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| <p>Institution: Queen's University Belfast</p> |
| <p>Unit of Assessment: 7</p> |
| <p>Title of case study: Saving Freshwater Pearl Mussels from Extinction through Captive Breeding</p> |
| <p>1. Summary of the impact (indicative maximum 100 words)</p> <p>UK Species Action Plans (SAP) and selection of Special Areas of Conservation under the EC Habitats Directive for declining populations of the critically endangered freshwater pearl mussel <i>Margaritifera margaritifera</i> were informed by QUB research. As an element of the Northern Ireland SAP, in 2009 about 350 mussels produced in a unique captive-breeding facility at a fish farm were released into a river where mussels face extinction. Up to 99% of released mussels survived and a further 240 additional juveniles were released in 2013. This approach complements policy for habitat restoration through catchment management, was a first in Europe and is now being emulated for endangered populations in Austria.</p> |
| <p>2. Underpinning research (indicative maximum 500 words)</p> <p>Context: Freshwater pearl mussels (<i>Margaritifera margaritifera</i>), which can live for over 100 years, have a life cycle phase parasitic on fish gills and require clean water. Large populations of mussels, which can help maintain river water quality, have or will shortly become extinct in parts of Europe and North America due to impacts such as pearl-fishing and siltation from land drainage and run-off from agriculture and forestry. The species is included in Annexes II and IV of the EC Habitats Directive (92/43/EEC) and Appendix II of the Bern Convention. Failure of EU member states to protect remaining populations risks their exposure to large infraction fines. The freshwater pearl mussel has been described as a flagship species because measures taken to ensure its survival have broader environmental benefits.</p> <p>QUB research: Research on the status and distribution of pearl mussels in the mid to late 1990s evidenced their decline and predicted extinction in the north of Ireland (Dai Roberts with research students Tim Mackie and Colin Beasley).^{1,2} Populations in rivers that historically supported hundreds of thousands of mussels had declined to hundreds or a few thousand, dominated by older individuals, with little evidence of recruitment. Our predictions of local extinctions, based on life expectancies of the youngest individuals, have been reinforced by recent research (Roberts and research student Conor Wilson 2007-2010) modelling extinction trajectories for mussel populations in England, Scotland, Wales and Ireland.⁴ Protection of wild populations of pearl mussels is unlikely itself to lead to natural recovery. In Northern Ireland (NI) both reproduction and habitat are compromised and sufficient improvement is unlikely to occur before the predicted date of extinction.⁴</p> <p>Research by Roberts and researcher Jane Preston on captive breeding of pearl mussels was initiated in 1995, in collaboration with Alan Keys (Ballinderry Fish Hatchery)³. Captive breeding is one of the key approaches to the restoration of endangered species, often seen as the method of last resort. Roberts and co-workers demonstrated that large numbers of young mussels (3,600 in 1999; 19,000 in 2000) could be successfully propagated from a relatively small broodstock under semi-natural conditions³. The system involves infecting trout with mussel larvae, so that larval mussels can complete the parasitic stage of their life cycle in the hatchery, with less than 1% host fish mortality. This pioneering method for cultivation of pearl mussels represents a significant breakthrough in the conservation of this species, intermediate between the release of infected fish into rivers and the intensive cultivation systems developed in continental Europe and the USA for</p> |

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other species of pearl mussels³. Genetic research (Roberts and geneticist Jim Provan with their research groups) in 2007-10 found differences between captive-bred juveniles, their parent broodstock, and mussels from the source river, indicating a loss of genetic variability probably due to founder effects⁶. This issue has been addressed by introducing new individuals to adjust the composition of the broodstock. Habitat suitability modelling (Roberts with ecologist Neil Reid) provided a means by which to select release sites for further reintroductions⁵ where captive-bred mussels were tagged with Passive Integrated Transponders (PIT tags) to follow their survival.

3. References to the research (indicative maximum of six references)

- 1) Beasley C.R., Roberts D. & Mackie T.G. (1998). Does the freshwater pearl mussel *Margaritifera margaritifera* L., face extinction in Northern Ireland? *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 265-272.
- 2) *Beasley C.R. & Roberts D. (1999). Towards a strategy for the conservation of the freshwater pearl mussel *Margaritifera margaritifera* in County Donegal, Ireland. *Biological Conservation* 89: 275-284.)
- 3) Preston S.J., Keys A. & Roberts D. (2007). Culturing freshwater pearl mussel *Margaritifera margaritifera*: a breakthrough in the conservation of an endangered species. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17: 539-549.
- 4) *Wilson C.D. & Roberts D. (2011). Modelling distributional trends to inform conservation strategies for an endangered species. *Diversity and Distributions* 17: 182-189.
- 5) *Wilson C.D., Roberts D. & Reid N. (2011). Applying species distribution modelling to identify areas of high conservation value for endangered species: A case study using *Margaritifera margaritifera* (L.). *Biological Conservation* 144: 821-829.
- 6) Wilson C.D., Beatty G.E., Bradley C.R., Clarke H.C., Preston S.J., Roberts D. & Provan, J. (2012). The importance of population genetic information in formulating *ex situ* conservation strategies for the freshwater pearl mussel (*Margaritifera margaritifera* L.) in Northern Ireland. *Animal Conservation* 15: 593-602.

*References that best indicate the quality of the underpinning research

4. Details of the impact (indicative maximum 750 words)

Our impact on legislation, designations, policy and practice: The incorporation of our research outputs (Sections 2, 3) into policy development and captive breeding of the critically endangered (IUCN Red List) freshwater pearl mussel has benefitted this species and its habitat locally, nationally and internationally. In Europe, Special Areas of Conservation (SACs) are the legal instrument enforcing protection under the Habitats Directive, with a statutory requirement for regular monitoring. Legal protection ensures a direct link between policy and practice as it addresses issues that affect this species, such as over-fishing and habitat deterioration.

Northern Ireland: Our research^{1,2} is cited, with detailed results and ongoing and future activities, in the Northern Ireland Environment Agency (NIEA)'s current *Margaritifera margaritifera* Species Action Plan (SAP).⁵¹ This undertook to establish appropriate culturing programmes for the enhancement of populations in suitable rivers by 2010, and re-establish one extinct population by 2015. Because natural populations are dominated by ageing individuals, captive breeding is required to produce young mussels for restocking rivers. In 1995, the research collaboration between QUB and Ballinderry Fish Hatchery (funded through Department of the Environment Northern Ireland and WWF)³ started using techniques differing from the initial mussel cultivation attempts in the Czech Republic and Germany. Elsewhere in Europe, and in similar programmes for endangered freshwater mussels in the USA, mussels are harvested from host fish and grown in cages.⁵⁸ Our method,

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developed with the Ballinderry Fish Hatchery, releases fish carrying larval mussels into semi-natural containers to grow on, which is less labour intensive, hence cheaper and more practicable.^{S6}

350 nine-year old captive-bred mussels were released between 2008 and 2009 into natural sediments in their natal Ballinderry River where the remnant population consists of <900 mussels. Each mussel was individually PIT tagged and survival rates after three years were very high (99% at some sites). This compares very favourably with survival rates elsewhere of 0-20% after two years, summarized in Table 2 of McIvor and Aldridge's 2008 report for CCW.^{S7} In 2009, the Ballinderry Fish Hatchery Trust won an Association of Rivers Trusts Contribution to Science Award for setting up Europe's first successful freshwater pearl mussel breeding project, with our scientific input. We achieved the NIEA's SAP target of developing an appropriate culturing programme by 2010, which resulted in a policy document for *ex situ* conservation and reintroduction of pearl mussels adapted from the IUCN Guidelines for Reintroductions^{S2}. Our habitat suitability modelling⁶ has identified sites for reintroduction experiments, important progress towards the SAP target of reintroducing an extinct population by 2015.

In 2013, 240 captive-bred juveniles 4-21 mm long, all PIT tagged, have been released to sanctuary sites in the natal river, and an equal number will be placed in specially designed 'mussel-silos' that ensure constant water flow. Our research has contributed to the establishment of sanctuary sites to which mussels from remnant, functionally extinct populations in the same river are moved with juveniles from the captive breeding programme – a novel approach in Europe. Sanctuary populations are used for further captive breeding and release. The Mussel Rescue Project^{S6} runs from 2012-15, with UK Lottery funding (£450k) awarded to Ballinderry Rivers Trust and scientific input from Roberts, Reid, O'Connor and PhD student Rebecca Kyle. It includes catchment-level restoration and contributes to the strategic River Basin Management Plan for the Neagh Bann, as part of the delivery of the EU Water Framework Directive (2000/60/EC).^{S6}

Great Britain: The UK Biodiversity Action Plan (BAP) for *Margaritifera margaritifera*^{S3} cites our work¹ to provide background information on selection criteria for Special Areas of Conservation (SACs). JNCC's policy of selecting SACs^{S4} for *Margaritifera* further cites our research on population sizes and age structure¹, noting that increasing rarity in mainland Europe gives extra significance to UK populations³.

Europe: Our research findings on the rapid and drastic decline of pearl mussels in north-west Ireland², due to poor water quality and high siltation from land drainage and run-off from agriculture and forestry, directly informed Article 11 surveillance under the EC Habitats Directive in the Republic of Ireland^{S5}. Because our captive breeding program¹ is amongst the most successful in reviews of captive breeding techniques^{S7-S8} it is now being emulated in Austria^{S10}, where the pearl mussel is one of the most threatened species, with no natural reproduction. Following the complete failure of all previous attempts at assisted breeding of mussels in the River Waldaist, an 18-year action plan is underway, including use of our captive-breeding techniques and fish hatcheries^{S9}. This began in 2009, funded by the Office of the State Government of Upper Austria.

5. Sources to corroborate the impact (indicative maximum of 10 references)

- S1) NIEA (2005) Northern Ireland Species Action Plan: Freshwater pearl mussel *Margaritifera margaritifera*. http://www.doeni.gov.uk/niea/fwpearlmussel_pdf.pdf
- S2) Wilson C.D., Keys A., Horton M., Moorkens E., Roberts D. & Reid N. 2012. *Protocols for the ex situ conservation and reintroduction of the freshwater pearl mussel Margaritifera margaritifera in Northern Ireland*. Prepared for Northern Ireland Environment Agency Research and Development Series **No. 12/09**. Belfast.
- S3) JNCC (2010) UK Priority Species data collation *Margaritifera margaritifera* <http://jncc.defra.gov.uk/speciespages/437.pdf>
- S4) <http://jncc.defra.gov.uk/protectedsites/sacselection/species.asp?featureintcode=s1029>
- S5) NPWS (2012) Report on the main results of the surveillance under article 11 for annex II, IV and V species (Annex B). http://npws.ie/publications/archive/1029_Freshwater_Pearl_Mussel_assessment.pdf
- S6) The Ballinderry Freshwater Pearl Mussel Rescue Project Conservation Management Plan [2012-2015]
- S7) McIvor A. & Aldridge D. 2008. The cultivation of the freshwater pearl mussel, *Margaritifera margaritifera*. CCW Contract Science Report No: 849, Countryside Council for Wales/Environment Agency, Bangor.
- S8) Thomas G.R., Taylor J. & Garcia de Leaniz C., 2010. Captive breeding of the endangered freshwater pearl mussel *Margaritifera margaritifera*. *Endangered Species Research*. 12, 1–9.
- S9) Csar D., Scheder C. & Gumpinger C. 2012. The freshwater pearl mussel in Austria – current status and prospects for the future. In: Henrikson, L., Arvidsson, B. and Osterling, M. (eds.) Aquatic conservation with focus on *Margaritifera margaritifera*. Proceedings of the International Conference in Sundsvall, Sweden, 12-14 August, 2009. Karlstad University Studies 2012:40. <http://www.wwf.se/source.php/1509189/Proceedings%20FPM%20Conference%20in%20Sweden.pdf>
- S10) Supporting letter from Museo Nacional de Ciencias Naturales (MNCN-CSIC)