*, has been spreading quickly down the River Danube and could soon reach neighboring countries including Turkey. The North American signal crayfish, *P. leniusculus* is known from Greece and could be a threat to native stocks if it is introduced into Turkey for aquaculture. Additional threats may come from the release of other North American species, which are widely available through the aquarium trade. We conclude that the spread of non-native crayfish introductions throughout Turkey will increase local problems, because introductions of non-native crayfish in many parts of the world have been known to have caused important reductions in population density and numbers of native crayfish species. Furthermore, freshwater ecosystems may be altered by such introductions and the economic viability of native crayfish species fisheries could be severely reduced in Turkey.

Keywords Aquaculture · Crayfish · Harvest · Introduction · Native · Non-native · Production · Turkey

M. M. Harlioğlu (✉) · A. G. Harlioğlu
Fisheries Faculty, Fırat University, 23119 Elazığ, Turkey
e-mail: mharlioglu@firat.edu.tr

Introduction

The harvest of the native narrow-clawed crayfish, *Astacus leptodactylus* (Eschscholtz, 1823), in Turkey is on the increase again after decades of low catches caused by overfishing, pollution and disease (Harlıoğlu 2004; Harlıoğlu and Harlıoğlu 2004). However, if non-native North American crayfish enter Turkish waters they may compete with native crayfish for resources as well as potentially causing further problems with introduced diseases.

Astacus leptodactylus has a widespread distribution in lakes and ponds in many parts of Turkey. It has also been widely established in Europe through introductions, although not in Iberian Peninsula and Nordic countries (Erençin and Köksal 1977; Köksal 1988; Holdich 2002a; Skurdal and Taugbøl 2002; Souty-Grosset et al. 2006). Large quantities of *A. leptodactylus* were harvested (as high as 8,000 tonnes) from Turkey and were exported to Europe (Köksal 1988). However, the total production of *A. leptodactylus* in Turkey reduced dramatically and harvest was forbidden from 1986 to 1990 (Harlıoğlu and Harlıoğlu 2004). Between 1991 and 2004, harvest of *A. leptodactylus* in Turkey has increased to 2317 (in 2004) tonnes (Anonymous 2005). However, the present harvest of *A. leptodactylus* is still only 25% of the crayfish catch in 1980s.

In recent years, the presence of a new crayfish species, *Austropotamobius torrentium* (Schrank, 1803), has been observed in the Velika River in the European part of Turkey (Trontelj et al. 2005; Machino and Holdich 2006), although as in the rest of Europe its relatively small size makes it of little commercial interest (Harlıoğlu and Güner 2006). *A. torrentium* is mainly confined to Central Europe, where it is known from 20 countries including neighboring Bulgaria and Greece (Souty-Grosset et al. 2006). It is unclear if its occurrence in European Turkey is a natural extension of its range, or if it has been introduced locally. A recent study of 13 rivers and brooks close to the Velika River has not revealed any other populations (Harlıoğlu and Güner 2006).

Except the presence of *A. torrentium* in the European part of Turkey no crayfish species in Turkey were reported. However, the North American spiny-cheek crayfish, *Orconectes limosus* (Rafinesque, 1817), has been spreading quickly down the River Danube and could reach neighboring countries soon (Maguire and Gottstein-Matoec 2004). The North American signal crayfish, *Pacifastacus leniusculus* (Dana, 1852), is known from Greece (Souty-Grosset et al. 2006) and could be a threat to native stocks if it is introduced into Turkey for aquacultural purposes. Additional threats may come from the release of other North American species, which are widely available through the aquarium trade (Souty-Grosset et al. 2006).

According to Souty-Grosset et al. (2006) *O. limosus*, originally introduced into Germany in 1890 for aquaculture and stocking purposes, is now common in countries associated with the R. Danube catchment, including Germany, Hungary, Austria, Czech Republic and most recently Croatia (Maguire and Gottstein-Matoec 2004) and Serbia, where it competes with and/or has replaced the native noble crayfish, *Astacus astacus*. *O. limosus* is now present in at least 20 European countries/regions and according to Souty-Grosset et al. (2006) it is likely that it will spread into Bulgaria, Romania and the Ukraine via the R. Danube naturally, accidentally or deliberately by humans. If it gets into Bulgaria it may spread into Turkey. As with all North American crayfish tested so far, *O. limosus* acts as a carrier of the virulent crayfish plague, caused by the Oomycete, *Aphanomyces astaci* Shikora, which has been implicated in mortalities in some Turkish populations of *A. leptodactylus* (Baran and Soylu 1989). The plague can still be found in some Turkish populations (Diler et al. 1999; Bolat 2001; Aydın and Dilek 2004).

Introductions of crayfish species from their home range to new environments have occurred in many parts of the world, and the negative or positive impacts of the introductions have been widely discussed (Westman 1992; Westman and Westman 1992; Laurent 1997; Ackefors 1999; Holdich et al. 1999; Lodge et al. 2000a, b; Westman 2002; Souty-Grosset et al. 2006). As a result of many of these studies, it has been concluded that non-native crayfish introductions are one of the most important threats to freshwater biodiversity and ecosystem function after land use

change (Lodge et al. 2000a). Therefore, the aim of this paper is to present a critical review of the potential threat of non-native crayfish species introductions into Turkey and to draw some global lessons from the experience of the crayfish introductions carried out throughout the world.

Crayfish species of aquacultural importance, introduced crayfish and recent world crayfish production

There are approximately 600 freshwater crayfish species that occur naturally on every continent except Africa and Antarctica. They can be observed in a wide range of habitats, for example lakes, rivers, swamps, cave pools, temporary ponds and in estuaries (Hobbs 1988; Nyström 2002). This widespread distribution of crayfish has been realized through ecological, behavioral and physiological, adaptations. In addition, human influences have also caused some species, generally those of potential economic importance, to enlarge their range unnaturally (Hogger 1988; Holdich 1999a). The most important crayfish species that have been translocated for this purpose are *Procambarus clarkii* found in Africa, Asia, California, Europe and many other parts of world; *Pacifastacus leniusculus* found in California, Japan and Europe; *Cherax destructor* found in Africa and Australia; *Cherax quadricarinatus* found in South America; *Orconectes* species found in Europe and *O. rusticus* in North America; and *Astacus leptodactylus* in Europe (Momot 1997; Holdich 1999a; Lodge et al. 2000a).

According to Holdich (1993), the peak of adaptive radiation in crayfish has been reached in North America where approximately 70% of the world's crayfish species occur, and in Australia with over 20% of the known species. In comparison to America and Australia, Europe has only five native crayfish species (Souty-Grosset et al. 2006). Interestingly, only a few crayfish species are currently of commercial importance. These species are *P. leniusculus, P. clarkii, Procambarus* ssp. (*P. acutus* and *P. zonangulus*), *A. astacus, A. leptodactylus, Cherax tenuimanus, C. destructor, C. quadricarinatus* (Holdich 1993).

Despite the growing importance of Chinese production, crayfish are mainly harvested, cultured and consumed in the USA, Europe and Australia (Ackefors 2000; Wickins and Lee 2002). The production of freshwater crayfish from aquaculture (''astaciculture'') and harvest is in the order of 120,000–150,000 tonnes/annum, more than four times the quantity depicted by FAO statistics. China is the largest crayfish producer, followed by the USA (70,000 and 50,000 tonnes in 1999, respectively) (Ackefors 2000). The Chinese harvest is based on the Lousiana red swamp crayfish, *Procambarus clarkii* (Girard), originally introduced from Japan in the 1930s and was estimated as 40,000 tonnes in the early 1990s and as high as 70,000 tonnes in 1999 (Wickins and Lee 2002).

In the southern USA, mainly in Louisiana, the red swamp crayfish is the main species cultured together with the white river crayfish, *Procambarus zonangulus*. Total production of these two species in aquaculture in 1999 was approximately 35,000 tonnes, of which 85% consisted of *P. clarkii*. In addition, in northern USA and Canada, *P. clarkii* and *Orconectes* sp. are produced in small quantities (Ackefors 2000).

The native range of *O. rusticus* is centered in the streams of western Ohio and encompassing neighboring parts of Indiana and Kentucky, however, it has expanded its range into streams, rivers and lakes throughout much of Illinois, Michigan, Wisconsin, and Minnesota. It is also present in parts of Iowa, Tennessee, Pennsylvania, seven other northeastern states, New Mexico, and Ontario (Momot 1997; Lodge et al. 2000b).

In Australia, the main cultured species is *Cherax destructor* with a production of 250 tonnes in 1998–1999. The second most important species is *C. quadricarinatus* with a harvest of 79 tonnes. In addition, 49 tonnes of *C. tenuimanus* were produced in Australia in 1998–1999. These species are relatively larger than those produced in other parts of the world, therefore, they fetch a good price commercially and prospects for export production appear good (Holdich 1993; Ackefors 2000; Wickins and Lee 2002).

The native crayfish species of Europe are *Astacus astacus* (noble crayfish), *A. leptodactylus* (Turkish or narrow-clawed crayfish), *A. pachypus*

(thick-clawed crayfish), *Austropotamobius pallipes* (white-clawed crayfish), and *A. torrentium* (stone crayfish) (Hobbs 1988; Ackefors 1998; Holdich et al. 1999). In addition to these native crayfish species, four American (*Orconectes limosus, O. immunis, Pacifastacus leniusculus* and *Procambarus clarkii*) and three Australian crayfish species (*Cherax destructor, C. tenuimanus* and *C. quadricarinatus*) have been introduced into Europe (Holdich et al. 1999). Only the Australian species *C. destructor* has become established in the wild (Souty-Grosset et al. 2006). The total production of crayfish in Europe is approximately 5 000 tonnes per annum. Two native species (*A. astacus* and *A. leptodactylus*) and two introduced species (*P. leniusculus* and *P. clarkii*) are the most important crayfish species produced in Europe. In addition, two introduced species (*C. destructor* and *O. limosus*) are cultured in small quantities. The crayfish harvest in Europe is approximately 3,000 tonnes annually (with 80% coming from Spain) (Ackefors 1998, 2000; Wickins and Lee 2002; Skurdal and Taugbøl 2002). European culture fisheries yielded about 160 tonnes in 1994, 40% of this was *P. clarkii*, 32% *P. leniusculus*, 17% *A. astacus*, 8% *A. leptodactylus* and 2% *C. destructor*. Spain, Sweden, Russia, Germany, UK, France, Denmark and Finland were the principal producing countries (Ackefors 1998).

Freshwater crayfish are a popular, luxury food in many West European countries (Harlıoğlu and Holdich 2001). The crayfish demand in Europe up to the mid-1980s was satisfied by Turkey, Russia and Spain (Ackefors 1998, 2000). When *Aphanomyces astaci* arrived to Turkey in the 1980s, the annual catch of *A. leptodactylus* was reduced to 2,000 from 7,000 tonnes (Köksal 1988). The harvest of *A. leptodactylus* in Turkey was only 320 tonnes in 1991, which nearly eliminated exports from Turkey to Europe (Harlıoğlu 2004). As a result of this, to provide crayfish demand (approximately 10,000 tonnes per year) western European markets resorted to other suppliers, including *P. clarkii* from Spain and China, and Louisiana (Lodge et al. 2000b).

It has been suggested that the market for crayfish in Europe could be in the region of 10 000 tonnes per year, with Scandinavia, Germany and France being the main consumers (Holdich 1993; Wickins and Lee 2002). Therefore, it is highly likely that there will be a steady increase in demand for crayfish in Europe, mainly satisfied by imports, because most native crayfish species populations still need time and support in order to fully recover from the crayfish plague (Harlıoğlu and Harlıoğlu 2004).

The capture and aquaculture production of crayfish between 2000 and 2003 in different continents are given in Table 1 (FAO, 2005). According to FAO (2005) several countries still report their catches by large groups of species. In these circumstances the catch data presented in Table 1 are likely to be underestimated (for example, Chinese national corresponding office to FAO hasn't completed freshwater crustaceans catch information).

Table 1 The capture and aquaculture production (tonnes) of crayfish between 2000 and 2003 in different continents (FAO 2005)

Continents	2000	2001	2002	2003
Capture				
Oceania	24	24	52	13
America, North	325	4693	7219	3838
Europe	2731	2722	2785	2820
Atlantic, Northeast	4	4	7	7
Africa	22	3	14	19
Asia	1681	1634	1894	2183
Total	4787	9080	11971	8880
Aquaculture				
Oceania	409	423	305	245
America, South	62	60	48	1
America, North	7732	13865	27846	33519
Europe	27	33	28	29
Africa	15	7	5	5
Total	8245	14388	28232	33799

According to FAO statistics there was an increase in the quantity of captured and cultured crayfish production between 2000 and 2003. The capture production of crayfish reached to 8,880 from 4,787 tonnes and aquaculture production of crayfish reached to 33,799 from 8,245 tonnes in 2003. The capture production (not counting Chinese production) was mainly carried out in North America and Europe (3,838 and 2,820 tonnes, respectively) in 2003. The bulk of 2003's cultured crayfish production also came from North America (33,519 tonnes). In Europe, aquaculture production of crayfish was carried out in France, Spain, Sweden, Estonia, Ukraine and the United Kingdom (FAO 2005).

The data of FAO (2005) on the capture production of crayfish in Europe between 2000 and 2003 contains information from Finland, Sweden, Greece, Bulgaria, Lithuania, Romania, Denmark, Estonia, Poland, Norway, Spain and the United Kingdom. Although, Turkey represents the capture production of crayfish in Asia, an increasing supply of *A. leptodactylus* is being harvested and exported to Europe from the Iranian waters of the Caspian Sea (D. M. Holdich, pers. com.).

Crayfish introductions and global lessons

Crayfish species have been introduced outside their natural ranges either naturally (migrations, floods and continental drift), accidentally (in ballast water, via canals, as bait, by escapes from captured facilities, inadvertently by predators and humans) or deliberately by humans as aquarium pets, for food, for snail and weed control, and because of inappropriate disposal (Holdich 1988, 1999a).

Relatively few crayfish species give rise to environmental problems, and these problems are mainly confined to North America, Australia, Africa and Europe. The environmental impact of crayfish introduction can be positive, negative or neutral. However, it has been well documented that crayfish populations in Europe have been greatly affected by the introductions of plague carrying non-indigenous crayfish species from America (Laurent 1997; Holdich 1999a, b, 2002a, b, 2003; Lodge et al. 2000a, b; Gherardi and Holdich 1999; Holdich et al. 1999; Westman 2002). However, more American species are still being introduced in order to restock the plague-stricken waters of Europe as these species are fast growing, prolific, highly fecund and are not usually susceptible to *A. astaci* (Laurent 1997; Ackefors 2000).

Crayfish plague was first observed in Europe in 1860. After this observation, introductions of plague-resistant crayfish species from the USA began throughout Europe. In 1890, *Orconectes limosus* was first introduced into Germany and in the 1960s *P. leniusculus* was stocked into Sweden. Following these species, *P. clarkii* was introduced into Spain in 1973. *Cherax destructor* was also introduced into Spain in 1983 (Holdich 1999b). In addition to these, *C. destructor* and *C. quadricarinatus* were stocked into Italy in 1985 (D'agaro et al. 1999). Moreover, according to Holdich (1999a) the spread of one of the native crayfish species of Europe, *A. leptodactylus*, into Northern and Western Europe also deserves comments. Although *A. leptodactylus* is the native crayfish of Turkey and the Near East, it has also become widely distributed in Europe, although not in the Iberian Peninsula and Nordic countries. The main effect of *A. leptodactylus* introductions seems to be the displacement of other native European species such as *A. astacus* due to its invasive capabilities and its fast population growth (Holdich 1999a). The recent distribution of crayfish in Europe and some adjoining countries has been given by Holdich (2002a), Machino and Holdich (2006) and Souty-Grosset et al. (2006).

In Africa, a number of North American and Australian species have been introduced from the 1970s onwards. *P. clarkii* has been introduced in great numbers into Egypt, Kenya, South Africa, Zambia and Sudan. *Cherax destructor* from Australia was introduced into South Africa for aquacultural purpose (Gherardi and Holdich 1999). *Cherax quadricarinatus* was introduced into Israel for experimental culture (Karplus et al. 1995). In addition, *C. destructor, C. quadricarinatus* and *C. tenuimanus* have been introduced into China (Ackefors 2000).

Although the crayfish plague has not been observed in Australia, the movement of a native

species (*Cherax* sp.) from one state to others for aquaculture, culinary and recreational purposes has been forbidden in this country. Such translocations of *Cherax* may give rise to the elimination of native species, hybridization and habitat alteration (Horwitz 1990). However, there is concern that the growing export market for *Cherax* species from Australia may eventually result in a global distribution of species of this genus (Holdich 1999a).

In the western, southwestern and southeastern USA, *O. rusticus* was introduced in order to culture it commercially and to use it as live bait. In addition, a native species of Oregon, *P. leniusculus*, was introduced to California in 1912 (Lodge et al. 2000a, b). Introductions in California have led to declines in *Pacifasacus fortis* Faxon, the native Shasta crayfish species (Light et al. 1995; Light 2005). Now, this invasive species is caught commercially in the Sacromento-San Joaquin delta and has been introduced widely elsewhere, mainly for anglers as bait (McGriff 1983). *P. clarkii*, is a native to the south central USA and northeastern Mexico, but it was transferred to at least 15 other states (Hobbs et al. 1989).

In North America, at least 10 crayfish species have expanded their range by human assistance, and the effects of these species on new environments have been severe, even where native crayfish species already existed (Lodge et al. 2000a). A number of *Orconectes* species were transferred outside of their natural range and gave rise to the elimination of native crayfish species (Hobbs et al. 1989; Taylor 2002). *O. rusticus* has given most concern as it causes environmental damage through competitive exclusion of other crayfish species, predation on fish eggs, reduction in fish stocks and consumption of large amounts of macrophytes and invertebrates (Magnuson et al. 1975; Hobbs et al. 1989).

The problems of introductions are usually the same. There are many documented examples of the negative effects of non-native crayfish species (Light et al. 1995; Laurent 1997; Lodge et al. 2000a, 2000b; Holdich 1988, 1999a, b, 2003; Gherardi and Holdich 1999; Holdich et al. 1999; Westman 2002; Taylor 2002, 2003; Light 2005). These negative effects of non-native crayfish introductions include displacement of native crayfish species, transfer of disease, consumption of fish eggs, reduction of native fish stocks, consumption of large amounts of macrophytes, indirect and direct effects on other invertebrates, upsetting production in rice fields and displacement of native amphibians. Other mechanisms of the impact of non-native crayfish introductions on native crayfish constitute interspecific competition for shelter and food, making the native species more vulnerable to predatory fishes; and interspecific matings that lower reproductive success of the native species (Laurent 1997; Holdich 1999a; Gherardi and Holdich 1999). In addition, the burrowing activities of some species can cause physical damage to irrigation structures and banks of rivers and lakes (Holdich et al. 1999).

Although none of the native species in Europe are near extinction, thousands of local populations have disappeared, and abundance in many lake and stream populations has been much decreased by non-native introductions (Souty-Grosset et al. 2006). In Portugal, natural populations of *A. pallipes* are almost extinct, occurring only in the small rivers Azibo and Tortulhas (Gutierrez-Yurrita et al. 1999). In Spain, Sweden and Finland, *P. leniusculus* has proved to be an excellent substitute for recreational purposes to the native species, although in Spain *P. clarkii* has caused considerable damage to the native crayfish habitats (Gutierrez-Yurrita et al. 1999). In Britain, some of the introduced populations of non-native crayfish had negative physical and biological impacts on the freshwater environment through their burrowing and tropic activities. Crayfish plague has also caused the loss of many populations since the early 1980s (Holdich 1999b).

Because of burrowing ability *P. clarkii* increases the costs of rice production, for example, in Portugal (Fonseca et al. 1996). This species burrows into dykes and eats rice seedlings. Rice producers in Spain use pesticides to eradicate *P. clarkii* from their fields, sometimes with disastrous consequences for bird life. Rice production is also damaged during the harvest of *P. clarkii* by harvesters. It is therefore thought that the

majority of *P. clarkii* introductions in Spain had negative effects. On the other hand, it was reported that the introduction of *P. clarkii* in Kenya as a biological control agent for freshwater snails has caused positive effects (Lodge et al. 2000a).

Similar to the European experience, North American crayfish species and aquatic ecosystems are at risk from crayfish transferred from other continents. For example, the Australian red claw crayfish, *Cherax quadricarinatus*, has been introduced for culture purpose into the United States. However, no wild populations of *C. quadricarinatus* have as yet been reported (Lodge et al. 2000b).

In USA there are many examples involving the rapid displacement of native species by non-native crayfish introductions. For example, in northern Wisconsin the introduction of *O. rusticus* caused a greater than 50% reduction in the number of native populations of *O. virilis* and entirely elimination of some populations. Similarly, *O. propinquus* was rapidly displaced by *O. rusticus* in northern Illinois. The introduction of *P. leniusculus*, urbanization and over exploitation caused the extinction of *P. nigrescens*, native to the San Francisco Bay region of northern California. Similary, *P. fortis* has been affected severely by the introduction of *P. leniusculus*. It has been limited to small and isolated populations in its native habitat (Light et al. 1995; Lodge et al. 2000a, b).

To protect European native crayfish populations (especially for *A. astacus* and *A. pallipes*) professional management support, conservation studies and action plans have been put in place (Souty-Grosset et al. 2006). These activities must include preventing the spread of diseases and new non-native crayfish introductions; introducing harvest regulations; informing Governments, fisherman and public on the importance of native crayfish species population protection; production of disease-free native juveniles for stocking; removing plague infected crayfish from populations; protecting crayfish from predators; and providing natural shelters and food for native species (Westman and Westman 1992; Huner et al. 1992; Pursiainen and Westman 1992; Laurent et al. 1993; Skurdal 1994; Rogers and Holdich 1995; Holdich et al. 1995; Arrignon 1997; Von Lukowicz 1999).

Despite the negative impacts of non-native crayfish, the positive impacts of non-native crayfish introductions have been summarized by Ackefors (1999) as below: (1) rapid restoration of traditional habitats, e.g. fishing for crayfish in Sweden; (2) economic benefit for local crayfishermen, e.g. Spanish netsmen; (3) diversification of agriculture to include astaciculture, e.g. crayfish farmers in Britain and in Sweden; (4) developmental research into astaciculture, e.g. various universities and institutes including commercial companies, e.g. in Sweden; (5) creating large artificial waterbodies; (6) restocking of lakes with plague-resistant species, e.g. Finland and Sweden; (7) preventing lakes from being overgrown by water plants, e.g. Finland and Sweden; (8) socio-economic advantages for rural people; and (9) increased trade between countries inside Europe as well as between European countries and countries outside Europe.

Discussion and conclusion

It is highly likely that the spread of non-native crayfish introductions throughout Turkey will only increase problems. The introduction of non-native crayfish in Europe, as well as many part of the world, are known to have caused important reductions in population density and numbers of native crayfish species populations. As a result, freshwater ecosystems have changed, and the economic viability of native crayfish species fisheries has been reduced severely. It is thought that many of these changes are probably irreversible. Therefore, many European countries have taken very strong and successful regulatory and management steps to reduce ecological and economic disruptions from non-native crayfish species (Lodge et al. 2000b; Souty-Grosset et al. 2006). For example, to protect native crayfish species and their freshwater habitats from crayfish introductions, legislation has been put in place in many European countries (Gherardi and Holdich, 1999; Holdich and Pöckl 2005). *A. pallipes* has been listed as warranting protection by the European Union. The World Conservation Union has also

listed *A. astacus* and *A. torrentium* as threatened species. In England and other British countries, *A. pallipes* is considered as a protected species under the Wildlife and Countryside Act. It cannot be bought or sold without a license, which is rarely granted. *A. astacus, A. leptodactylus* and *P. leniusculus* are defined as pests under the Wildlife and Countryside Act in Britain. Therefore, it is illegal throughout Britain to keep *A. astacus* and *A. leptodactylus* without a license, unless they are being used for culinary purposes, although because *P. leniusculus* is so wide-spread the ban only applies to certain regions (Holdich et al. 2004). In addition, European countries are obligated to ensure that deliberate introductions of non-native species are regulated (Lodge et al. 2000b).

On the other hand, contents of the regulatory methods vary from one country to another in Europe. For example, the import of live non-native crayfish species is forbidden in Ireland and Norway. Similarly, the importation of *P. clarkii* in France is prohibited, but the General Agreement on Trade and Tariffs and Single European Market regulations may prevent other countries from taking such stringent steps (Lodge et al. 2000a).

In Turkey, import, transport, stock and sell of any creatures living in water are licensed by Agriculture Ministry (Fisheries Law No: 1380, Fisheries Regulation, Paragraph 16 and 22). Stocking of non-native species into water resources for any aims is also licensed by Agriculture Ministry, and scientific research must be carried out before stock (Environment Law No: 2872, Wetland Protection Regulation, Paragraph 12) (Sağlam 2003). In addition, the import of eggs, juveniles and adults of any non-native creatures living in water is licensed by Agriculture Ministry (Fisheries Law No: 1380, Aquaculture Regulation, Paragraph 18) (Anonymous 2004). Except for these laws and regulations, and current harvest regulations, no population management or conservation strategies have been carried out for the populations of *A. leptodactylus* in Turkey.

To protect the native crayfish populations in USA, Lodge et al. (2000b) recommended that the adoption of a white list approach that would prevent moving any species between catchments within a state, between states, and from other continents until adequate screening of the characteristics of a given species has been conducted. It was also recommended that research should be carried out on methods to eradicate localized populations of invasive crayfish while minimizing impact on non target species, and on methods for maintenance control of more widespread non-native crayfish species. Lodge et al. (2000b) concluded that ''Otherwise, losses of biodiversity and changes in ecosystem function are a virtual certainty''. Holdich et al. (1999) also concluded that if European fisheries managers could turn back to 1850, many would surely choose to protect their native crayfish fisheries instead of replacing them with fisheries based on North American species, because of the fact that crayfish consumers prefer to pay substantially higher prices for the native *A. astacus* relative to *P. lenisusculus*.

In conclusion, any introduction of a non-native crayfish species into Turkey could be very critical. For example, there are over 300 freshwater crayfish species in North and Central America, but the majority of them have many characteristics that could have an adverse effect in new environments. Because of the fact that they are invasive, they tolerate a wide range of habitat conditions, are mobile, fast growing, and more fecund than native species. They are omnivorous and so have a wide trophic spectrum; often they are excellent accumulators of heavy metals and pesticides. Moreover, they can carry a wide range of commensals, epizootics, spores and viruses of fish and crayfish diseases into new environments. To prevent any possible changes to Turkish freshwater ecosystem function and any losses of crayfish biodiversity, the government and public should take lessons from the European and American experiences. It is therefore clear that to prevent any crayfish species introductions and to increase the production of *A. leptodactylus* that has economic importance in Turkey, following studies should be carried out:

1. Government authorities, fisherman and public should be educated on the potential dangers of non-native crayfish introductions and crayfish diseases;

2. Sale and importation of live non-native crayfish should be banned by the government for any purposes;
3. *A. leptodactylus* populations should be conserved and managed;
4. More research should be done on the biology, ecology, artificial production, feeding, juvenile rearing to stock (or re-stock) freshwaters, and diseases of *A. leptodactylus*;
5. The restoration of damaged populations of *A. leptodactylus* should be considered;
6. An investigation should be made into the current level of crayfish plague among Turkish crayfish populations.

Acknowledgment Many thanks to Dr. David Holdich for constructive criticisms of drafts of this study.

References

Ackefors H (1998) The culture and capture crayfish fisheries in Europe. World Aquacult 29(2):18–24; 64–67

Ackefors H (1999) The Positive Effects of Established crayfish Introductions in Europe. In: Gherardi F, Holdich DM (eds) Crayfish in Europe as alien species. how to make the best of a bad Situation? Balkema, Rotterdam/Brookfield, pp 49–61

Ackefors H (2000) Freshwater crayfish farming technology in the 1990s: a European and global perspective. Fish Fish 1:337–359

Anonymous (2004) The official newspaper of the Government, No: 25507, 29 June, 2004. Ankara, Turkey

Anonymous (2005) Fisheries statistics of prime ministry state planning organization. Republic of Turkey, Ankara

Arrignon JCV (1997) Status of foreign crayfish in France. Freshw Crayfish 11:665–670

Aydın H, Dilek MK (2004) Effects of different water temperatures on the hatching time and survival rates of Freshwater crayfish *Astacus leptodactylus* (Esch., 1823) eggs. *Turkish J Fish Aquat Sci* 4:75–79

Baran İ, Soylu E (1989) Crayfish plague in Turkey. J Fish Dis 12:193–197

Bolat Y (2001) An estimation in the population density of freshwater crayfish (*Astacus leptodactylus salinus* Nordman 1842) living in Hoyran Area of Eğirdir Lake, Isparta, Turkey. PhD thesis (In Turkish with English summary), The University of Süleyman Demirel, Turkey, 116 pp

D'agaro E, De Luise G, Lanari D (1999) The current status of crayfish farming in Italy. Freshw Crayfish 12:506–517

Diler Ö, Bolat Y, Kuşat M (1999) An epidemiological study on the fungal disease of *Astacus leptodactylus slinus* Nordmann, 1842 in Eğirdir Lake. (In Turkish with English summary). Süleyman Demirel Üniversitesi Eğirdir Su Ürünleri Fakültesi Dergisi 6:1–17

Erençin Z, Köksal G (1977) On the crayfish, *Astacus leptodactylus*, in Anatolia. Freshw Crayfish 3:187–192

FAO (2005) Fishery Information, Data and Statistics Unit (FIDI). Available at: http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp

Fonseca JC, Marques JC, Madeira CM (1996) Oxygen uptake inhibition in *Procambarus clarkii*, red swamp crayfish, by biogradable surfactants: An ecotechnolocigal approach for population control in rice fields. Freshw Crayfish 11:235–242

Gherardi F, Holdich DM (1999) Crayfish in Europe as non-native species - how to make the best of a bad situation. *Crustacean Issues 11*. A. A. Balkema, Rotterdam. ISBN 90 5410 469 4, 299 pp

Gutierrez-Yurrita P, Martinez JM, Bravo-Utrera MA, Montes C (1999) The status of crayfish populations in Spain and Portugal. In: Gherardi F, Holdich DM (eds) Crayfish in Europe as Non-native Species – How to make the best of a bad situation?. Balkema, Rotterdam/Brookfield, pp 161–192

Harlıoğlu MM (2004) The present situation of freshwater crayfish, *Astacus leptodactylus* (Eschscholtz, 1823) in Turkey. Aquaculture 230:181–187

Harlıoğlu MM, Holdich DM (2001) Meat yields in the introduced crayfish, *Pacifastacus leniusculus* and *Astacus leptodactylus*, from British waters. Aquacult Res 32:411–417

Harlıoğlu MM, Harlıoğlu AG (2004) The harvest of freshwater crayfish, *Astacus leptodactylus* (Eschscholtz, 1823) in Turkey. Rev Fish Fish Biol 14:415–419

Harlıoğlu MM, Güner U (2006) Studies on the recently discovered crayfish, *Austropotamobius torrentium* (Shrank, 1803), in Turkey: morphological analysis and meat yield. Aquaculture Research. Aquacult Res 37:538–542

Hobbs HH Jr (1988) Crayfish distrubution, adaptive radiation and evolution. In: Holdich DM, Lowery RS (eds) Freshwater crayfish: biology, management and exploitation. Croom-helm, London, pp 52–83

Hobbs HH III, Jass JP, Huner JV (1989) A review of global crayfish introductions with particular emphasis on two North American species (Decapoda, Cambaridae). Crustaceana 56:300–316

Hogger JB (1988) Ecology, population biology and behaviour. In: Holdich DM, Lowery RS (eds) Freshwater crayfish: biology, management and exploitation. Croom-helm, London, pp 114–144

Holdich DM (1988) Abrahamson Memorial lecture. The dangers of introducing alien animals with particular reference to crayfish. Freshw Crayfish 7:15–30

Holdich DM (1993) A review of astaciculture freshwater crayfish farming. Aquat Living Resour 6(3):307–317

Holdich DM, Rogers WD, Reader JP (1995) Crayfish Conservation. Report for the National Rivers Authority, England, Project Record: 378/10/N & Y

Holdich DM (1999a) The negative effects of established crayfish introductions. In: Ghrardi F, Holdich DM (eds) Crayfish in Europe as alien species. how to make the best of a bad situation? Balkema, Rotterdam/Brookfield, pp 31–47

Holdich DM (1999b) The introduction of alien crayfish into Britain for commercial exploitation – an own goal? In: Von Vauple Klein JC, Schram FR (eds) The Biodiversity crisis and Crustacea, Proceedings of the 4th International Crustacean Congress, Amsterdam, The Netherlands, July 20–24, 1998. Crustacean Issues 12. A. A. Balkema, Rotterdam, pp 85–97

Holdich DM (2002a) Present distribution of crayfish in Europe and some adjoining countries. Bulletin Français de la Peche et de la Pisciculture 367(4):611–650

Holdich DM (2002b) Biology of freshwater crayfish. Blackwell Science, Oxford, 702 pp

Holdich DM (2003) Crayfish in Europe – an overview of their taxonomy, legislation, distribution, and crayfish plague outbreaks. In: Holdich DM, Sibley PJ (eds) Management and conservation of crayfish. Environment Agency, Bristol, pp 15–34

Holdich DM, Ackefors H, Gherardi F, Rogers D, Skurdal J (1999) Native and alien crayfish in Europe: some conclusions. In: Ghrardi F, Holdich DM (eds) Crayfish in Europe as alien species. how to make the best of a bad situation? Balkema, Rotterdam/Brookfield, pp 281–292

Holdich D, Sibley P, Peay S (2004) The white-clawed crayfish – a decade on. Br Wildlife 15(3):153–164

Holdich DM, Pöckl M (2005) Can legislation protect vulnerable crayfish species? Bulletin de Français de la Pêche et de la Pisciculture 376–377:809–827

Horwitz P (1990) The translocation of freshwater crayfish in Australia: potential impact, the need for control and global relevance. Biol Conserv 54: 291–305

Huner JV, Holdich DM, Westman K (1992) Crayfish management starategies and management methods in Europe: a summary. Finnish Fish Res 14: 157–159

Karplus I, Barki A, Levi T, Hulata G, Harpaz S (1995) Effects of kinship and shelters on growth and survival of juvenile Australian redclaw crayfish (*Cherax quadricarinatus*). Freshw Crayfish 10:494–505

Köksal G (1988) *Astacus leptodactylus* in Europe. In: Holdich DM, Lowery RS (eds) Freshwater crayfish: biology, management and exploitation. Croom Helm, London and Timber Press, Oregon, pp 365–400

Laurent PJ (1997) Crayfish introductions into France and in the world, history and consequences. Bulletin Francais De La Peche Et De La Pisciculture 344–45:345–356

Laurent PJ, Nicolas J, Paris L (1993) Five years of action in Lorraine and Morvan (France) to restore the noble crayfish *Astacus astacus*. Freshw Crayfish 9:380–389

Light T (2005) Behavioral effects of invaders: alien crayfish and native sculpin in a California stream. Biol Invasions 7:353–367

Light T, Erman DC, Myrick C, Clarke J (1995) Decline of the Shasta crayfish (*Pacifastacus fortis* Faxon) of northeastern California. Conserv Biol 9:1567–1577

Lodge D, Taylor C, Holdich DM, Skurdal J (2000a) Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fisheries 25(8):7–20

Lodge D, Taylor C, Holdich DM, Skurdal J (2000b) Reducing impacts of exotic crayfish introductions: new policies needed. Fisheries 25(8):21–23

Machino Y, Holdich DM (2006) Distribution of crayfish in Europe and adjacent countries: updates and comments. Freshw Crayfish 15:292–323

Maguire I, Gottstein-Matoec S (2004) The distribution pattern of freshwater crayfish in Croatia. Crustaceana 77(1):25–47

Magnuson JJ, Capelli GM, Lorman JG, Stein RA (1975) Consideration of crayfish for macrophyte control. In: Bezonik PL, Fox JL (eds) The proceedings of a symposium on water quality management through biological control. University of Florida, Gainesville, pp 66–74

McGriff D (1983) The commercial fishery for *Pacifastacus leniusculus* Dana in the Sacramento San Joaquin delta. Freshw Crayfish 5:403–417

Momot WT (1997) History of the range extension of *Orconectes rusticus* into northwestern Ontario and Lake Superior. Freshw Crayfish 11:61–72

Nyström P (2002) Ecology. In: Holdich DM (ed) Biology of freshwater crayfish. Blackwell Science Company, pp 192–235

Pursiainen M, Westman K (1992) The restoration of the crayfish (*Astacus astacus*) stocks in Rivers Siikajoki and Tiilikanjoki, Finland. Finnish Fish Res 14:85–91

Rogers WD, Holdich DM (1995) Conservation and management of crayfish in Britain. Freshw Crayfish 10:92–97

Sağlam N (2003) Fisheries regulations. University Bookstore Press, Elazığ, Turkey, 281 pp

Skurdal J (1994) Crayfish Management in the Nordic and Baltic Countries. Nordic J Freshwater Research 69:181–184

Skurdal J, Taugbøl T (2002) Crayfish of commercial importance-Astacus. *In*: Holdich DM (ed) Biology of freshwater crayfish. Blackwell Science Company. pp 467–510

Souty-Grosset C, Holdich DM, Noël PY, Reynolds JD, Haffner P (2006) Atlas of Crayfish in Europe. Muséum national d[1]Histoire naturelle, Paris, (Patrimoines naturels, 64). (In press)

Taylor CA (2002) Conservation assessment for the Kentucky crayfish (*Orconectes kentuckiensis*). USDA Forest Service, Threatened and Endangered Species Program 310 W Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203, USA. pp 11

Taylor CA (2003) Conservation assessment for a crayfish (*Orconectes placidus*). USDA Forest Service, Eastern Region, Center for Biodiversity, Illinois Natural History Survey 607 E. Peabody Drive, Champaign, IL 61820, USA. pp 11

Trontelj P, Yoichi M, Boris S (2005) Phylogenetic and phylogeographic relationships in the crayfish genus *Austropotamobius* inferred from mitochondrial COI gene sequences. Mol Phylogenet Evol 34:212–226

Von Lukowicz M (1999) Freshwater crayfish in the fishery legislation of the Federal States (Bundeslander) of Germany. Freshw Crayfish 12:890–898

Westman K (2002) Non-native crayfish in Europe: negative and positive impacts and interactions with native crayfish. In: Leppäkoski E, Gollasch S, Olenin S (eds) *Invasive aquatic species of Europe. Distribution, impacts and management*, Kluwer Academic Publishers, Dordrecht, Boston, London: 76–95, 548–583

Westman K (1992) Management of the noble crayfish *Astacus astacus* (L). and the signal crayfish *Pacifastacus leniusculus* (Dana) in Finland. Finnish Fish Res 14:39–51

Westman K, Westman P (1992) Present status of crayfish management in Europe. Finnish Fish Res 14:1–22

Wickins JF, Lee DO'C (2002) Crustacean farming ranching and culture. Blackwell Science, Oxford, 446 pp