The global trade in crayfish as pets

Zen Faulkes

Abstract.—The sale of crayfish in the pet trade has increased in recent decades, and a substantial fraction of the world’s entire range of crayfish species is available in the pet trade. The market for pet crayfish creates two major concerns: the potential for over exploitation of natural populations of crayfish to supply the pet trade, and the negative consequences resulting from the release of non-indigenous crayfish into natural habitats. The chain from the source of crayfish to the final owner can be lengthy, and each step in the supply chain needs to be studied by different methods. While there are often regulations intended to limit the trade of crayfish as pets, they differ widely from place to place and seem to have limited success in changing the behaviour of owners of pet crayfish.

Key words: aquarium, ornamental animals, methodology, new species, policy, risk assessment

Introduction

Pet keeping is tremendously popular, but the trade in pets is largely a “grey market”. It is difficult to find information on species availability, the amount of trade, and the source of pets (Calado et al., 2003; Rhyne et al., 2012, 2015). In the United States, 10% of people are estimated to have aquaria (Chapman et al., 1997), which can house many different kinds of organisms. Fish are probably both the most popular organisms kept in aquaria, and the most popular subjects for research on the pet trade. The trade in aquatic plants and invertebrates for aquarium use has been less well studied (but see Kay & Hoyle, 2001 on aquatic plants). There has been a tendency to describe invertebrates as “incidental” contaminant species in the pet trade, hitchhiking on larger organisms (Keller & Lodge, 2009; Duggan, 2010). Many different kinds of aquatic crustaceans are sold as pets (Calado et al., 2003; Klotz et al., 2013; Ng et al., 2015), but this review focuses on crayfish for these reasons. First, more people buy freshwater organisms than marine ones (Chapman et al., 1997). Thus, crayfish have a potentially greater distribution among pet owners than marine crustaceans. Second, there has been a pronounced increase in the keeping of crayfish as pets, particularly in Europe, since the 1990s (Patoka et al., 2015c; Chucholl, 2016). Third, the release of crayfish, often unintentional, has already had very clear ecological and economic effects, and they are usually bad ones (Gherardi et al., 2011; Twardochleb et al., 2013). These negative effects include the introduction of diseases, such as crayfish plague (Mrugała et al., 2015), and direct competition with indigenous species (Lodge et al., 2000). To date, crayfish-caused problems are more severe than yet seen for other decapod crustaceans sold as pets, such as freshwater crabs (Ng et al., 2015) or shrimps (Klotz et al., 2013).

In this paper, I describe the trade in crayfish as pets, discuss the reasons and methods used to study the pet trade, and the regulation and policy issues around the trade.
Many crayfish species are sold as pets

The trade in crayfish has been systematically examined in eight countries, with partial reports in others. There are about 600 known crayfish species in the world (Crandall & Buhay, 2008; Richman et al., 2015), and about 130 crayfish species have been reported as available for sale as pets (Tables 1 and 2). Most of these species originate from North America and Australasia (Chucholl, 2013b; Faulkes, 2015b), which are the hotspots for crayfish biodiversity (Crandall & Buhay, 2008; Richman et al., 2015).

Thirty-eight crayfish species are available in more than one country (Table 1), and the only species not from North America or Australasia are Astacus leptodactylus and Astacus astacus. Germany, the United States, and the United Kingdom have crayfish species sold exclusively in those countries (Table 2), although differences in species availability are probably likely to get smaller over time, as more research on the trade is conducted, and as more species are distributed across borders. It is probably not possible to give an exact number of species in any given market. Several species are sold without a specific name or sold under incorrect names. Indeed, one study found that pet stores never gave scientific names for animals sold, and pet stores were more likely to give incorrect identification than other businesses, such as bait sellers or biological supply companies (Keller & Lodge, 2009). To add to confusion, sometimes the same common name is used for multiple species. For example, both Cherax gherardiae (Patoka et al. 2015a; Patoka et al., 2015c) and Cherax pulcher (Lukhaup, 2015) were sold as “blue moon crayfish.”

Seven crayfish species are sold as pets in more than five countries, roughly evenly split between North American and Australian species. Four species are probably popular pets because of their attractive appearance. Hobbyists strongly prefer brightly colored fish (Macedo-Vega et al., 2014), and there is no reason to expect the same would not hold true for crayfish. Cherax peknyi has a striking natural colour pattern (Lukhaup & Herbert, 2008). Cambarellus patzcuarensis and Procambarus alleni sold in the pet trade are available in bright coloured morphs that are dramatically different than their normal, relatively drab, wild type colouration. The orange morph of Cambarellus patzcuarensis appears to be traceable back to a single hobbyist in the 1990s (Dost, 2013), and completely took over the pet niche for this species: the wild type colour, brown, is virtually never available. Procambarus alleni is often available in a bright blue morph. Procambarus fallax f. virginalis is marbled, and is parthenogenetic (Scholtz et al., 2003), which makes them easy to rear and gives them novelty value. Both C. patzcuarensis and P. fallax f. virginalis are small species, which is also attractive to pet owners, since they can fit into smaller tanks, more can be kept in larger tanks, and they are unlikely to attack or harm fish in the same tank (Faulkes, 2013).

The remaining three species—Procambarus clarkii, Cherax quadricarinatus, and Cherax destructor—are also distributed for food-related aquaculture (P. clarkii, Marshall et al., 1988; C. quadricarinatus; Jones, 1995, Garza de Yta 2016; C. destructor, Jerry et al., 2005), and perhaps only secondarily used as pets (Kouba et al., 2014). Nevertheless, colour may play an important role in their transition from plate to tank. Like C. patzcuarensis and P. alleni, P. clarkii also comes in a variety of brightly coloured morphs, including blue, white, and several others, and buyers will pay more for blue morphs (Faulkes, 2015b). The bright red patches on the claws of male C. quadricarinatus may also be a selling point for pet owners.
<table>
<thead>
<tr>
<th>Species</th>
<th>United States (Faulkes, 2015b)</th>
<th>Brazil (Loureiro et al., 2015)</th>
<th>Ireland* (Faulkes, 2015a)</th>
<th>United Kingdom (Peay et al., 2010)</th>
<th>Netherlands (Soes &amp; Koese, 2010)</th>
<th>Germany (Chucholl, 2013b)</th>
<th>Greece (Papavlasopoulou et al., 2014)</th>
<th>Czech Republic (Patioka et al., 2014a; Patioka et al., 2015c)</th>
<th>Slovakia (Lipták &amp; Vízalková, 2015)</th>
<th>Turkey (Turkmen &amp; Karadal, 2012)</th>
<th>Singapore* (Belle et al., 2011)</th>
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Given the recent descriptions of these species, several species names appearing in a short time frame (two descriptions were published while this paper was being reviewed), it would not be surprising if the taxonomic status of some of these species will be revised in the future. Nevertheless, many of these new crayfish are not simply cryptic species of crayfish that were revealed by minor morphological or genetic differences compared to existing species. Procambarus fallax f. virginalis, the asexual form of a species from the southeastern United States, revealed an entirely new mode of reproduction for decapod crustaceans: obligate parthenogenesis that produced genetically identical offspring (Martin et al., 2007). Since its discovery, it has attracted the interest of several labs, and may become a model organism for decapod crustaceans (Vogt, 2008, 2011), much as zebrafish (Danio rerio) became a model laboratory organism for vertebrates (Grunwald & Eisen, 2002), another example of a common
pet being adopted for laboratory research (Maceda-Veiga et al., 2014). Similarly, the new Cherax species, all from the island of New Guinea, are more than 10 cm long and charismatic. The initial announcement of C. pulcher (Lukhaup, 2015) was noted in media worldwide (Blaszczak-Boxe, 2015; Izadi, 2015).

There may be more undescribed crayfish species that are already sold as pets. Chucholl (2013b) and Patoka et al. (2015c) list crayfish in several genera (Cambarellus, Cambarus, Cherax, Hobseus, Orconectes, and Procambarus) that were not identified to species. While some of these may be due to difficulty in identifying existing species, it is also possible that these represent species new to science.

Risk assessment

One of the major reasons for an increase in the papers examining the pet trade in crayfish is due to their releases into the wild, with many species becoming established as non-indigenous populations. The titles of several papers on the pet trade carry ominous overtones, using words such as “invaders” (Chucholl, 2013b), “invasive” (Lipták & Vitázková, 2015), “enemy” (Papavlasopoulou et al., 2014), or “bomb” (Faulkes, 2015a). There are valid reasons for this tone: the effects on non-indigenous crayfish species are consistently and strongly negative (Holdich et al., 2009; Twardochleb et al., 2013). First, crayfish themselves have strong ecological effects. Because crayfish are omnivorous, non-indigenous crayfish can significantly change ecosystems by consuming plants (Chambers et al., 1990; Chucholl, 2013a) and smaller prey animals (Nunes et al., 2010; Gomez-Mestre & Diaz-Paniagua, 2011; Klose, 2011; Chucholl, 2013a; Hansen et al., 2013; Nunes et al., 2014). Non-indigenous species may outcompete native crayfish species (Capelli & Munjal, 1982; Gherardi & Daniels, 2004; Klocker & Strayer, 2004; Nakata & Goshima, 2006; Weis, 2010; Sandra & Karlo, 2012). Second, crayfish act as hosts to other organisms. The best known example is that North American crayfish can act as vectors for Aphanomyces astaci, a water mold that causes “crayfish plague” (Unestam, 1965; Unestam, 1966; Rezinciuc et al., 2016). Aphanomyces astaci causes few effects in North American crayfish species, but is extremely pathogenic to many crayfish species outside North America (Unestam, 1972). There have been outbreaks of crayfish plague in multiple European countries that have caused severe declines in native species (Alderman et al., 1987; Reynolds, 1988; Kozubíková-Balcarová et al., 2014; Chucholl & Schrimpf, 2015). Incidental spread of crayfish plague has even affected Ireland, which has no recorded examples of non-indigenous crayfish in the wild (Reynolds, 1988; Matthews & Reynolds, 1992). Crayfish are also hosts to many other organisms (Moore & Faust, 1972; Mestre et al., 2013) that could be distributed along with crayfish through the pet trade. To date, these small organisms have received less attention as risks, probably because these parasitic or symbiotic organisms are not well studied, and there have not been clear cases of negative ecological effects from most of these organisms.

Introductions of crayfish via the pet trade

Crayfish have been introduced into natural ecosystems in multiple countries (Holdich et al., 2009), with the most notable cases in western European countries. Since 1980, at least seven crayfish species have been introduced into European countries, with the pet trade suspected as one of the main sources of introduction of new non-indigenous crayfish species (Holdich et al., 2009; Chucholl, 2013b; Kouba et al., 2014), including C. destructor, C. quadricarinatus, P. alleni and P. fallax f. virginalis (Chucholl, 2013b). Although the pet trade may not be responsible for the introduction of Orconectes immuris or P. clarkii in Europe (Chucholl, 2013b), it may have contributed to
their later spread (Kouba et al., 2014). Mar-morkrebs are a particularly interesting case, because there is a fairly clear timeline from their discovery as a new parthenogenetic form of Procambarus (Scholtz et al., 2003) to discoveries of single individuals in the wild (Nonnis Marzano et al., 2009; Martin et al., 2010b) to discoveries of established populations (Chucholl & Pfeiffer, 2010; Chucholl et al., 2012; Chucholl, 2014).

Outside of Europe, the introduction of C. quadricarinatus in Singapore (Belle et al., 2011) and P. clarkii in Brazil (Loureiro et al., 2015) were clearly linked to their sale as pets. The release of pets was suggested as one possible route for an introduction of C. quadricarinatus in Israel (Snovsky & Galil, 2011), but there was no strong evidence to separate that possibility from others (e.g., escape from aquaculture).

In North America and Australia, there are few well-documented cases of non-indigenous crayfish from other countries establishing populations from release from aquaria. Instead, more issues arise from the translocation of crayfish that could considered indigenous at a large scale (e.g., at a national or state / provincial level) across watersheds (DiStefano et al., 2009; Keller & Lodge, 2009; Coughran & Daly, 2012; Leland et al., 2012). The exact reason(s) people might have transported crayfish into new areas are often not discernable (Coughran & Daly, 2012), but could include pet keeping, using crayfish for bait (DiStefano et al., 2009; Keller & Lodge, 2009), or human consumption (Coughran & Daly, 2012; Leland et al., 2012).

Risk assessment techniques

“Risk assessment” covers a wide range of practices, and understanding the pet trade informs what species of crayfish need risk assessments, and helps to estimate the propagule pressure for each species.

The availability of a species in the aquarium trade can be assessed quickly by using public information, such as visiting retail stores or monitoring sales websites. Availability of a crayfish species was one of two key predictors of whether that species was introduced into the wild (Chucholl, 2013b). The availability for sale may be a reasonable proxy for the number of crayfish owned, although that a species is readily available does not always mean it will be frequently purchased (Faulkes, 2015b).

While understanding which species are available in the pet trade is reasonably straightforward, estimating propagule pressure is more complicated. In theory, propagule pressure from the pet trade should be zero: crayfish should be contained by their owners. This is not borne out in practice, unfortunately, because people deliberately or accidentally release crayfish into natural habitats. Thus, more realistic estimates of propagule pressure might consider the number and distribution of owners, and, perhaps most critically, the behaviour of owners, including how many crayfish they own.

Species distribution models are one risk assessment tool that can include the number and distribution of owners, and perhaps, in a very indirect way, their behaviour. In brief, a species distribution model uses the known distribution of a species to generate variables describing where the species lives, from which the potential distribution of the species in other locations are predicted (reviewed in Feria & Faulkes, 2015). Species distribution models have the advantage of being explicit, quantifiable models. Some species distribution models incorporate a “socioeconomic development” index or “economic drivers” (Gallardo & Aldridge, 2013; Chucholl, 2014), and these may be a reasonable proxy for the probability that crayfish would be released by pet owners. Economic development tends to be associated with high population density, which in turn is correlated with number of non-indigenous crayfish species in Europe (Perdikaris et al., 2012). Urban
centers are more likely to be near airports, ports, and other major entry points for imports. Economically developed communities are more likely to have disposable income to spend on hobbies such as pet keeping.

The behaviour of pet owners is more difficult to assess. For example, one aspect of owner behaviour that is relevant to risk assessment is how owners decide to contain crayfish. While many papers tend to use “pet trade” & “aquarium trade” interchangeably, not all crayfish are kept in indoor aquariums. Crayfish are sometimes kept in outdoor ponds (Soes & Koese, 2010; Patoka et al., 2014b), which creates a possibility not faced with most fish. Several crayfish species can, and do, walk over land to migrate to new bodies of water (Williams & Hynes, 1976), including staple species in the pet trade such as *P. clarkii* (Penn, 1943; Cruz & Rebelo, 2007; Chucholl, 2011; Ramalho & Anastácio, 2015), *P. fallax f. virginalis* (Chucholl et al., 2012), and *C. destructor* (Olszewski, 1980; Coughran & Daly, 2012). The most critical element of owner behaviour is the likelihood that owners would release crayfish into natural habitats. Two independent studies showed that about 6–7% of aquarium owners released fish into natural habitats per year (Gertzen et al., 2008; Strecker et al., 2011). It seems a reasonable assumption that a similar percentage would release crayfish. Patoka et al. (2014b) found 3.6% of crayfish owners released them, either into natural habitats (2.1%) or the sewers (1.5%). While most surveys show people support prevention of invasive species (e.g., Chang et al., 2009; Bohman & Edsman, 2011), about 70% of the releases are associated with convenience, rather than consideration of the environment (Drake et al., 2015). However, about 30% of risky behaviour is unpredictable (Drake et al., 2015).

Another major tool for assessing risk of introduced crayfish is the Freshwater Invertebrate Invasiveness Scoring Kit (FI-ISK), which has been often used for crayfish (Tricarico et al., 2010; Gherardi et al., 2011; Chucholl, 2013b; Papavlasopoulou et al., 2014; Patoka et al., 2014a; Loureiro et al., 2015). The FI-ISK assessment focuses on the biology of the species being assessed, but two of its 49 questions are, “Is the species adapted for aquacultural or ornamental purposes?” and “In its naturalised range are there impacts to aquaculture, aquarium or ornamental species?” Thus, understanding the pet trade is a small but important part of using this risk assessment tool.

### Methodology of studying the pet trade

Many studies of the pet trade in aquatic animals are conducted by biologists who are interested in the organisms being collected and sold, rather than by economists who are interested in the economics of the pet trade’s grey market. Because of this, there are a wide variety of approaches to studying the trade of aquatic species, and they are not standardized or tightly integrated. The methods used to study the pet trade are intimately linked to the stage in the supply chain being examined. The vast majority of papers study just one, or at best, a small number of steps in a lengthy supply chain. To the best of my knowledge, no aquatic organism in the pet trade has been well studied throughout its supply chain, from source to final owner.

### Contact with breeders and collectors

There are two possible sources for pet animals: they can be bred in captivity or collected from the wild. The source of aquatic organisms for the pet trade varies substantially within different branches of the aquarium trade, and on a species by species basis. Few papers in the scientific literature systematically describe aquatic animal suppliers, and studying the sources of animal supply would probably require interviews with suppliers, which would constitute human research and require institutional review.
and approval. The term “captive breeding” covers a wide array of practices. At one end, an individual hobbyist might give away surplus individuals to a friend, or advertise on a website or local classified ad (Faulkes, 2010). At the other extreme, there may be massive breeding programs to provide enough animals to meet needs for national chains, as retailers do not breed their own supplies (Keller & Lodge, 2009). Such large scale breeding programs are properly described as aquaculture.

About 90% of fishes in the freshwater aquarium trade are bred in captivity (Olivier, 2001; Tlusty, 2002; Whittington & Chong, 2007), which might suggest most crayfish are bred rather than collected. There is only preliminary research on how many individual crayfish of different species are bred through these various techniques. Logically, two of the most abundant species in the pet trade worldwide, *P. fallax* f. *virginalis* and *C. patzcuarensis*, must be bred in captivity (Faulkes, 2015b). There are no known indigenous populations of *P. fallax* f. *virginalis* (Martin et al., 2010a). The orange morph of *C. patzcuarensis*, which is by far the most common morph available in the pet trade (Chucholl, 2013b; Faulkes, 2015b), apparently originated in captivity (Dost, 2013), and is probably very rare in nature. In the Czech Republic, about 95% of crayfish are locally produced (Patoka et al., 2014a). Although several North American species of crayfish are imported into the Czech Republic, none of them came from North America (Patoka et al., 2015c), suggesting these are bred in captivity, probably in Asian countries (Patoka et al., 2014a; Patoka et al., 2015c).

**Exploiting natural populations of crayfish**

In the marine aquarium trade, organisms are often taken from the wild, and collecting practices are often not sustainable (Rhyne et al., 2009), raising the possibility that collection of for the pet trade may threaten natural populations of crayfish. Several crayfish harvested for the pet trade have an unknown distribution, and they may be very restricted. This was noted for many of the most recent species descriptions, such as *C. pulcher* (Lukhaup, 2015) and *C. gherardiae* (Patoka et al., 2015a). *Cherax peknyi* appears to be predominantly collected from wild populations (Lukhaup & Herbert, 2008), and its distribution has not been well described.

For crayfish caught for the pet trade, several important questions remain unanswered, including how many crayfish are collected from the wild, how businesses decide which organisms to breed for commercial sale, how they develop care and breeding regimes, and how many individuals they breed.

**Import permits**

Most nations regulate and record the import and export of goods across their borders through customs forms. Several researchers have attempted to estimate the volume of trade by examining import and export permits (Rhyne et al., 2012; Patoka et al., 2015c). A major advantage of this is that it can help identify the sources of species in the pet trade, at least at the national level. It also allows an estimate of the volume and value of animals intended for trades. These declaration forms and invoices also have significant limitations and problems, primarily because the systems were not designed with the intent of monitoring wildlife trade (Rhyne et al., 2012). First, there is little information on these forms about what species are being imported or exported; in one case, one code (“marine aquarium tropical fish”) could apply to thousands of species (Rhyne et al., 2015). Second, the forms are not easily accessible (Balboa, 2003), so getting, reading, and analyzing them is labor intensive. Third, shipment manifests may have a wide variety of mistakes (Chucholl, 2013b; Rhyne et al., 2015). Fourth, customs declarations cannot, by definition, record any sales of animals that...
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occur without crossing a border; that is, domestic production. Such direct, person to person distribution was a significant pathway for people to acquire Marmorkrebs (Faulkes, 2010). Fifth, these forms cannot track any illegal transport of pets.

Using customs forms, Patoka et al. (2015c) tracked a steep increase in the number of individual crayfish imported into the Czech Republic over a decade, and a shift in the source of those animals, from China to Indonesia. For example, crayfish bred in Indonesia may be imported in the Czech Republic before being exported again to Germany (Patoka et al., 2015c), emphasizing the roundabout path a supply chain may take.

Contact with retailers

Retailers, whether operating through storefronts, local pet fairs, or aquarium clubs, may be the only point of contact between the supply chain and owner. As such, they are in a unique position to influence and educate pet owners. Stores present both public information, but many policies and practices are not readily observable, and are better investigated by directly questioning employees and managers. Because such interviews are research with human subjects, they also require institutional review and approval (e.g., from an institutional review board). Further, some stores are unwilling to discuss their business models (Faulkes, 2015b).

Retail stores span a wide range of businesses, ranging from independently owned businesses to large national retail chains. Store surveys for fish showed differences between store types: chain stores were more likely to have species identification of fish being sold, and those identifications were more likely to be correct (Chang et al., 2009).

Online advertisements and website usage

Increasingly, there is a perception that the Internet is the source of many sales of aquatic organisms, although in reality face to face interactions may be the source of more transactions (Faulkes, 2010). Examining online stores, auction listings, and giveaways has the advantage of usually being public information, therefore more readily verifiable. Surveying online websites are unlikely to be able to provide as good estimates of the total number of individuals sold compared to customs forms, but may be able to provide more detail about the number of different species available, and the relative proportions of the species being sold (Kay & Hoyle, 2001; Chucholl, 2013b). The number of online ads can be a predictor of the likelihood of introduction (Kikillus et al., 2012).

Collecting data from public websites permits passive observation; that is, online users are unlikely to change their behaviour because they are being observed by scientists. It also has the potential to show the behaviour of buyers rather than sellers. The ready supply of some species may not be met with much interest from owners, reflected in either sales or prices paid (Faulkes, 2015b).

A related way to examine interest in a pet species is to monitor website traffic. Several tools allow domain owners to track the number of visitors and their geographic location (Faulkes, 2013). For example, the number of visitors from American states and Canadian provinces to a blog about Marmorkrebs was significantly correlated with the number of Marmorkrebs owners in those jurisdictions (Fig. 1). This might allow early detection of crayfish ownership, which could then inform monitoring.

One limitation of monitoring online sales websites is that it may be difficult to compare different websites, particularly in different jurisdictions. For example, two classified advertising websites, the American site Craigslist and the Canadian site Kijiji, have been used to sell crayfish (Faulkes, 2013), but differences in population and website traffic would need to be accounted for before the relative risk of crayfish distribution in the two countries could be compared.
Owner surveys

Owner surveys require contacting owners, who must be willing to volunteer to be interviewed. Such interviews also require institutional review and approval.

Marmorkrebs owners surveyed (Faulkes, 2010; Jimenez & Faulkes, 2010) provided information about owners’ care regimes (Jimenez & Faulkes, 2010). The latter has the potential to be particularly valuable, as there is often little research by professional scientists on the optimal conditions for rearing and breeding crayfish in captivity. Rhyne (2010) recommended that scientists do more empirical research on the breeding conditions of species that are likely to be heavily exploited for the pet trade, because it is preferable to have a strong captive breeding program than to put continual collection pressure on a wild population. For example, *C. pulcher* would probably benefit greatly from having well documented care techniques, because their bright colours make them attractive to pet owners, creating a potential demand that would probably most likely be met with collection from the wild.

Because its range is unknown, but potentially very small (Lukhaup, 2015), it could be vulnerable to over collection for the pet trade.

**Legislation and education about crayfish as pets**

The regulations concerning crayfish trade are inconsistent across jurisdictions, hard to find, receive minimal enforcement, and are rarely enacted until after a problem occurs (Peters & Lodge, 2009). In North American states and provinces, the use of crayfish as pets was generally subject to less regulation than selling crayfish for bait, using crayfish for angling, or aquaculture (Peters & Lodge, 2009). Consequently, there are many examples of pet crayfish being found in regions where importing or owning them is illegal (Peay et al., 2010; Faulkes, 2013, 2015a, b; Magalhães & Andrade, 2015).

As noted above, the two main concerns for crayfish are the pressures on local populations from collecting for the pet trade, and introductions from the release of pets, and there are laws that try to address both of these, though not necessarily in the same jurisdiction. In most cases, general legislation relating to threatened or endangered species could be invoked to protect natural populations of crayfish from pet trade collecting. Nevertheless, illegal collection of indigenous crayfish for ornamental purposes definitely occurs (Patoka et al., 2014b). Few jurisdictions attempt to regulate the export of crayfish; exceptions include Australia (Horwitz, 1990) and the American state of Georgia, whose rules were specifically intended to limit export of crayfish for the pet trade (Skelton, 2010). More legislation concerning crayfish is geared towards preventing introductions, usually by restricting imports (Edsman, 2004; Peay et al., 2010; Faulkes, 2013), although some jurisdictions attempt to regulate ownership or release (Faulkes, 2013). Legislating the trade in animals falls on a con-
tinuum from restrictive to permissive. At one extreme, legislation might make trade of all crayfish species illegal, unless a species is cleared (a “white list” approach) (Reaser et al., 2008). For example, *C. quadricarinatus* has been white-listed for sale as pets in England and Wales (Peay et al., 2010). An advantage of this approach is that it puts the burden of proof on those who wish to import the species to provide reasonable evidence that a species is unlikely to establish populations in a region (Peters & Lodge, 2009), perhaps using standardized risk assessment tools like FI-ISK (see above). At the other extreme, the trade of all crayfish species might be completely unregulated, unless a species is specifically prohibited (a “black list” approach). The latter approach is probably more common due to political pressure from vested interests in the pet trade, but may be less effective in preventing unwanted introductions (Reaser et al., 2008).

A significant impediment to any legislation between these two extremes is the lack of people with the expertise to identify crayfish correctly (Peters & Lodge, 2009). Suppliers and retailers are often unable to identify the aquatic species they sell (Chang et al., 2009; DiStefano et al., 2009), even if there are legislative requirements to know what species is being sold. For example, 97% of bait shops in the American state of Missouri surveyed were unable to identify which crayfish species they sold, although state law specified that only four species were allowed to be sold for bait, meaning that retailers could not know if they were compliant with the regulation (DiStefano et al., 2009). That many species were found in the pet trade, described above, is also indicative of the low level of interest in identifying animals for sale.

Several authors and organizations have argued for trade controls (Belle et al., 2011), including the leading professional society for the study of crayfish, the International Association of Astacology (1987). The effectiveness of trade regulations is still uncertain. In Sweden, creating trade legislation to make the introduction of signal crayfish (*Pacifastacus leniusculus*) illegal took years (Edsman, 2004), but illegal introductions of *P. leniusculus* remained a significant threat to native crayfish populations after the legislation took effect (Bohman & Edsman, 2011). In Brazil, the availability of *P. clarkii* in the pet trade was seldom significantly reduced after import of the species was made illegal (Magalhães & Andrade, 2015). Trade regulations seem better suited to regulate large businesses, such as those aimed at providing crayfish for food, aquaculture, or large retail chains, rather than hobbyists selling through the Internet. It is clear that some people keep or sell crayfish as pets despite laws in their jurisdiction (Faulkes, 2013; Patoka et al., 2014b; Faulkes, 2015a; Magalhães & Andrade, 2015), so it is not clear whether regulations aimed at individual owners are effective. Thus, limiting unwanted releases of pet crayfish may require substantial consumer awareness and education.

While it may seem difficult to convince pet owners that it is not a good idea to keep aquariums, or to restrict the animals they keep to indigenous species, hobbyists can be responsive to environmental concerns (Maceda-Veiga et al., 2014). Pet owner education about crayfish specifically, particularly about release of crayfish into natural habitats, appears to be rare or subsumed under more general education efforts about responsible pet ownership or aquarium ownership. While there are some education efforts concerning crayfish (e.g., Reynolds & O’Keeffe, 2010), there does not appear to be any published research on their reach or effectiveness. Additionally, education and outreach to businesses, not just consumers, particularly retailers, may be helpful. Recommendations for fish sold as pets would also apply to crayfish and other invertebrates, such as increasing retail employee awareness, working to improve species identification and labelling, and assessing which species are non-invasive and most
appropriate for use as pets (Chang et al., 2009). While the negative side of a trade in crayfish pets is well documented (unwanted releases), there are benefits to the market for crayfish as pets, both scientific and cultural. Certain individuals (e.g., breeders, retailers) also stand to make economic gains, although the negative economic effects of introductions on the large scale (Twardochleb et al., 2013) may outweigh such individual profits. As noted above, scientific research has been advanced because of the pet trade, including the discovery of several new species and a new mode of reproduction. Greater public interest in and awareness of biology in general can be fueled by people having the chance to observe pets at close range in their own homes (Prokop et al., 2008; Prokop & Tunnicliffe, 2010). To date, the personal impacts of aquarium keeping of animals like crayfish have been little studied. Nevertheless, that people keep, tend to, and rear crayfish voluntarily makes it clear that crayfish can make people happy.

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