Eradication of invasive alien crayfish: past experiences and further possibilities

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Abstract The EU regulation 1143/2014 "On the prevention and management of the introduction and spread of invasive alien species" entered into force on 1 January 2015. On 13 July 2016, the EU list of invasive alien species that require action was adopted. The list includes five different crayfish species. Member states will be required to take measures for early detection and rapid eradication of these species. Except for some eradications performed in the United Kingdom and Norway, there has not been much effort put into eradication of invasive crayfish species throughout Europe. The reasons for this are probably complex and differ between member states. Are the main reasons legislative constraints, ability to eradicate or lack of knowledge and experience? Is eradication of alien crayfish possible and desirable, and what is left to save in Europe? Focus could be put into identifying or creating island populations of special concern and preserve them for the future survival of European native crayfish populations. Eradication measures should be considered as an option in this work. What are the experiences from completed eradication efforts in Europe? Two crayfish eradications have been performed in Norway, and both have been successful. The eradications were performed in locations with several ponds and small streams and performed using the synthetic pyrethroid-based pharmaceutical BETAMAX VET®. Both legislative and funding constraints seem less prominent as successful eradications have been confirmed. Time will show if this trend will spread throughout Europe.

Keywords: crayfish management, invasive alien species, IAS, pyrethroids, signal crayfish

INTRODUCTION

The EU regulation 1143/2014 "On the prevention and management of the introduction and spread of invasive alien species" (<http://data.europa.eu/eli/reg/2014/1143/oj>) entered into force on 1 January 2015. On 13 July 2016 the EU list of invasive alien species, IAS that requires action was adopted. The list includes five different crayfish species, spinycheek crayfish (*Orconectes limosus*), virile crayfish (*Orconectes virilis*), signal crayfish (*Pacifastacus leniusculus*), red swamp crayfish (*Procambarus clarkii*), and marbled crayfish (*Procambarus fallax*) (<http://data.europa.eu/eli/reg_impl/2016/1141/oj>). Crayfish are one of the most successful and widely distributed invasive species in the world (Holdich, et al., 2014). Twenty eight different crayfish species have been translocated from their native range, and seven of them have been identified with invasive potential (Gherardi, 2010). At least ten non-native species of crayfish have been introduced to Europe (Souty-Grosset, et al., 2006). The five indigenous European freshwater crayfish species are all threatened by different factors, but the most detrimental is probably the North American signal crayfish *Pacifastacus leniusculus* and the crayfish plague caused by the oomycete parasite *Aphanomyces astaci* (Holdich & Sibley, 2009). Signal crayfish are natural hosts for the crayfish plague (Unestam, 1972), the causal agent of crayfish plague, and a disease lethal to European freshwater crayfish (Alderman, et al., 1990; Souty-Grosset, et al., 2006), causing dramatic population reduction and in many cases extinction (Holdich, et al., 1999). The signal crayfish exhibits a number of biological adaptions which allow it to tolerate extreme environmental conditions (McMahon, 2002). This flexibility may facilitate the further spread of both he crayfish and the crayfish plague.

The EU regulation on invasive alien species includes restrictions on keeping, importing, selling, breeding and growing listed species. Taking action as early as possible and preventing introduction will ensure that unnecessary suffering of animals is avoided and is more cost effective than eradication. On the other hand, member states will be required to take measures for early detection and rapid eradication of listed species. If a new population is detected there is an eradication obligation, whereas for widely spread species management measures must take place. The list mainly contains species already present in the EU, but future updates are expected to introduce more species not yet present in the EU. Member states select the measures appropriate to the local conditions and do not have an obligation to eradicate IAS of Union concern that are already widely spread in their territory.

Throughout Europe there have been several attempts to eradicate different crayfish species. Reviews of possible methods for controlling nuisance populations of alien crayfish are available (Holdich, et al., 1999; Hiley, 2003; Ribbens & Graham, 2004; Peay & Hiley, 2006; Freeman, et al., 2010; Stebbing, et al., 2014). These methods include different legislative, mechanical, biological and physical measures, including the use of biocides and pheromones. Mechanical methods, such as trapping, seining, and electrofishing can control, but not eradicate crayfish populations (Holdich, et al., 1999; Hiley, 2003; Peay & Hiley, 2006). It seems that only chemical based treatments offer any hope for effective eradication of invasive crayfish species (Peay, 2001).

Except for some eradications performed in the United Kingdom (Peay, et al., 2006) and Norway (Sandodden & Bardal, 2010; Sandodden & Johnsen, 2010), there has not been much effort put into eradication of invasive crayfish species throughout Europe using chemicals. The reasons for this are probably complex and differ between countries. Are the main reasons legislative constraints, unwillingness or lack of knowledge and experience? Is eradication of alien crayfish possible and desirable, and what is left to save in Europe?

Chemical methods of eradication include the use of biocides, surfactants and pheromones. Ribbens & Graham (2004) review the use of biocides for control of crayfish populations. Organophosphates and organochlorines are reported to be effective, but these chemicals are known to bioaccumulate through the food chain (Holdich, et al. 1999). Crayfish can bioaccumulate organochlorines and, as crayfish are eaten by many predators, this is obviously important in terms of biomagnification through the food

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chain (Ludke, et al., 1971) In contrast, both natural pyrethrum (Pyblast) and synthetic pyrethroids, which have been shown to be effective at very low doses, break down rapidly and do not bioaccumulate (Holdich, et al., 1999; Hiley, 2003; Peay & Hiley, 2006). Synthetic pyrethrum is based on the chemical structure and biological activity of natural pyrethrum, an extract of plants of the genus *Chrysanthemum* (Holdich, et al., 1999).

Eversole & Seller (1997) concluded, in a comprehensive study based on 35 different chemical groups, that synthetic pyrethroids were the most poisonous to crayfish. Both natural pyrethrum and synthetic pyrethroids have low toxicity to birds, mammals, plants and many invertebrates (Van Wijngaarden, et al., 2005). They are, however, in varying degrees toxic to non-target fauna, including crustaceans, insects, arthropods, fish and amphibians (Mayer & Ellersieck, 1986; Burridge & Haya, 1997). The environmental fate and degradation of pyrethroid insecticides were reviewed by Leahey (1979). He concluded that pyrethroids do not persist in the environment for long periods, do not accumulate in the biosphere and do not biomagnify in the food chain. Ecosystem recovery is fairly rapid, with the toxic effect of pyrethroids lasting from days to months, and all major animal groups recovering within a year (Gydemo, 1995). Holdich, et al. (1999) states that ecosystems can recover fairly rapidly from the toxic effects of pyrethroids. Compared to natural pyrethrum the synthetic forms are more toxic, less degradable by light, more readily available and less expensive (Morolli, et al., 2006). To date, no crayfish-specific biocide has been developed.

O`Reilly (2015) suggested that lower concentrations of the natural pyrethrum may be suitable to eradicate or control signal crayfish in small standing waterbodies. Where the risk of damage to non-target species is not an issue and the water is not being used for another purpose, cheaper alternative biocides such as synthetic pyrethroids could be used.

Two successful signal crayfish eradications have been performed in Norway. On the basis of these results and EU regulation 1143/2014, more focus should be put into identifying or creating island populations of special concern and preserve them for the future survival of European native crayfish populations. Eradication measures should and must be considered as an option in this work. The number of eradication attempts probably will increase in Europe as both the knowledge base and environmental impacts increase.

MATERIALS AND METHODS

Both successful eradications were performed in southern Norway close to the capital Oslo (Fig. 1). The locations consisted of several ponds and small streams and involved the application of the synthetic pyrethroid-based pharmaceutical BETAMAX VET®, which is a cypermethrin-based pharmaceutical originally developed for treatment of salmon louse (*Lepeophtheirus salmonis*) infestation of farmed Atlantic salmon (*Salmo salar*). Cypermethrin is a synthetic pyrethroid and a common agent in many insecticides licensed throughout Europe.

Both eradications involved two separate consecutive treatments separated by two weeks and a partial drainage of some of the ponds. The first eradication was performed in the Dammane watershed in Telemark County, during May 2008. The watercourse consists of a creek with five small ponds, the largest measuring approximately 2,000 m^2 (Table 1). The treatment is described in detail in Sandodden & Johnsen (2010). The second eradication was undertaken using the same pharmaceutical, methods and equipment in the Oslo & Akershus County at Ostøya, an island in Oslo-fjord, during October 2009. The treatment involved six ponds on a golf course. The two largest ponds were close to 2,200 m^2 (Table 1). The treatment is described in Sandodden & Bardal (2010, in Norwegian). All ponds were treated with the help of pumps placed in a boat or on the shore (Fig. 2). The chemical was dispersed both on the water surface, along the pond bottom and on a 10 m onshore belt around each pond. Continuous drip stations were placed at the most upstream location of each creek or seep to ensure treatment of the whole drainage basin. This ensured a continuous, constant dosage of BETAMAX VET® during treatment. In the smallest of seeps, enclosed water bodies and small upstream creeks, watering cans were used to dispense a dilution of the chemical. For more details regarding methods, see Sandodden & Johnsen (2010).

The requirements set by the Norwegian Food and Safety Authority for issuing an eradication confirmation after eradication of signal crayfish are described in Johnsen, et al., (2010) and state: 1. No crayfish caught during trapping five to five and a half years after eradication is performed. 2. Noble crayfish (*Astacus astacus*) placed in cages in the treated area have shown no signs of crayfish plague during the last three years of monitoring. 3. Analyses of water and sediments show no sign of crayfish plague spores five to five and a half years after eradication. The methodology is described in Vrålstad, et al., (2009). Based

Table 1 Area, mean depth, volume and BETAMAX VET® used during treatment of the ponds at Dammane and Ostøya locations.

		Area m^2	Mean depth metres	Volume m^3	BETAMAX litres
Dammane	Dam 1	371	0.82	303	0.14
	Dam 2	697	0.92	639	0.17
	Dam 3	1,146	2.27	2,602	1.41
	Dam 4	3,154	1.92	6,054	2.78
	Dam 5	1,346	1.73	1,996	0.57
Ostøya	Dam 14	2,242	3.00	6,726	3.56
	Dam 18	1,400	1.80	2,520	1.33
	Dam 13	990	1.80	1,782	0.94
	Dam 2	2,200	1.80	3,960	2.09
	Dam 1	1,054	1.80	1,897	1.00
	Dam 8	370	2.00	370	0.20

on the investigations involved in eradication confirmation, the Norwegian Food and Safety Authority can issue a self-declaration of freedom of disease (OIE, 2009).

RESULTS

Dammane

No surviving crayfish was observed or found during the second treatment or during drainage of the ponds. On the basis of the Norwegian Food and Safety Authority self-declaration of freedom for disease procedure, the County Governor carried out trials with caged live noble crayfish in 2010 and 2011. In 2010, a total of 31 male crayfish were placed in three cages in three of the treated ponds. The caged crayfish suffered a high mortality during the trials that lasted for 136 days. Analyses performed at the Norwegian Veterinary Institute showed that the cause of death was not crayfish plague. In 2011, a total of 30 male crayfish were placed in three cages in two of the treated ponds. The caged crayfish suffered a high mortality during the trials that lasted for 129 days. Analyses performed at the Norwegian Veterinary Institute showed that the cause of death was not caused by crayfish plague. In 2011 a trapping trial for crayfish was carried out in two of the treated ponds. No crayfish were caught.

Regarding eradication confirmation, the Norwegian Food and Safety Authority concluded on the basis of these results in December 2011 that they could either issue an eradication confirmation based on the results alone or carry out trials with caged crayfish for another year. The relatively new method using molecular investigations based on water samples in search of crayfish plague spores might be carried out as an addition, but the more realistic approach would be caged crayfish trials. The Norwegian Food and Safety Authority's final advice was to issue an eradication confirmation based on the results given in Dammane. They have not yet issued a formal letter or report declaring eradication confirmation (Jan Egil Aronsen, Norwegian Food and Safety Authority pers. comm., 2017).

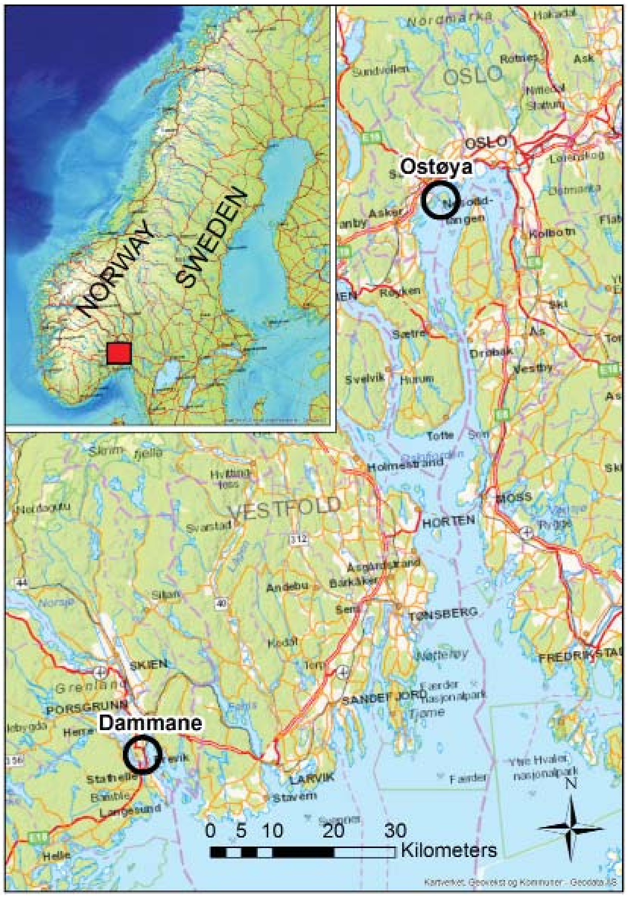

Fig. 1 Dammane and Ostøya locations in southern Norway.

Ostøya

No surviving crayfish was observed or found during the second treatment or during drainage of the ponds. The County Governor carried out trials with caged live noble crayfish in 2013 and 2014. Cages were placed in five of the treated ponds. No signs of disease or crayfish plague were detected. In 2014 a trapping trial for crayfish was carried out. No crayfish were caught. In June 2014 the Norwegian Veterinary Institute collected water samples for analyses of crayfish plague spores in two of the treated ponds (unpublished data). No spores were detected. On the basis of these results the County Governor concluded that the signal crayfish and the crayfish plague is eradicated form the infected ponds. These are unpublished results but summarized in a letter from the County Governor dated 17 March 2017 (ref. 2017/1978-1 M-NA).

DISCUSSION

What is left to save in Europe?

There are still significant native crayfish populations in Europe, which are being decimated through the spread of introduced invasive non-native crayfish (Gherardi, et al., 2011). Action to control invasive non-native crayfish would protect these rare and valuable species. Equally, the impacts from invasive non-native crayfish are wider, ranging from damage to river and flood defence banks (Guan, 1994), through to impact on recreational fisheries. So, there is a case for action based on both ecological and socio-economic factors.

Is eradication of alien crayfish possible and desirable?

As this paper shows, there are possibilities for crayfish eradication. We have the scientific evidence base regarding the species, their risks and impacts; we have the processes to make a robust case, tools, techniques and expertise to take action and now the powers under EU IAS regulations to make that a reality. It is possible to make robust cases to government and only by doing this can we tackle the final funding barrier. Reporting successful eradications should both inspire and motivate future eradication projects. To justify the use of chemicals, it is important to conduct and report the environmental impacts following the eradication attempts and evaluate these in comparison to not taking action.

Fig. 2 Boat mounted pump used to apply BETAMAX VET® during the Dammane and Ostøya treatments.

Lack of eradication projects

The answer to why there have been no eradication projects until now is probably mostly a combination of legislative constraints and lack of experience. Not all European countries are EU- members and most European countries have national legislation regulating the use of chemicals in freshwater. Both local and national regulatory agencies seem not to know where to start and which legislation to apply when trying to implement an eradication strategy involving chemicals. The answer to why not in future is, while complex, now only down to making a strong case to secure political backing and funding to take eradications forward.

Legislation is now a reason for crayfish control

To date, legislation has probably been one of the greatest constraints. Many countries lack effective legislation to carry out pro-active management/control of invasive non-native crayfish species. Legislation controlling import and trade of crayfish species, as well as introduction to the wild has, on the other hand, existed in several European countries (Edsman, 2008; Holdich & Sibley, 2009; Stentiford, et al., 2010), although there is no international regulatory framework for the trade of live animals (Chucholl, 2013). At least in principle, legislation has prevented introduction, and controlled exploitation to reduce risk of spread. Legislation to allow action to control spread or attempt to eradicate once invasive crayfish have been illegally introduced has been missing in many countries. That has all changed with the introduction of the EU invasive alien species regulations, which provide member states with mechanisms to issue Species Control Orders, and the powers behind them to take direct action to eradicate high risk invasive species. We have yet to see how this regulation will be enforced.

Ability to eradicate

Where the threats have been recognised, there seems to have been willingness to take action within the regulatory agencies and conservation bodies on the ground. However, that has been hampered by the lack of legislative powers, scientific evidence base and funding. This has been combined with a lack of public will (and therefore pressure on government) to take action. In most cases, the impacts from invasive crayfish species were not seen or understood by the general public.

Lack of knowledge?

This has probably been an important reason for not performing eradications. Lack of knowledge has been in three main areas: 1. a clear understanding of the species biology, impacts and risks; 2. leading on from this, an understanding of recognised processes such as risk assessments, risk management assessments, invasive species action plans etc. to build a robust case for action; and 3. a lack of knowledge regarding effective tools and techniques to translate that into action. Most of these areas we have now largely addressed or are working to do so. When a bigger experience base has been built more countries probably will try to address the legislative and funding issues necessary to reduce the detrimental effects of invasive non-native crayfish.

Lack of experience?

Historically this has been a factor. Biocide based programmes have only fairly recently become an alternative. Conventional means to manage aquatic invasive fish and crustaceans have been netting, trapping, electrofishing, draining waterways and liming etc. All of the above methods have been trialled to attempt eradication of invasive alien crayfish, but none have achieved more than population reduction (Peay, 2001). Eradication has not been feasible using conventional methods and long-term control is not financially or operationally sustainable, because of the costs associated and work load necessary. As in Norway, that is now changing, and the expertise, tools and techniques we have developed for application of rotenone-based pesticides are directly transferable to application of biocides (synthetic or natural pyrethrins) for crayfish management. These methods have been trialled and found to be very effective if applied correctly (Sandodden & Bardal, 2010; Sandodden & Johnsen, 2010). Total eradication of invasive alien crayfish in Europe is no longer feasible, but emphasis should be placed on sustaining viable island populations of native crayfish and creating new ones. Eradication programmes should be made an option throughout Europe during identification and establishment of suitable island populations and areas. Knowledge and experience to carry out successful crayfish eradications exists. The new EU regulation 1143/2014 is a new tool for securing necessary local legislation and funding.

CONCLUSION

There seems to be an increase in governmental willingness in Norway to conduct chemical eradications when projects are feasible and have acceptable short term environmental impacts. The opportunities for successful eradications should be weighed against not only the environmental impact but also the size and complexity of the waters holding the introduced species. Both legislative and funding constraints seem less prominent as successful eradications have been confirmed. Time will show if this trend will spread throughout Europe.

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