Conservation Letters
A journal of the Society for Conservation Biology
Open Access

POLICY PERSPECTIVE

A Proposal for the Feasible Exploitation of the Red Swamp Crayfish *Procambarus Clarkii* in Introduced Regions

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Keywords
Aquaculture; economic value; fisheries; invasive species; Iberian Peninsula.

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Received
12 June 2014
Accepted
2 February 2015

Editor
Xavier Basurto

doi: 10.1111/conl.12164

Abstract

The invasive red swamp crayfish *Procambarus clarkii* is a human-mediated introduced species in the Iberian Peninsula. The species was introduced for economic reasons in the south of the Peninsula, but it is currently abundant and widespread in Portugal and Spain. As an invasive species, it is regulated by different laws in the Iberian Peninsula. Thus, although exploitation of this crayfish is permitted by the central government in Spain, the species is subjected to severe restrictions in Portugal. Moreover, regional governments in Spain only allow recreational fishing of *P. clarki*, except in southern Spain where there is an industrial activity based on the red swamp crayfish. We propose compromise measures in order to reconcile the economic exploitation of this aquatic resource and environmental concerns. The proposal mainly consists of the sale of live male specimens of *P. clarkii* and of dead (processed) female specimens. Biological invasion resulting in new established populations of *P. clarkii* in the wild would therefore be impossible. Transformation of *P. clarkii* into an economic resource with minimum environmental hazard seems feasible.

Introduction

The introduction of nonnative species has been associated with human migrations since ancient times. Introduced species such as cattle, poultry, cereals, and tuberous plants provide food for most of the world's population. However, the introductions have sometimes led to biological invasion, as in the well-known case of rabbits in Australia (Gherardi & Angiolini 2008).

Crayfish play important roles in their natural ecosystems. In streams, they feed on benthic invertebrates, detritus, macrophytes, algae, and fish (Gherardi 2006), and the consumption of these resources contributes to high levels of energy processing and secondary production (Paglianti & Gherardi 2004). Crayfish are also prey for about two hundred animal species, including mammals, birds, reptiles, amphibians, fishes, and other invertebrates (Geiger *et al.* 2005; Gherardi 2006; DiStefano *et al.* 2009).

Populations of European crayfish declined due to diseases and overexploitation in the 19th century (Gherardi 2011). In order to satisfy the European demand, some crayfish were introduced from North America during the 20th century, resulting in the invasive spread of the introduced species (Gherardi 2011). As with any other alien species, the economic impact caused by introduced crayfish had positive and negative effects with ecological, economic, and social components (Tablado *et al.* 2010; Copp *et al.* 2014).

The introduction of a species with the aim of obtaining immediate benefit may transform any potential profit into a net loss (Gherardi & Angiolini 2008; Lodge *et al.* 2012). In order to overcome the negative component of biological introductions, here we propose a means of exploiting the crayfish *Procambarus clarkii* (Girard, 1852) that prevents biological invasion or further spread of the species to locations outside of its natural range of distribution. This proposal focuses on the Iberian Peninsula where *P. clarkii* is already established but largely banned for commercialization. This framework may also be extended to other locations and species with the same biological requirements as those identified here for *P. clarkii*. For instance, pathogen-free crayfish, crabs, mammals, and birds that can be easily sexed at early life stages and do not hybridize with native species could also be considered in the same way.

P.clarkii in the Iberian Peninsula

Procambarus clarkii is the most widely introduced crayfish species in the world (Lodge *et al.* 2012). This crayfish is found in natural habitats in all continents except Australia and Antarctica (Huner 2002). It is naturally distributed in the Northeast of Mexico and Southern United States (Huner 2002), where, in the latter case, it is cultivated or caught in the wild as an important economic resource (FAO 2007–2014).

The red swamp crayfish was introduced in Europe for commercial purposes (Gherardi 2006). In the early 1970s, *P. clarkii* was introduced in two aquaculture facilities separated by hundreds of kilometers in southern Spain (Habsburgo-Lorena 1983). The species was introduced with the joint aims of boosting the local economy and filling an ecological niche not occupied by the native crayfish *Austropotamobius pallipes*. Spread of the deadly infectious fungus carried by *P. clarkii* to native crayfish was not considered problematic as the native crayfish is largely absent from this part of the Iberian Peninsula (Gutierrez-Yurrita *et al.* 1999; Geiger *et al.* 2005). However, the introduction soon became unmanageable and the red swamp crayfish expanded throughout the Iberian Peninsula and to other European countries (Gutierrez-Yurrita *et al.* 1999; Geiger *et al.* 2005). In many cases, it was intentionally translocated because of its high market price (Henttonen & Huner 1999; Gherardi 2006). A few years after its arrival to the Iberian Peninsula, the species was reported in southern Portugal (Ramos & Pereira 1981). The red swamp crayfish is currently found throughout almost the entire Iberian Peninsula (Gutierrez-Yurrita *et al.* 1999; Holdich *et al.* 2009).

The laws regulating fisheries and marketing of *P. clarkii* in the Iberian Peninsula are controversial. Although trading of the red swamp crayfish is allowed in Spain (BOE 2013), economic exploitation of the species is prohibited in Portugal. The Portuguese laws are more restrictive and ban the transportation of any invasive species (Diário da República 1999). As a result, the crayfish must be killed on capture, which makes the *P. clarkii* fishery a less appealing venture in Portugal. However, live individuals of *P. clarkii* are exported illegally from Portugal to Spain (Gutierrez-Yurrita *et al.* 1999). Likewise, because of differences in trade and conservation regulations between the central and regional governments, most regional governments in Spain do not apply the legislation approved by the central government (BOE 2013), and capture of exotic crayfish is only permitted for recreational purposes. The applicable European legislation includes Council Regulation 708/07 (European Parliament 2007; see Gherardi 2011, for further legislation), devoted to the 'use of alien and locally absent species in aquaculture'. Nonetheless, legislative attempts to stop the spread of invasive species may quickly become ineffective for crayfish because the species represents a valuable socio-cultural and economic resource (live food or aquarium/pet trade, sport fishing) susceptible to illegal transactions. Moreover, *P. clarkii* displays a remarkable capacity to spread naturally (Gutierrez-Yurrita *et al.* 1999; Henttonen & Huner 1999; Gherardi & Angiolini 2008). On the other hand, free trading of exotic species without further regulations would contribute likewise to their spread (Nuñez *et al.* 2012). Therefore, management of an economically valuable alien species, such as *P. clarkii*, should optimally be regulated by laws with two goals: prevention of further spread of the species, and ecologically sound exploitation of the species.

Ecological and economic aspects of *P. clarkii* in the Iberian Peninsula

Procambarus clarkii plays a central role in the new invaded habitats where it occurs in the Iberian Peninsula (Geiger *et al.* 2005). The red swamp crayfish has modified trophic relationships in Mediterranean wetlands by opening up new trophic pathways, reducing the number of trophic levels and consequently providing more energy to the highest levels of the food chain (Geiger *et al.* 2005). The key position occupied by *P. clarkii* in the ecosystem (Gherardi 2006) suggests that a reduction in the population numbers rather than total eradication would be probably the best approach for managing the invasion by the swamp crayfish in some cases (Geiger *et al.* 2005; Tablado *et al.* 2010). A number of negative ecological impacts can be attributed to *P. clarkii* in the Iberian Peninsula, such as habitat modification (Angeler *et al.* 2001), negative effects on native invertebrates (Correia & Anastácio 2008) and amphibian communities (Cruz *et al.* 2006), reduction in macrophyte biomass (Rodríguez *et al.* 2003), or replacement of indigenous crayfish by competitive exclusion and disease transmission (Gherardi 2006). In some cases, local economies are also affected as a result of damage to irrigation structures and rice fields (Anastácio & Marques 1995). Human health may even be endangered by the transmission of pathogens such as the infectious bacteria *Francisella tularensis* (Anda *et al.* 2001) and toxins from cyanobacteria (Vasconcelos 2006). *Procambarus clarkii* also accumulates persistent pollutants such as heavy metals (Alcorlo *et al.* 2006), thus representing an additional hazard to human health.

Information about the economic benefits derived from the swamp crayfish in the Iberian Peninsula is scarce. Commercial fisheries of *P. clarkii* are based on wild stocks of *P. clarkii* from the lower Guadalquivir basin (e.g., Doñana marshes, Andalusia), where professional fishing is permitted by the Andalusian Regional Government (BOJA 2014). Records of incomes are as high as 1.8 million € in favor of local fishermen (2006 campaign, Martín-López *et al.* 2011) and commercial captures reach about 4000 t/year in this area (Tablado *et al.* 2010). The value per kilo was greater in the first year after the introduction (approximately 8 €kg^{-1}), but it declined sharply a few years later (to approximately 2 €kg^{-1}) because of an increased number of captures (Molina 1982). The most recent estimated value of the crayfish caught by fishermen was 1.1 €kg^{-1} (Martín-López *et al.* 2011). Approximately 42% of the catches are exported (Martín-López *et al.* 2011) and the remainder is consumed locally, reflecting the economic and cultural importance that *P. clarkii* has attained in southern Spain. The Spanish central government's law that allows trading of the swamp crayfish (BOE 2013) could be interpreted as a stimulus for expanding the economic use of the species beyond its current area of exploitation.

Procambarus clarkii is mainly commercially exploited in Kenya, Spain, China, and the United States (Gutierrez-Yurrita *et al*. 1999; Henttonen & Huner 1999). The major market places for *P. clarkii* in the Iberian Peninsula are the provinces of Madrid and Valladolid and the region of Andalusia in Spain, along with France, Sweden, Belgium and some potential markets in the US that are also destinations for exports (Gutierrez-Yurrita *et al*. 1999; Martín-López *et al.* 2011; FAO 2007–2014). When there is an overabundance and live markets become saturated, the crayfish are processed and sold as fresh or frozen products (FAO 2007–2014). The profitability of the resource could be increased by diversification of production outside of the months in which the natural yield is maximal (Gutierrez-Yurrita *et al*. 1999), which could be achieved by aquaculture. The long-term prospect for crayfish aquaculture is sound, mainly for sustainable models (FAO 2007–2014). Aquaculture production of crayfish is currently residual in the Iberian Peninsula (Gutierrez-Yurrita *et al*. 1999) and has not been reported to international organizations since 2005 (FAO 2007–2014).

The proposal

Biological aspects

Most arthropods are gonochoristic organisms. In other words, they reproduce sexually and have separate sexes. Crayfish, which are arthropods, copulate by using modified appendages for sperm transfer. The female has a seminal receptacle for storing sperm until fertilization (Ruppert & Barnes 1994). In *P. clarkii*, females usually fertilize the eggs 1 month after copulation, although they are able to store the sperm until they moult (Aquiloni & Gherardi 2008). Crayfish can be easily sexed by identification of both modified swimmerets for sperm transfer in males and a conspicuous seminal receptacle (*annulus ventralis*) in females.

Monosex male culture of *P. clarkii* and trading of male specimens

Monosex culture of prawns, crabs, and crayfish is a managerial strategy to increase the profitability of aquaculture systems (Ventura & Sagi 2012). For instance, monosex cultures of crayfish belonging to the genus *Cherax* grow faster and attain larger sizes than mixed cultures (Curtis & Jones 1995; Lawrence *et al.* 2000). These authors showed that males grow faster and reach larger sizes than females in monosex cultures. The better performance of monosex cultures is mainly attributed to exclusive allocation of energy for growth instead of gonad ripening (Ventura & Sagi 2012). Monosex culture of *P. clarkii* probably remains unexplored because current exploitation methods are already profitable (FAO 2007–2014). The higher growth of male crayfish of the genus *Cherax* in monosex cultures may be expected in *P. clarkii* male monosex cultures because of a higher efficiency in the use of energy for somatic growth in males (Curtis & Jones 1995; Lawrence *et al.* 2000).

Trading living male specimens of *P. clarkii* would encourage the creation of commercial fisheries of this species in areas where populations have been established (and possibly in other locations; see Nuñez *et al.* 2012). Male specimens can be sold live because release of males only cannot lead to biological invasion by the species, whereas females should be processed (boiled, canned, or packed) before reaching the market.

Exploitation model for male monosex cultures

The high level of concern about containing and controlling populations of invasive species is manifested by the legislation addressing this matter (Diário da República 1999; European Parliament 2007; BOE 2013). Commercial exploitation of *P. clarkii* by male monosex culture would also need approval and monitoring by the corresponding authorities. The process of rearing male specimens would begin in a government-authorized hatchery/nursery (hereafter referred as hatchery). Juvenile males reared in such facilities would then be supplied to licensed farmers for growing on to

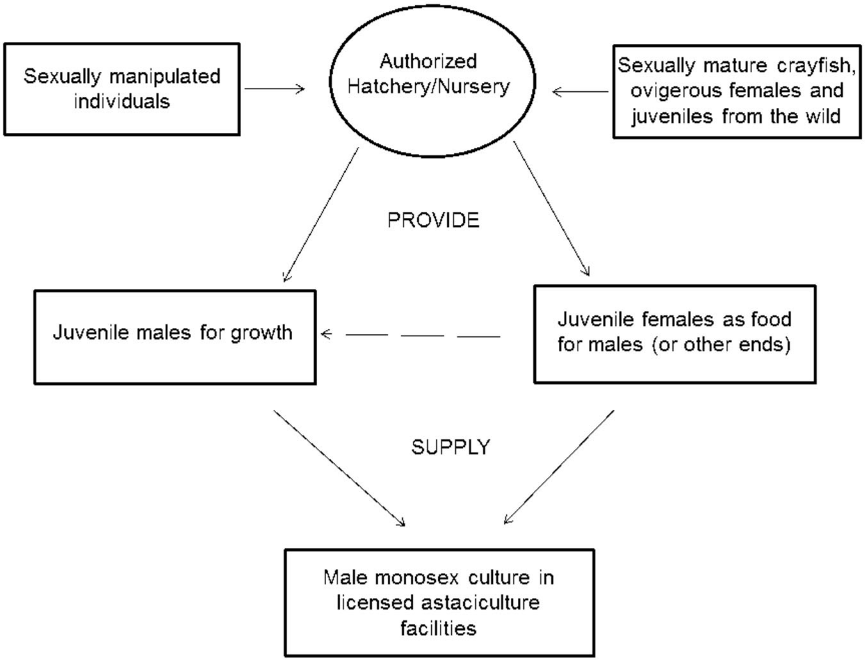

Figure 1 Schematic representation of the exploitation of *P. clarkii* by all-male monosex culture. Authorized hatcheries produce juveniles of the species from breeding stocks or from specimens captured in the wild. Juvenile males are supplied to licensed growers and juvenile females are used as foodstuff for both male crayfish in hatcheries or in licensed breeding facilities. Other uses for female specimens are also possible, for example, as dead bait for anglers.

marketable size (Figure 1). Additional legislation and control of aquaculture facilities and markets should ensure that only living male specimens of red swamp crayfish are commercialized. Licenses for exploitation would restrict the culture to male specimens as well as imposing conditions for environmental safety to avoid escapes of cultured animals. Although male monosex cultures would disrupt sexual reproduction, resulting in a form of biological confinement (Kapuscinski 2005), the implementation of physical confinement by screens or other mechanical barriers (Kapuscinski 2005; Gherardi & Angiolini 2008) may prevent escapes from growing facilities. Prevention of the escape of exotic species used for human consumption is already considered, for instance, in the Spanish and European laws (European Parliament 2007; BOE 2013). Closed aquaculture facilities in which barriers are used and water is recirculated to prevent the escape of reared specimens or biological material are considered by the Council Regulation 708/07 (European Parliament 2007). This type of facility would be suitable for the hatchery stage of production. The same production method should be considered by licensed farmers for the growing stage, although current aquaculture production of *P. clarkii* mainly relies on the use of earth ponds and extensive methods of production (FAO 2007–2014). A double barrier system made by a smooth surface material (such as PVC) surrounding the production ponds to a height of 30–40 cm would be sufficient to retain crayfish, which cannot climb smooth surfaces. The barriers could be placed about 1 meter apart, with the ground between covered with a white rigid material (e.g., white polyethylene mesh) so that any escaped specimens would be easily noticed, and also to prevent such escapees burrowing into the ground. This barrier method could be even reinforced with a surrounding fence to minimize movement in and out of the farm.

The authorized hatcheries would produce juvenile male specimens either by sexual manipulation of individuals (Ventura & Sagi 2012) or by use of reproductive stocks, ovigerous females, or juveniles collected from the wild, depending on which system yielded the highest benefit-cost ratio. Massive fishing in locations with large populations of *P. clarkii* during the reproductive season may be an appropriate strategy. This approach is doubly beneficial because (1) overfishing generates the decline of wild populations (Hein *et al.* 2007) and (2) captured individuals could be used to supply adults for reproduction and juveniles for further distribution to growers in authorized hatcheries/nurseries (Figure 1).

Ovigerous females could be kept in the authorized hatcheries until hatching. After leaving their mother, crayfish hatchlings possess similar features and feeding habits as their adult counterparts (Gherardi 2011). Hatchlings could be reared in the authorized facilities until the sexes can be separated manually. Moreover, sexually manipulated individuals produce monosex descendants (Ventura & Sagi 2012), thus facilitating the provision of juveniles at any time to growers. Manual separation of the sexes has the drawback of increasing production costs (Curtis & Jones 1995).

Male juveniles can be fed with commercial food and/or with juvenile or adult female crayfish (Figure 1). Cannibalistic behavior has been reported in adult and juvenile crayfish (Olsson & Nyström 2009). The red swamp crayfish has been shown to be a suitable food resource in aquaculture (Abd El-Rahman & Badrawy 2007). The body and exoskeleton of *P. clarkii* contain large amounts of protein, nine essential amino acids, nine non-essential amino acids, nine unsaturated fatty acids, including essential fatty acids (such as Omega 6 and Omega 3), minerals, and vitamins (Hamdi 2011). As a food resource, *P. clarkii* supplies carotenoids, carotenoproteins, and chitin (Cremades *et al*. 2001; Abd El-Rahman & Badrawy 2007; Pérez-Galvez *et al.* 2008; Gherardi 2011), which are essential for growth and development of juveniles (Paglianti & Gherardi 2004). However, wild crayfish can accumulate persistent pollutants such as heavy metals (Alcorlo *et al.* 2006), which might limit their use as a food resource. Juvenile female specimens also have other uses such as dead bait for professional or sport fishing (DiStefano *et al.* 2009).

Benefits and risks

Risk-benefit analysis is required to assess the exploitability of *P. clarkii* in areas where the species is already present (Geiger *et al.* 2005; Gherardi 2011). Intensive fishing has been suggested as an appropriate means of controlling exotic crayfish populations (Hein *et al.* 2007; Jones *et al.* 2009; Lodge *et al.* 2012). As such, a *P. clarkii* fishery could be granted on a short time basis when high population densities are reached. Unrestricted harvesting of invasive species for human consumption may create the temptation to introduce the species to uninvaded regions as an economic resource (Nuñez *et al.* 2012). Rearing monosex cultures could overcome this problem in the case of the invasive crayfish *P. clarkii*, with males being cultured as an economic resource in areas where wild populations are overexploited, fisheries are banned or where the species is not present. Indeed, monosex culture has been proposed as a promising sustainable solution to the problems caused by the introduction of invasive crustaceans (Ventura & Sagi 2012). Some advantages of monosex culture of *P. clarkii* in licensed facilities over the exploitation of invasive populations in the wild are shown in Table 1. Development of a crayfish industry may also be applicable to the mass production of the native crayfish *A. pallipes* for release to aid recovery of threatened native populations (Henttonen & Huner 1999; Holdich *et al.* 2009).

Our proposal does not collide with managerial measures implemented to control the invasion of *P. clarkii*. On the contrary, it offers the possibility of legal exploitation in locations where environmental concerns currently restrain the commercialization of this crayfish (Diário da República 1999). However, it could compromise the current exploitation of the red swamp crayfish (such as the fishery in the Guadalquivir Marshes; BOJA 2014). The supply of cultured *P. clarkii* to the market may replace the supply from fisheries, with consequent negative effects on fishermen economies. However, because of the high consumption of seafood in the Iberian Peninsula and because the *P. clarkii* market is under-saturated in Spain and Portugal (Gutierrez-Yurrita et al. 1999; Martín-López et al. 2011), no conflict between extractive and aquaculture mode of production of *P. clarkii* is expected, at least in the short term.

The existence of red swamp crayfish fisheries may facilitate illegal movements to new areas in order set up profitable businesses (Nuñez *et al*. 2012). Therefore, fisheries should be permitted in locations where they already occur and be banned elsewhere, unless occasional permits are granted to manage wild populations. Fisheries may eventually provide breeding stocks and juveniles to authorized hatcheries. For coherence within the current framework, the sale of live females caught in the wild should be also prohibited in markets. As an alternative to fishing, male monosex cultures of *P. clarkii* would be legally established in areas where there is a willingness to do so. Under these circumstances, illegal business would tend to decline.

Trading of *P. clarkii* males has some disadvantages. The potential escape of male specimens of *P. clarkii* from licensed facilities and the sale of live crayfish in markets may represent a risk regarding the reintroduction of this species in the environment. However, wild stocks would only increase if females were available to be fertilized. Because the red swamp crayfish is a promiscuous species (Aquiloni & Gherardi 2008), escapee males may be more important in increasing the genetic diversity of a wild population rather than augmenting the number of ovigerous females. The presence of male escapees should not affect population growth as this depends on the number of fertilized females, which would remain constant. Additionally, X-ray sterilization could be used to limit

Table 1 Comparison between the benefits of monosex male culture of *P. clarkii* and the disadvantages related to their established populations in the wild. All these aspect are considered in the text.

Wild populations	Monosex male culture
Difficult to manage, out of control	Under control in ad hoc facilities
Ecosystem modification	Under control in ad hoc facilities
Establishment/spreading of the invasion	Minimum risk of biological invasion
Comprises males and females	Composed only by males
Numerous offspring	No offspring
Outcompetition of native species	Hazardless within aquaculture facilities
Risk for human health	Safe product for human consumption
Variable yield and incomes	Constant and maximized production

the reproductive success of live males sold on the market (Aquiloni *et al.* 2009), thus further reducing any environmental threat related to the release of male specimens of *P. clarkii* through trading.

The establishment of male monosex cultures of *P. clarkii* from authorized hatcheries would be in accordance with the European Council Regulation 708/07 (European Parliament 2007), and therefore the proposal could be implemented at sites where the species is locally absent. Copp *et al*. (2014) considered *P. clarkii* as one of two case study species to illustrate the use of the European risk assessment scheme for nonnative species in aquaculture (for compliance with Regulation 708/07; European Parliament 2007). These authors found an intermediate level risk for all of the different aspects related to introduction or translocation of *P. clarkii*: dispersal of infectious agents, release of specimens and pathogens from rearing facilities, introduction and establishment of the species in open water through transport pathways, and the socio-economic impacts in case of biological invasion. However, all of these potential threats are minimized by a productive model based on uninfected monosex male populations (Henttonen & Huner 1999; Kouba *et al*. 2012). For instance, the accidental mass release of individuals (e.g., during transport between hatcheries and growing facilities and between these and markets) into sites without wild populations of the red swamp crayfish could be easily managed. Intense capture would be followed by regular monitoring until the male population would extinguish itself at the end of its relatively short life span (Gherardi 2006). Therefore, any environmental impact in case of a mass release would occur during a short period of time followed by natural recovery of the ecosystem.

Hybridization is also an important factor. It is known that hybridization between an invader and a native species may endanger the latter in favor of the hybrid form (Perry *et al.* 2001). Hybridization has been described in crayfish species of the genera *Orconectes* (Perry *et al.* 2001) and *Cherax* (Lawrence 2004), although there is no evidence of hybridization involving the genus *Procambarus*. Parthenogenesis, an asexual process of development of embryos without fertilization, may also occur. Parthenogenesis has been described in marmorkrebs, the parthenogenic form of *Procambarus fallax*, a species that was introduced in Europe as a pet (Scholtz *et al.* 2003). The parthenogenetic marmorkrebs represents a serious threat to freshwater biodiversity and human livelihoods in Madagascar (Jones *et al.* 2009). Experimental evidence has also shown that the crayfish *Orconectes limosus* is capable of facultative parthenogenesis (Buřič *et al.* 2011). Parthenogenesis has not been confirmed in *P. clarkii*, although it has been suggested that it may occur (Yue *et al.* 2008). In all of the aforementioned cases, only females reproduce parthenogenetically and therefore the associated risk is overcome by the culture of males.

There is some risk of transferring the crayfish plague agent *Aphanomyces astaci* to native crayfish. This fungus was brought to Europe via imported North American crayfish. Vertical transmission of the crayfish plague can occur between parents and descents in hatchery incubated individuals (Makkonen et al. 2010). Consequently, *P. clarkii* juveniles could transfer the pathogen between authorized hatcheries and licensed growing facilities unless they are disinfected before being transported. Use of a product containing peracetic acid has proved adequate for disinfection of crayfish before stocking them in closed culture systems (Henttonen & Huner 1999; Kouba *et al*. 2012) and helps to prevent spread of crayfish plague and other diseases in astaciculture (e.g., the fungal pathogen *Batrachochytrium dendrobatidis*; see Copp *et al.* 2014). Treated individuals reared in hatchery facilities would thus reach markets as disease-free specimens. Regular veterinary inspections should be carried out to ensure the healthy status of reared specimens.

Concluding remarks

Exploitation and maintenance of populations of the red swamp crayfish outside of its natural range of distribution may lead to loss of ecosystem services that would outweigh any economic benefits (Henttonen & Huner 1999). However, we hope that the present proposal serves as a rational basis to take advantage of a valuable nonnative species, enabling ecologically sound commercial exploitation.

Any valuable introduced species used in aquaculture can be similarly exploited as *P. clarkii* if a number of requirements are met. Thus, the species should show sexual dimorphism, should not be capable of hybridizing with native species or be capable of parthenogenetic reproduction, should be able to be reared as monosex culture in order to be biologically and physically confined, and should be able to be treated to prevent the dispersion of pathogens or invasive nontarget species. An invasive species with these features can be harvested for commerce considering both managerial (e.g., maintain low population levels) and economic factors (e.g., maintenance in sites where the resource is already exploited from the wild).

The economic value of introduced species should be regulated to ensure that releases do not occur, as this would clash with environmental aims. Monitoring and surveillance of marketplaces by the relevant authorities is the key toward compliance with regulations and laws relating to the economic value of the nonnative species. Crayfish cultured according to this proposal would facilitate inspections by authorities as specimens sold in markets should be of the same gender, disease-free, and genetically traceable back to the parental stock. Specimens obtained from illegal sources and sold on the market would fail to meet all or some of the latter conditions. The sellers of wild specimens should possess a document provided by fishermen referring the date and place of capture and the authorized person who conducted the catchment, with sanctions imposed on those sellers who cannot supply such documentation at points of sale. These rules would enforce the commerce of specimens exclusively obtained from legal sources. Marketplace inspections would be conducted by the specialized administrative authority dedicated to food safety and economic surveillance (as for instance the Food and Economic Security Authority, ASAE, in Portugal, www.asae.pt).

In summary, the current proposal considers the legal exploitation of *P. clarkii* males, mainly in licensed aquaculture facilities. Juvenile males reared by farmers would be previously produced in authorized hatchery facilities. Rearing crayfish under controlled conditions would provide safe products for human consumption. Fishing could be allowed in order to manage the invasion of *P. clarkii* or to prevent the economic collapse of fishing communities who legally exploit this resource. Live males could be sold in marketplaces, but female specimens should only be sold after processing. Males would be used for human consumption, ornamental or aesthetic use, recreational fishing, or scientific and educational purposes. Processed females could be used for human consumption or as an animal feed, among other uses. From the point of view of conservation, the risk of reintroduction of marketable crayfish would be almost negligible because wild populations cannot be established from male specimens alone. The proposed legal framework would help prevent illegal exploitation, as it would establish a clear basis for legal exploitation of this resource. There is room for commercialization of the red swamp crayfish in international and domestic markets, thus locally providing food supplies, employment opportunities, and economic growth. Trading of the species in an ecologically sound manner, as described in this proposal, should be accompanied by surveillance and monitoring of markets by the relevant authorities. Surveillance of markets might be a good strategy to guarantee that traded crayfishes come from authorized producers that comply with the legal framework. Heavy sanctions for infractions would help prevent illegal business and therefore minimize the human-mediated spread of the red swamp crayfish. The current proposal could also be applied to other introduced species susceptible of being cultured. Implementation of the current proposal for the exploitation of *P. clarkii* would provide economic and social benefits within a conservationist context, thus overcoming the current general perception of the red swamp crayfish as a negative flagship species in locations where it has become invasive.

Acknowledgments

The authors are grateful to Prof. Francesca Gherardi for her dedication to promoting and disseminating scientific knowledge about crayfish. We are also indebted to two anonymous referees and to the editors, whose helpful comments helped us to improve an earlier version of this article. The first author was partially funded by the Ecuadorian Government Secretary for Higher Education, Science, Technology and Innovation (Senecyt).

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