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Forest management and freshwater pearl mussels

A practitioners' perspective from the north of Scotland

Most of the world's remaining globally threatened freshwater pearl mussel populations occur in northern European rivers and streams in partially or wholly forested catchments. As a consequence, sustainable forest management in this area has a pivotal role to play in conserving this species and its aquatic habitat. Using recent experiences from the north of Scotland, we report on how targeted practical forest management has been developed and implemented to aid the protection and recovery of this keystone species.

By considering the unique life-cycle of the freshwater pearl mussel, forest management effort in the north of Scotland has been directed towards: (i) establishing the baseline conditions (pearl mussel population status) in forested catchments, (ii) blocking forest drainage ditches to reduce forestry derived siltation and runoff, (iii) managing harvesting in such a way as to minimise impacts on the pearl mussel and its host fish, (iv) instream barrier management and (v) tree restocking/planting.

The management measures are straightforward, very modest in terms of cost and can easily be implemented by forest practitioners. Consideration of this endangered species in forest management is required to comply with a range of policy drivers and, in particular, forest sustainability certification.

Introduction

The freshwater pearl mussel *Margaritifera margaritifera* (hereafter referred to as 'pearl mussel') is a globally threatened species which is classified by the International Union for Conservation of Nature as Endangered in its world range (Mollusc Specialist Group, IUCN 1996). Across Central Europe the population has declined by 95% (Degerman *et al* 2009) and is classified as Critically Endangered in Europe (Moorkens 2011). As a consequence of this decline considerable conservation efforts are now being directed towards this species. The largest remaining populations in Scotland, Ireland, Norway, Finland, Sweden and northwest Russia are of international importance.

The pearl mussel is a long-lived aquatic species and individuals usually have a lifespan of between 100–200 years depending on latitude and environmental conditions (Zuiganov *et al* 2000), but exceptionally up to 280 years in northern Sweden (Dunca and Mutvei 2009). Today, most surviving populations are found in northern European rivers and streams in partially or wholly forested catchments. As a consequence, forest management practices have an important role to play in the global survival of this species. Unfortunately, until very recently forestry management across northern Europe has paid little regard to its impact on pearl mussel populations. Indeed, many pearl mussel rivers have been dredged, damned, polluted and the species' requirements simply ignored (Degerman *et al* 2009). However, due to its conservation listing, interest in restoring degraded ecosystem services and sustainable forest management, there is now growing awareness that such poor approaches to catchment management must stop if the species is not to become extinct.

This paper reports on how targeted practical forest management in the north of Scotland, an area of global importance for pearl mussels (Cosgrove *et al* 2000a), has recently been developed and implemented to aid the protection and recovery of this important keystone species.

THE AUTHORS

Peter Cosgrove*, Donald Shields and Cameron Cosgrove undertook the pearl mussel survey work referred to in the paper. In 2014 they were awarded the RSPB's Species Champion Award for their work on pearl mussels under the auspices of Alba Ecology's *Mollusc of the Glen* project at the Nature of Scotland Awards. Peter is a world authority on the survey methods, ecology and conservation of the freshwater pearl mussels.

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Kenny Kortland is Forest Enterprise Scotland's Species Ecologist and is responsible for reconciling species conservation with other objectives on the national forest estate. He is involved in developing good practice forestry guidance for priority species such as pearl mussels across Scotland.

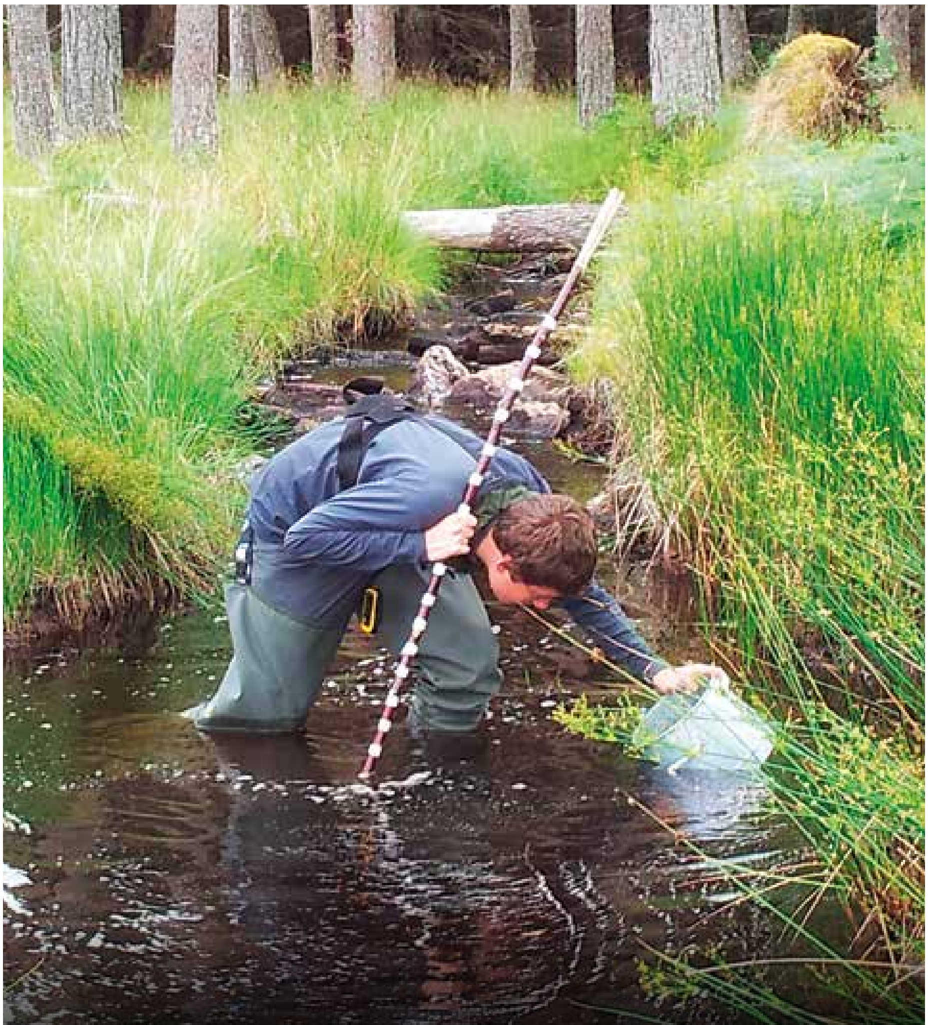

Figure 1: Surveying a small previously unsurveyed watercourse in Catchment A. Pearl mussels were discovered in this watercourse in 2013.

Pearl mussel habitat requirements

The pearl mussel has a unique symbiotic lifecycle that plays an important and significant role in the ecology and economy of many northern European rivers (Cosgrove *et al* 2000b). Pearl mussels are found in fast flowing unpolluted rivers and streams, with detailed studies on Scottish pearl mussel populations suggesting that optimum water depths of 0.3-0.4m and optimum current velocities of 0.25-0.75ms^{-1} at intermediate water levels are most suitable (Hastie *et al* 2000a). River bed substrate characteristics appear to be the best physical parameters for describing pearl mussel habitat in Scotland. Pearl mussels prefer clean, stable cobble/boulder dominated substrates with some fine sandy substrate material that allows the mussels to burrow (Cosgrove *et al* 2000b). Adult and juvenile mussels tend to have similar habitat 'preferences', although adults are found over a wider range of physical conditions and juveniles are more exacting in their requirements and sensitivity to environmental disturbance, pollution and silt (Hastie *et al* 2000a). Juvenile mussels require fine stable sediments, particularly clean, well-oxygenated sand and gravel. Of specific importance to pearl mussel survival are levels of silt, suspended solids, biochemical oxygen demand, calcium and chemical compounds generally associated with nutrient enrichment (eutrophication) i.e. nitrate and phosphate (Bauer 1983). In Sweden, Norway and Finland, acidification is also considered a major ongoing problem (Degerman *et al* 2009).

Pearl mussel host requirements

Pearl mussels have a short parasitic larval phase on the gills of suitable native host salmonid fish. The larvae (called glochidia) of pearl mussels are host-specific and can only complete their development on Atlantic salmon (*Salmo salar*) or brown/sea trout (*Salmo trutta*). Usually juvenile fish (fry and parr) are utilised (Young and Williams 1984). The presence of pearl mussels in any watercourse therefore depends on salmonid host fish availability and that there is some adaptive matching between local races of fish and pearl mussels (Geist *et al* 2006). Furthermore, declines in host fish populations have been followed by declines in pearl mussel populations within the same catchments (Hastie and Cosgrove 2001). This lifecycle complexity illustrates the many potential threats and pressures that operate within catchments on pearl mussels and why a catchment management approach to their conservation and restoration is required (Moorkens 2009).

Legislative and policy drivers

Several key legislative and policy drivers now influence forest management in Scotland, including the Scottish Forestry Strategy, Scottish Biodiversity Strategy, Scotland River Basin Management Plans, Scottish Landuse Strategy and UK Forestry Standard. What all these have in common is their requirement to significantly improve forest management for multi-purpose public benefits, including specifically, biodiversity conservation.

The international forest products market seeks assurance about the quality, environmental and social impacts of forest management. One way this assurance is provided is through independent verification and certification against published standards which define appropriate sustainable forest management practices. Forest products which meet these standards are easier to market and sometimes gain a premium price compared to products that are not certified. In 2015, the value of Scotland's forestry sector was estimated to be contributing nearly £1 billion to the Scottish economy through forest management, timber processing and recreation (CJC Consulting 2015). Forest Enterprise Scotland (FES) manages Scotland's National Forest Estate, which occupies 9% of Scotland's total land area. All of FES woodland products carry the Forest Stewardship Council's stamp of approval and are certified as 'sustainably produced'. Sustainable management of watercourses and their biodiversity are

Table 1: Forested catchment surveys for pearl mussels in North Highland Forest District 2013-2014.

Catchment	No. of watercourses surveyed	No. of known pearl mussel watercourses within catchment	No. of new pearl mussel watercourses discovered
Catchment A	8	1	2
Catchment B	13	2	1
Catchment C	11	1	0

an integral part of the standards required, although to date, what this entails has not been defined in relation to pearl mussels or indeed other aquatic species.

Water quality issues arising from, among other things, land management, has been, and is, of crucial importance to the status of many Scottish pearl mussel populations. Pollution/poor water quality was identified as a detrimental factor implicated in the decline and extinction of pearl mussel populations in 34 rivers during the first national pearl mussel survey prior to 1998 (Cosgrove *et al* 2000a). More recently, pollution/poor water quality was identified as a specific threat in 31 extant populations, a quarter of all remaining Scottish pearl mussel populations in 2013-2015 (Cosgrove *et al* 2016).

Pearl mussels are fully protected under the Wildlife and Countryside Act 1981 (as amended) and the species is also listed on Annexes II and V of the EC Habitats Directive and Appendix III of the Bern Convention. Despite being fully protected since 1998, large numbers of pearl mussels are illegally killed each year in Scotland by pearl fishers. It is because of this ongoing threat to the species' survival, that the pearl mussel is a UK wildlife crime priority (http://www.nwcu.police.uk/how-do-we-prioritise/priorities/freshwater-pearl-mussels). As a consequence of this, the names and locations of specific pearl mussel rivers are treated as confidential and are not reported here, but are instead coded to protect them from the ongoing threat of wildlife crime.

Study area description

The FES North Highland Forest District, which covers approximately a tenth of Scotland's National Forest Estate, was selected as the study area. It comprises a total of 43,500ha of woodland, 16,464ha of open space, watercourses and bogs, and 3,531ha of farmland (Forestry Commission Scotland 2014). This FES district coincides with the largest concentration of extant pearl mussel rivers in Scotland and the UK (Cosgrove *et al* 2000a). Consequently, North Highland Forest District has led FES efforts to conserve pearl mussel populations on its landholdings on behalf of the people of Scotland.

Forestry pressures

Forest management can directly and indirectly affect pearl mussel watercourses in a number of ways (Törnblom *et al* 2009). Irish Forest Service (2008) research has shown that on some sites with peaty soils, significant amounts of sediment and nutrients can be lost to ditches and small streams during various stages of the forest cycle. The nutrients and suspended solids are then washed down through forest ditches into pearl mussel rivers. The three main sources of in-stream nutrients are: fertiliser, decaying organic matter and sediment. These are delivered to watercourses during forest activities as follows:

- Disruption of the soil surface, causing the subsoil to be exposed to erosion and eventually the transportation of finer particles by overland flow
- Weathering of parent material resulting in particle movement by overland flow
- The transportation of loose or decaying organic particles.

Ring *et al* (2008) reviewed how different forestry operations caused chemical and physical disturbances to aquatic habitats in Sweden. Forestry and forest management activities can influence watercourse morphology, water chemistry, substrate quality, insolation, water temperature, oxygen concentrations, organic materials and nutrient supply. The main losses of nutrients and sediment from forested areas are associated with water moving through forestry sites into a watercourse. Rainfall falling on such sites reaches a watercourse through three main pathways:

- Over surface: Surface run-off tends to occur more frequently on impermeable soils such as peat or heavy clays or on very thin soils over bedrock or iron pans. It is most evident during heavy rainfall
- Through the soil/subsoil: This pathway is associated with highly permeable soils, e.g. brown earths and brown podsols
- Through ditches/channels flowing directly from the forest site to a watercourse. This pathway also includes temporary ditches (in which water may not be permanently present) that may only operate during and immediately after heavy rainfall. Such ditches, which are a legacy of old-fashioned forestry management, can be a chronic problem, conveying nutrients and sediments into watercourses for many years after harvesting.

Figure 2 Freshwater pearl mussel shell length frequencies in new Catchment A population, 2013.

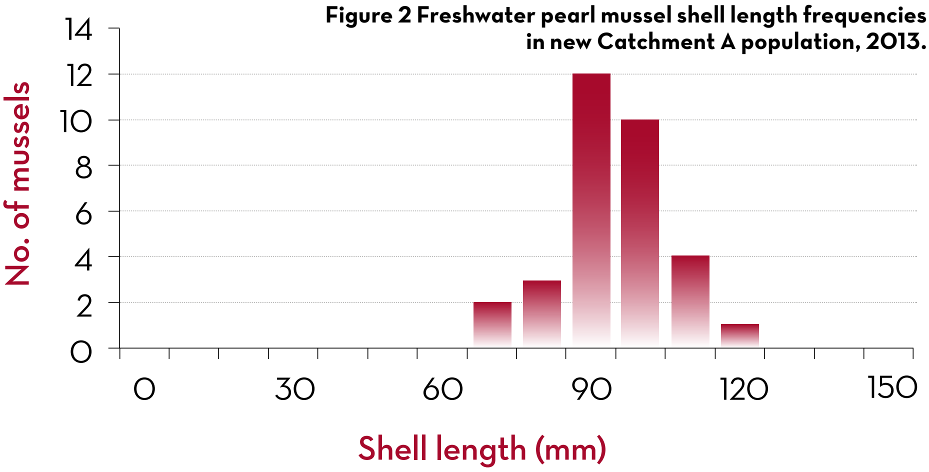

Figure 3: All newly discovered pearl mussel populations within FES landholdings were characterised by adult mussels only, such as these from Catchment A.

Most catchments within the North Highland Forest District are nutrient poor and dominated by peaty soils. Nutrient transfer along these pathways has the potential to adversely affect water quality in pearl mussel catchments and so this is one of the key focuses for FES forest management. Suspended soil (e.g. peat silt) acts to block the interstitial substrate spaces, smothering (and killing) any recently laid host fish eggs and settled or buried juvenile pearl mussels, something the adult mussels are more able to tolerate.

Conservation action: Establishing the baseline

All known Scottish rivers containing pearl mussel populations were systematically surveyed in 1997-1998 (Cosgrove *et al* 2000a) and in 2013-2015 (Cosgrove *et al* 2016). Starting in 2013, FES has conducted a series of targeted pearl mussel surveys of unsurveyed watercourses on its landholdings in North Highland Forest District. The watercourses in most Scottish catchments have not been systematically surveyed for pearl mussels. Consequently, the presence or otherwise of this sensitive species within most forested catchments is not fully understood.

The unsurveyed tributaries of three main river catchments (A, B and C) in North Highland Forest District known to contain pearl mussels were identified by a map study. Those on FES land that were permanently wetted and with potentially suitable gentle gradients were selected for survey under licence, using standard shallow-water survey methods (e.g. Cosgrove *et al* 2000a).

The first of these targeted surveys in Catchment A investigated eight previously unsurveyed tributaries and found two unknown and previously undescribed pearl mussel populations. The second survey discovered one unknown, previously undescribed pearl mussel population in Catchment B, but none were discovered in the third survey in Catchment C (**Table 1**). Although only a limited survey sample (n=32 tributaries), to date a 'new for science' pearl mussel population has been found in approximately one in every ten unsurveyed watercourses on FES ground in North Highland Forest District.

These surveys show the value of establishing systematic baseline data for unsurveyed watercourses in forested catchments. Discovering three 'new for science' populations of this endangered species has helped inform FES forest management plans within these catchments. An important feature of these newly discovered pearl mussel watercourses was their small size (**see Figure 1**). Pearl mussels were found in watercourses which ranged in size from 1.5m wide and 0.2m deep to 5m wide and 0.3m deep.

A sample of pearl mussels was measured and returned in each 'new to science' population and the shell lengths used to construct age/length population profiles. These profiles are used to assess the status of populations and help determine what, if any, pressures are apparent (Bauer 1983; Hastie *et al* 2000b). **Figure 2** provides an example population profile from one of the two new tributary populations discovered in Catchment A. All three newly described populations show the same type of population profile, specifically a complete lack of juvenile pearl mussels (defined as mussels <65mm in length). The population profiles show ageing adult mussel dominated populations (**Figure 3**), with no evidence of juvenile recruitment in the last two decades.

Pressures on these populations are affecting both juvenile pearl mussel recruitment and survival. Survey work in the newly discovered populations also identified large quantities of peat sediment (silt) covering the substrate, including the majority of pearl mussels and their habitats. The vast majority of this peat sediment appeared to originate from adjacent forest ditches and exposed windthrown tree root-plates.

By way of example, the following sections explain the rationale adopted for forestry management within Catchment C, where the most pressing issues for pearl mussels have arisen due to scheduled harvesting. The management already undertaken (and also planned) for Catchment C provides an opportunity to explore some of the issues faced and how they have been tackled by forest practitioners in relation

Figure 4: Conifer plantings pre-harvesting over Catchment C pearl mussel watercourse, note high levels of suspended soils from forest ditches, 2015.

to pearl mussel conservation and active forest management in North Highland Forest District.

Harvesting

Although surveys within catchment C failed to find any new populations, a full survey of a known population was completed for the first time and hundreds of adult pearl mussels were found in an unsurveyed and densely forested part of the catchment. In this previously unsurveyed part of Catchment C a coupe surrounded the pearl mussel watercourse and comprised circa 30ha of Sitka spruce (*Picea sitchensis*), with components of lodgepole pine (*Pinus contorta*), Japanese larch (*Larix kaempferi)* and Norway spruce (*Picea abies*). It was due to be harvested in late 2015.

When the coupe was planted in the 1960s, it was common practice to plant these species up to the water's edge. Consequently the watercourse was almost entirely overshadowed by conifers and aquatic habitats were severely degraded. Such an approach is contrary to current best practice as outlined in *Forests and Water: UK Forestry Standard Guidelines* (Forestry Commission 2011) and is no longer carried out.

The 30ha coupe was criss-crossed with linear forestry ditches, many of which emptied directly into the pearl mussel watercourse. These ditches carried high to very high levels of suspended solids (mainly peat) into the watercourse, particularly during periods of moderate-heavy precipitation (**Figure 4**). This is detrimental to pearl mussels and their instream habitats, blocking the interstitial spaces in the substrate. The plantings were so dense, and also comprised several areas of storm-damaged windthrown trees, that pre-felling surveys were not possible until a chainsaw team cut a narrow path to facilitate access along the edge of the watercourse. Once a path was cut, surveyors were able to identify the number and location of forest ditches entering the watercourse as well as to quantify the presence of adult pearl mussels throughout the planned felling coupe area. The overhanging and windthrown conifers blocked most light reaching the watercourse and also provided large quantities of needle and cone litter that covered the watercourse substrate, further contributing to the blocking of interstitial spaces, nutrient enrichment and potentially acidification.

Prior to felling, plastic pile dams (similar to those used in peatland restoration projects) were carefully installed across all the forest ditches entering the pearl mussel watercourse (**Figure 5**). The number of dams installed and intervals between them in each forest ditch depended upon the ditch gradient, flow and the professional judgement of FES staff. A total of 20 dams were installed initially and once harvesting began, surveyors monitored the efficacy of dams and, where necessary, installed additional dams within the felling coupe area. Although the plastic dams are expected to gradually degrade over time, experience from peatland restoration projects suggests most should last for decades. In some situations other materials like wood, geotextile membranes and peat may be preferred as dam building materials.

The cost of materials and labour to install the plastic dams within the 30ha felling coupe was very modest and the installation and subsequent checking of dams took only two workers two days to complete (**Table 2**). Targeted ditch blocking will be considered in FES forward work plans, well ahead of planned harvesting in all pearl mussel catchments.

Felling and extraction were carried out mechanically by harvester and forwarder machines, with a 5-10m wide 'no-track buffer zone' along the watercourse. Prior to this work commencing, the forestry contractors received a 'toolbox' talk covering the sensitivity of the watercourse for rare aquatic species and their responsibilities when working

"Scottish forestry practitioners have a vital role to play in securing the future of these important populations"

Table 2: Cost of materials and installation for forestry ditch dams in 30ha coupe, Catchment C, North Highland Forest District 2015.

	Unit	Cost £ (€)
Materials	20 plastic pile damns	£440 (€625)
Labour, initial installation and follow-up checks	30 hours	£600 (€850)

within the catchment.

Several of the windthrown tree root-plates along the watercourse edge had opened up bare mineral soil/peat, which was being eroded away and washed onto downstream pearl mussel habitats (**see Figure 6**). In an attempt to substantially reduce the quantities of suspended peat/soil material entering the watercourse, these upturned watercourse edge root-plates were identified for remediation. The harvester team cut the windthrown trees close to the root-plate and used the forwarder to push the root plate back down, so that bare ground was not open to weathering and associated sedimentation. It is recognised that water erosion along the bank edge may still lift some sediment material from underneath these remediated root plates and deposit it within the watercourse.

Instream barrier management

Although the Catchment C coupe had suffered significant storm damage, which resulted in windblown trees spanning the width of the watercourse, only those trees that were shedding needle litter into the watercourse or providing a barrier to migratory host fish were removed. Many windthrown trees spanning the watercourse were retained for their long-term deadwood interest and to provide cover/shelter for migratory host fish. Furthermore, the windthrown trees identified for retention did not have open, eroding root-plates.

An old redundant weir across the watercourse was discovered within the felling coupe during survey work in Catchment C. The weir was assessed as being impassable to migratory fish under most flow conditions and so was scheduled for complete removal to facilitate host fish passage throughout the watercourse.

Restocking

After Catchment C coupe felling was completed, FES planted riparian woodland habitat (60% native broadleaves, 40% open habitat) along the main pearl mussel watercourse and associated tributaries; width 20-30m on both sides of each watercourse. Native woodland planting in the riparian zone is an important part of aquatic ecosystem restoration, helping to regulate the temperature of the water by providing shade, while falling leaves and insects will eventually provide food for host trout and salmon. Broadleaved trees will eventually also help to stabilise riparian banks.

Similar approaches to riparian management are planned for other pearl mussel catchments in North Highland Forest District, with the exception of all but the most exposed watercourses or those watercourses running across wetland restoration areas. The management approaches illustrated in this paper for Catchment C have begun to be rolled out across other FES pearl mussel catchments in North Highland Forest District. For example, under the Pearls in Peril LIFE+ project, FES has blocked dozens of drains and created riparian woodlands in Catchment A.

Discussion

Of Scotland's 115 (known) extant pearl mussel rivers (Watt *et al* 2015), 38 occur on land owned and managed by FES (33%) and many more are found on privately owned forestry land. Thus, Scottish forestry practitioners have a vital role to play in securing the future of these important populations and, as has been demonstrated in this paper, discovering previous undescribed populations. The peak pressure from pearl fishing in Scotland took place from the mid 1960s, when personal car ownership opened up many remote

Figure 5: Example of a plastic dam installed to block and reduce instream sediment and nutrient enrichment prior to felling 30ha coupe in Catchment C pearl mussel watercourse, 2015.

areas and watercourses to unsustainable exploitation. This time period also coincided with large areas of Scotland being planted with trees and it seems likely that public access to many small watercourses was blocked or made difficult by tree plantings. This may have been fortuitous, preventing pearl fishers from discovering and destroying tributary pearl mussel populations within forestry areas. The downside is that some of these pearl mussel populations clearly remain undiscovered and so at risk from forestry management decisions that do not consider the requirements of pearl mussels.

The recent FES work on pearl mussels in North Highland Forest District has been important and innovative for a number of reasons. Whilst the planting of conifers up to the water's edge no longer occurs in Scotland, the legacy of historically poor management practices (when single purpose policy objectives drove forest planting) needs to be addressed today. The first stage is to understand where rare species such as pearl mussels are within commercial forests. Establishing baseline conditions has helped inform forest management decisions and practices across North Highland Forest District and led to the discovery of three 'new for science' populations of the endangered pearl mussel on FES land and more may follow.

The presence of pearl mussels in one forest area to be harvested within Catchment C provided the opportunity for a range of practical measures to be planned, tested and implemented to help protect pearl mussels and ultimately restore degraded aquatic habitats. Although formal 'before and after' water quality monitoring has not been undertaken, the installation of dams across forest ditches prior to harvesting immediately and dramatically reduced the amount of suspended solids visible within the watercourse. It presumably also reduced associated nutrient enrichment. Such an approach to forest management is considered to be best practice and should be implemented within all forested pearl mussel catchments.

The direct financial costs of the management work undertaken in Catchment C are very small in relation to the overall harvesting and restocking costs and the biodiversity benefits that have accrued. In the context of maintaining the certified status of the National Forest Estate, and delivering significant benefits for pearl mussels and other aquatic biodiversity, the investment in such action represents extremely good value for money. Such proactive conservation management also leads to enhanced reputational benefits within regional frameworks such as the Local Biodiversity Action Plan and among ecological stakeholders both local and national.

Through targeted efforts to remove and reduce sedimentation, it is hoped over time to improve the river bed habitat and restore conditions conducive for juvenile pearl mussel recruitment once again in the felled area of Catchment C. New, innovative methods, tested in Finland and Sweden (Tammela *et al* 2010) using instream deflectors to speed up water flows (which moves loose sediment) in the affected reaches are planned. It is not clear how long such habitat restoration will take before conditions become suitable, but with pearl mussels so long-lived, it is anticipated that successful recruitment will begin again relatively quickly (c. 5 years) as habitats improve. Such a relatively rapid recovery is expected because there is a reasonably substantial recruiting pearl mussel population immediately upstream of the felled coupe. Monitoring of the pearl mussel population, habitat conditions and host fish populations will take place at regular intervals over the next decade and beyond.

There is increasing interest from across Europe in sharing best practice and practical examples of the situations forest practitioners face when working in pearl mussel catchments. Forestry provides a variety of ecosystem services and the examples provided in this paper should help to guide forest managers on how to respond appropriately when faced with management decisions that

Figure 6: Windthrown root-plate identified for remediation in Catchment C pearl mussel watercourse, 2015.

"Monitoring of the pearl mussel population, habitat conditions and host fish populations will take place at regular intervals over the next decade and beyond"

may affect this endangered species. It is recognised that the experiences from North Highland Forest District will not match every situation a forest manager may face. Nevertheless, the approach of establishing baseline conditions in watercourses, which are then used to inform subsequent forest management plans (e.g. harvesting and restocking) within a catchment are likely to be highly beneficial to not only pearl mussels and their salmonid hosts. The 'no regrets' conservation measures outlined in this paper to reduce sedimentation and nutrient enrichment in watercourses, along with native broadleaved riparian woodland creation, will clearly benefit a range of other aquatic and forest biodiversity.

Conclusion

This paper demonstrates how targeted practical forest management in northern Scotland has been developed and implemented to aid the protection and recovery of the endangered pearl mussel. The measures outlined are straightforward, good value in terms of cost and can easily be implemented by practitioners when planning forestry management. Consideration of this important keystone species in forest management is required to comply with a range of policy drivers and, in particular, forest sustainability certification. Failure to do so may jeopardise sustainability certification, with substantial financial consequences for those who ignore important biodiversity and evolving best practice forest management.

Funding

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