THE DECLINE OF MIGRATORY SALMONID STOCKS: A NEW THREAT TO PEARL MUSSELS IN SCOTLAND

LEE HASTIE AND PETER COSGROVE

(Drs L. C. Hastie and P. J. Cosgrove, University of Aberdeen, Culterty Field Station, Newburgh, Aberdeenshire AB4J OAA, Scotland.)
[E-mail: HastieL®abdn.ac.uk]

Introduction

The general decline of the endangered freshwater pearl mussel *Margaritifera margaritifera* (L.) throughout its holarctic range is well documented (Kerney 1975; Young & Williams 1983; Bauer 1986, 1988; Ziuganov et al. 1994). Several reasons have been suggested, including the effects of overfishing, industrial and agricultural pollution, and habitat reduction due to river engineering (Young 1991). Scotland is considered to be a stronghold of *margaritifera,* containing approximately half of the world's known remaining viable populations (Fig. 1) (Young et al. 2001). However, even here the majority of populations have declined and many have disappeared completely. According to Cosgrove et al. (2000a), populations of pearl mussels are now either extinct or no longer viable in almost 70% of historical sites that were occupied 100 years ago. Although remaining populations are now provided better protection by a recent ban on pearl fishing, stronger pollution control measures and restrictions on river engineering activity (Cosgrove & Hastie 2001), the fate of the pearl mussel in Scotland is by no means secure. For example, as explained below, there is concern that recent changes in native salmonid populations may pose a serious new threat to the long-term survival of *margaritifera* in Scotland.

Freshwater mussels have a short parasitic larval phase on the gills of suitable host fish (Fig. 2). The larvae (glochidia) of *margaritifera* are very host specific and, as far as is known, can only complete their development on Atlantic salmon *Salmo salar* (L.) or sea trout and brown trout *Salmo trutta* (L.), usually 0+ fish, i.e. fry in their first year after hatching (Young & Williams 1984; Hastie & Young 2001). Changes in salmonid host populations are not considered to have been a significant factor in the general decline of *margaritifera* over the past 50 to 100 years (Young & Williams 1983; Young 1991). However, although very little is known about the mussel-host relationship, long-term survival clearly depends on host availability, and there is concern that significant changes in wild salmonid stocks may threaten mussel populations (Bauer 1988; Chesney & Oliver 1998; Cosgrove et al. 2000a). According to Ziuganov et al. (1994), a low density of fish hosts can be

FIG. 1. Freshwater pearl mussels. *Above:* adult and juvenile *M. margaritifera* from a stable population in north-west Scotland (photo by B. Henninger). *Below:* a typical bed of pearl mussels (photo by S. Scott). In some rivers these mussel-beds may provide important microhabitats for juvenile salmonids and the aquatic invertebrates upon which they feed.

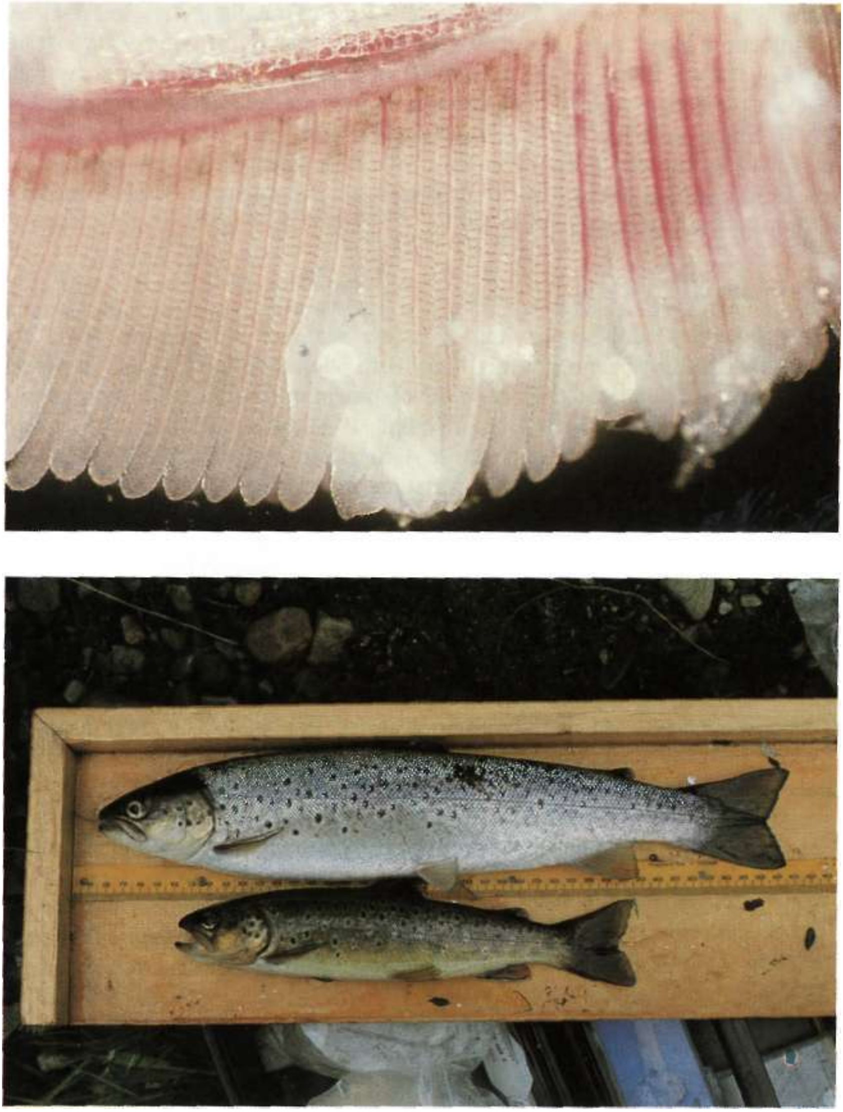

FIG. 2. *Above:* salmon gill, showing encysted glochidia of *M. margaritifera* (photo by M. Young). Natural infestations of glochidia last for several months but do not appear to harm wild fish. *Below:* examples of migratory sea trout (upper) and non-migratory brown trout (lower) (photo by J. Butler).

a limiting factor in some mussel populations. Trout densities lowered by acidification have been implicated in the decline of *M. margaritifera* in Sweden (Bauer 1988). In the north-west of Scotland, several migratory trout stocks have collapsed recently and some salmon stocks are declining (Walker 1993). Since more than 90% of surviving Scottish *margaritifera* populations are found in this area (Cosgrove et al. 2000a), it is important that appropriate research is carried out in order to determine the significance of these changes in terms of pearl mussel conservation.

The salmonid life-cycle

The life-cycles of *S. salar* and *S. trutta* are well known but not fully understood. Both species are migratory fish; adults return to spawn in parent rivers, juveniles undergo their early development in fresh water and pre-adults grow to reproductive size at sea (Walker 1993). A proportion of *S. trutta* populations (that have access to the sea) migrate to feed in coastal waters (sea trout), whilst others, mainly males, mature and remain wholly in fresh water (brown trout). Above natural and artificial obstacles (e.g. waterfalls, dams, polluted reaches), a sex ratio of about 1:1 would be expected for this species (J. Watt, personal communication). Some male salmon also mature and spend most of their lives in fresh water (precocious male parr).

In Scotland, trout and salmon usually spawn in the autumn and winter. Eggs are buried in gravel nests (redds) and hatch in the following spring. The newly-hatched alevins remain in the gravel for several weeks until their yolk-sacs are absorbed, when they emerge as fry (0+ fish). The migratory fish remain in fresh water for another 1 to 5 years as parr. The parr eventually become silver-coloured smolts that migrate downstream during spring and spend one or more years feeding in the sea. Fish *(S. salar)* which return to breed in fresh water after only one winter are known as grilse, whereas those which spend more than two years at sea are known as salmon. Most of the spent fish (kelts) die after spawning, but a proportion of the females survive and manage to repeat the process and spawn again. In contrast, adult trout typically spawn annually for many years. More complete descriptions of the life-cycles of *S. salar* and *S. trutta* are provided in reviews by Gibson (1993) and Elliott (1994).

The freshwater pearl mussel life-cycle

The life-cycle of the freshwater pearl mussel is less well known, but equally fascinating. The slow-growing *M. margaritifera* is one of the longest-lived invertebrates known, capable of reaching ages greater than 100 years (Bauer

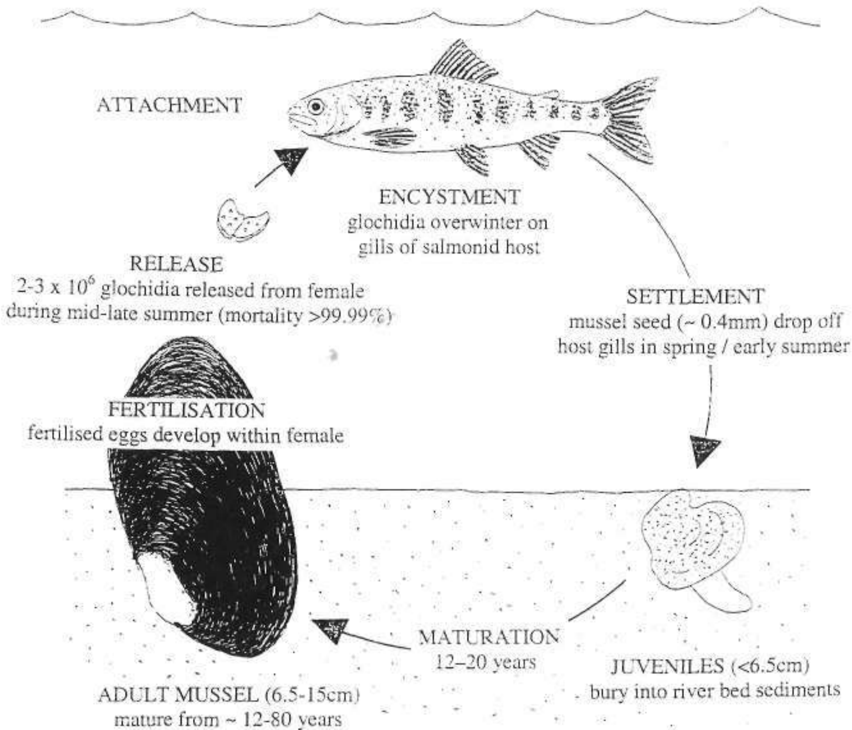

FIG. 3. Life-cycle of the freshwater pearl mussel. Quantitative data from Young & Williams (1984) and Buddensiek (1991).

1992). In common with other freshwater bivalves the sexes are separate; both sexes mature at age 12 to 20 years (Young & Williams 1984). An annual cycle of gametogenesis is apparent (Ross 1992). Up to 3 million unfertilised eggs pass out of the ovary into the mantle cavity and collect in brood pouches in the gills (marsupia), where they are fertilised in early summer. The female mussels inhale sperm by normal filtering action, in which a stream of water (containing food particles) enters the mantle cavity via the inhalent siphon. In mid to late summer, following an incubation period of several weeks, the females discharge their glochidia into the river. Glochidia resemble miniature mussels, measuring 0.06-0.08 mm across (Buddensiek 1991). They are obligate parasites of fish and are usually found encysted on the gills and/or fins of their hosts. Of the many glochidia released by pearl mussels, only a few that are ingested or inhaled by host fish become attached to and encyst on their gills (Fig. 2). In *margaritifera* the parasitic phase, which does not appear to harm wild fish, lasts for several months before the glochidia metamorphose into tiny mussels (by then *c.* 0.4 mm across), excyst from the host gills and drop off and settle onto the river bed (Young & Williams 1984). Those that settle in clean, stable sand may survive to adulthood. A diagram of the complete life cycle *of margaritifera* is provided in Fig. 3.

The glochidia of *Margaritifera* species are closely associated with salmonids. Those of *M. margaritifera* are very host-specific and can only complete their development on two, possibly three species of salmonid that occur in the holarctic region. Towards the north, the Atlantic salmon becomes more common and increasingly important as a host (Bauer 1987) and is the main host in northern areas such as Nova Scotia (Cunjak & McGladdery 1991) and Russia (Ziuganov et al. 1994). The northernmost mussel populations may in fact utilise the Arctic charr *Salvelinus alpinus* (L.), but this has not been established (Bauer 1987). Further south, brown trout are the main hosts in Ireland (Beasley 1996) and Germany (Bauer 1987). However, salmon are now extinct in Germany (Bauer 1987). Hence the importance of this species as a host of *margaritifera* in Germany (and other parts of central Europe) prior to extinction is unknown. In Scotland, there appears to be an overlap in host utilisation. In some rivers, salmon are the main hosts, but other rivers have no salmon and the mussels in these must be entirely dependent on trout (Hastie 1999).

Salmonid stocks in Scotland

Fishery managers and biologists have been concerned about the plight of sea trout in north-west Scotland for some time (Anon. 1993). Catches in this region have declined since the 1950s and are now at the lowest levels ever recorded (Fig. 4). Historical catch data, which are influenced by fishing effort and the types of gear used, are of limited use for assessing the status of wild fish stocks (Walker 1993). Nevertheless, the downward trend (supported by a small number of independent surveys) has been so dramatic that the general consensus is that sea trout are disappearing in north-west Scotland (Anon. 1993). A number of stocks have collapsed completely. The causes for this general decline have been attributed to numerous factors, including climatic/oceanographic changes, overfishing, increased predation, infestations by sea lice, pollution (acidification) and physical degradation of habitat (Marshall 1998). Whatever the reasons, the implications of this decline for the future of local sea trout fisheries are grave (Butler 1998).

Another concern is that during the past decade, average weights of sea trout

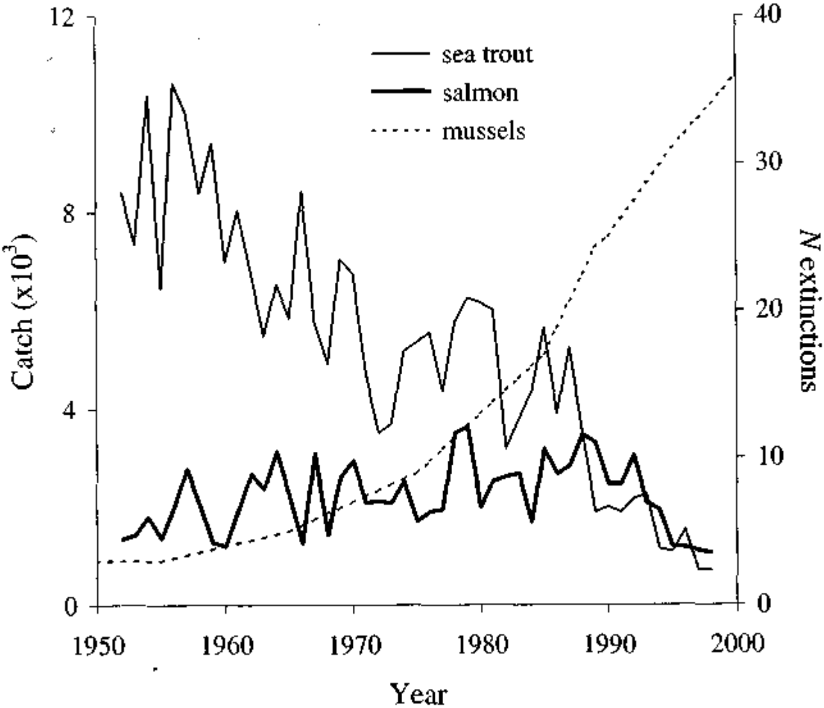

FIG. 4. The coincidental declines in catches of sea trout and salmon, and increasing loss of freshwater pearl mussel populations in north-west Scotland during the period 1952-2000. Data for salmonids are recorded annual rod and line catches (left ordinate; Scottish Fisheries Research Services) and estimated number of mussel population extinctions (right ordinate; Cosgrove: unpublished data).

started to fall in some populations (Walker 1993; Butler 1998). Most sea trout caught in north-west river systems are female and these exhibit a significant relationship between body size and fecundity: smaller females produce fewer eggs (Walker 1993). Therefore the decline in both numbers and sizes of individual fish may significantly reduce the potential fecundity of local sea trout populations (Fig. 2) and consequently affect their ability to recover in the long-term (Walker 1993). In contrast, non-migratory brown trout stocks in Scotland have largely remained stable, and in some areas they may even be increasing as sea trout stocks collapse (Butler 1998).

Salmon catches in north-west Scotland fluctuated considerably during the period 1952-1990, but overall the numbers appear to have been relatively stable for at least four decades (Fig. 4). However, during the 1990s a marked downturn occurred and catches are now at historically low levels. Salmon catches actually increased in a few local fisheries, but this is thought to be due to the significant numbers of fish farm escapees that invaded some rivers (Walker 1993; Webb 1993; Butler 1998), and possibly some intensive stock enhancement programmes.

Despite the dramatic decline of sea trout catches over the past 50 years, very few electrofishing surveys of juvenile salmonids in north-west rivers were carried out before 1990. As a result, it is still unclear whether or not local densities of fry and parr have been significantly affected by the reduced spawning stocks and lowered egg production now evident in many rivers. Walker (1993) compared densities of salmon and trout in north-west rivers over periods of 5 to 10 years (1984-1993) and found no evidence of a major change in overall juvenile abundance. However, in some small streams, very low densities - believed to be sub-critical for smolt production - have been recorded more recently (Butler 1999). There is some evidence that salmonid juvenile densities fluctuate widely between years, but little is known about the mechanisms involved (Butler 1998). Unfortunately, there is a lack of long-term data-series based on regular juvenile surveys in north-west Scotland (Walker 1993). In the 1990s, an attempt was made to rectify this by establishing local fisheries trusts committed to long-term monitoring of target rivers (Anon. 1997). A number of baseline surveys have already been carried out by the fisheries trust biologists (e.g. Butler 1998; Marshall 1998; Watt 1999), although it will take many years of monitoring before any long-term trends in juvenile salmonid abundance are apparent.

Implications for conservation

Since non-migratory brown trout are suitable hosts for *M. margaritifera* glochidia, it is possible that some (trout-dependent) pearl mussel populations will remain viable. In central Europe, brown trout are the main hosts of *margaritifera.* However, there is concern that the non-migratory trout which grow in very small oligotrophic streams in north-west Scotland do not produce enough (host) fry to sustain mussels in the long-term. Adult sea trout only return to spawn and therefore are not limited by stream resources. Since brown trout (and smaller sea trout) produce far fewer eggs, the decline in abundance and size of sea trout has resulted in substantial reductions in the fecundity of local trout populations, particularly in small streams (Walker 1993). Several *margaritifera* populations in small streams are already showing signs of reduced recruitment (Hastie et al. 2000).

At present, populations of *margaritifera* that are able to utilise salmon hosts may be less vulnerable, but this is unconfirmed. Salmon stocks naturally fluctuate between years (Butler 1998). As pearl mussels can have a reproductive life-span of up to 80 years (Bauer 1992) they are probably not greatly affected by annual fluctuations in numbers of host fish. However, the fact that north-west salmon stocks have also declined recently, and currently are at historically low levels, is cause for considerable concern. Unless salmon and sea trout stocks recover, then the long-term survival of all remaining *margaritifera* populations in north-west Scotland eventually may be threatened.

Although a number of baseline studies of the relationship between pearl mussels and their hosts have been carried out (Young & Williams 1984; Bauer 1987; Cunjak & McGladdery 1991; Ziuganov et al. 1994; Hastie 1999; Hastie & Young 2001), more research is required. For example, there is a distinct lack of field data from individual rivers, and little is known about the relationship between host stock sizes and the reproductive success of mussels (Chesney & Oliver 1998). Some workers (e.g. Ziuganov et al. 1994; Cosgrove et al. 2000b) have argued that the margaritiferid-salmonid relationship may be symbiotic, in that salmon and trout may benefit from the presence of mussels in some rivers. The rationale is as follows. (1) Mussels may be important for the maintenance of water quality in salmonid redds (spawning beds) and nursery areas because they reduce suspended organic material by filter-feeding and secrete "pseudofaeces" that are rapidly degraded to harmless products. (A single adult *M. margaritifera* can filter up to 50 litres of river-water each day: Ziuganov et al. 1994). (2) Mussel beds may, either as water-flow refugia or as a local source of calcium (leached from shells), provide critical microhabitats for aquatic invertebrates upon which juvenile salmonids feed (Fig. 1). Large numbers of small fish are often found in mussel beds (personal observation).

There is a need for the different fisheries interests and conservation organisations to work together. Given the close relationship between salmonids and pearl mussels, and with their coincidental decline in a number of rivers in north-west Scotland, perhaps an integrated approach to their conservation management is the best way forward. For example, in rivers where mussels may be threatened by a lack of juvenile salmonid hosts, regular stocking of native fish (perhaps jointly financed by fishery and conservation organisations) may be a very useful short-term remedial action. Methods used to manage the physical environment of a salmon or trout river may have a number of implications for the survival of local mussel beds and juvenile fish nurseries. However, since more understanding of the mussel-host relationship is urgently required, a considerable amount of research should be undertaken before any measures are implemented. An important first step in this direction was taken recently with the EC LIFE-funded investigation *'The Relationship between Freshwater Pearl Mussels and Salmonids: Implications for River Management (Safeguarding Natura 2000 Rivers in the UK)'.* This project, initiated by English Nature (EN) and Scottish Natural Heritage (SNH), and undertaken by Lee Hastie (University of Aberdeen), was started in July 2000.

Acknowledgements

Most of our research on freshwater pearl mussels would not have been possible without the continued support of Dr Phil Boon (Scottish Natural Heritage) and Dr Mark Young (University of Aberdeen). Salmonid catch data were kindly supplied by Scottish Fisheries Research Services (Scottish FRS, formerly DAFS/SOAFD). We would also like to thank Dr James Butler (Wester Ross Fisheries Trust) and Dr Jon Watt (Lochaber District Fisheries Trust) for their comments on an earlier draft of this paper.

References

Anon. (1993). *Problems with sea trout and salmon in the Western Highlands.* Atlantic Salmon Trust, Pitlochry. 79 pp.

Anon. (1997). *Freshwater fisheries laboratory biennial review.* Scottish Office Agriculture, Environment and Fisheries Department. Crown Copyright. 50 pp.

Bauer, G. (1986). The status of the freshwater pearl mussel *Margaritifera margaritifera* L. in the south of its European range. *Biological Conservation* 38, 1-9.

Bauer, G. (1987). The parasitic stage of the freshwater pearl mussel *{Margaritifera margaritifera* L.). III. Host relationships. *Archiv fiir Hydrobiologie* 76, 413-423.

Bauer, G. (1988). Threats to the freshwater pearl mussel, *Margaritifera margaritifera* in central Europe. *Biological Conservation* 45, 239-253.

Bauer, G. (1992). Variation in the life span and size of the freshwater pearl mussel. *Journal of Animal Ecology* 61, 425-436.

Buddensiek, V. (1991). Untersuchungen zu den aufwuchsbedingungen fluBperlmuschel *Margaritifera margaritifera* L. in iher fruhen postparasitaren phase. Dissertation an der Tierarztlichen Hochschule Hannover.

Butler, J. (1998). *Wester Ross fisheries trust (WRFT): annual review 1997.* Wester Ross Fisheries Trust, Inverness. 54 pp.

Butler, J. (1999). *Wester Ross fisheries trust (WRFT): annual review 1998-*

1999. Wester Ross Fisheries Trust, Inverness. 40 pp.

Chesney, H. C. G. & Oliver, P. G. (1998). Conservation issues for Margaritiferidae in the British Isles and western Europe. In *Molluscan conservation. A strategy for the 21st century* (eds I. J. Killeen & A. M. Holmes), pp. 231-242. *Journal of Conchology, Special Publication* 2, 231-242.

Cosgrove, P. J. & Hastie, L. C. (2001). Conservation of threatened freshwater pearl mussels: river management, translocation and conflict resolution. *Biological Conservation* (in press).

Cosgrove, P. J., Young, M. R., Hastie, L. C, Gaywood, M. & Boon, P. J. (2000a). The status of the freshwater pearl mussel *Margaritifera margaritifera* Linn, in Scotland. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 197-208.

Cosgrove, P. L., Hastie, L. C. & Young, M. R. (2000b). Freshwater pearl mussels in peril. *British Wildlife* 11, 340-347.

Cunjak, R. A. & McGladdery, S. E. (1991). The parasite-host relationship of glochidia (Mollusca: Margaritiferidae) on the gills of young-of-the-year Atlantic salmon *{Salmo salar). Canadian Journal of Zoology* 69, 353-358.

Elliott, J. M. (1994). *Quantitative ecology and the brown trout.* Oxford University Press, Oxford. 286 pp.

Gibson, R. J. (1993). The Atlantic salmon in freshwater: spawning, rearing and production. *Reviews in Fish Biology and Fisheries* 3, 39-73.

Hastie, L,C. (1999). Conservation and ecology of the freshwater pearl mussel, *Margaritifera margaritifera* (L.). Unpublished PhD thesis, University of Aberdeen.

Hastie, L. C. & Young, M. R. (2001). Freshwater pearl mussel *(Margaritifera margaritifera)* glochidiosis in wild and farmed salmonid stocks in Scotland. *Hydrobiologia* (in press).

Hastie, L. C, Young, M. R., Boon, P. L., Cosgrove, P. J. & Henninger, B. (2000). Sizes, densities and age structures of Scottish *Margaritifera margaritifera* (L.) populations. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10, 229-247.

Kerny, M. P. (1975). European distribution maps of *Pomatias elegans, Discus ruderatus, Eobania vermiculata* and *Margaritifera margaritifera. Archivfiir Molluskenkunde* 106, 243-249.

Marshall, S. (1998). *West Sutherland fisheries trust (WSFT): annual review 1997.* West Sutherland Fisheries Trust, Inverness 19 pp.

Ross, H. C. G. (1992). The reproductive biology of the freshwater pearl mussel *Margaritifera margaritifera* (L.) in Co. Donegal. *Irish Naturalist Journal* 24, 43-50.

Walker, A. F. (1993). Sea trout and salmon stocks in the Western Highlands.

In *Problems with sea trout and salmon in the Western Highlands,* pp. 6-18. Atlantic Salmon Trust, Pitlochry.

Webb, J. H. (1993). Prevalence and behaviour of escaped farmed salmon in coastal waters and rivers: western Scotland. In *Problems with sea trout and salmon in the Western Highlands,* pp. 19-23. Atlantic Salmon Trust, Pitlochry.

Watt, J. (1999). *Lochaber & District fisheries trust (LDFT): 2nd Annual Report 1997-1998.* Lochaber & District Fisheries Trust, Inverness. 49 pp.

Young, M. R. (1991). Conserving the freshwater pearl mussel *(Margaritifera margaritifera* L.) in the British Isles and continental Europe. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1, *73-11.*

Young, M. R. & Williams, J. C. (1983). The status and conservation of the freshwater pearl mussel in Great Britain. *Biological Conservation* 25, 35-52.

Young, M. R. & Williams, J. C. (1984). The reproductive biology of the freshwater pearl mussel *Margaritifera margaritifera* (Linn.) in Scotland. I. Field studies. *Archiv fur Hydrobiologie* 99, 405-422.

Young, M. R., Cosgrove, P. J. & Hastie, L. C. (2001). The extent of, and causes for, the decline of a highly threatened naiad: *Margaritifera margaritifera.* In *Ecology and evolutionary biology of the freshwater mussels, Unionoidea* (eds G. Bauer & K. Wachtler), pp. 337-357. Springer Verlag, Berlin.

Ziuganov, V., Zotin, A., Nezlin, L. & Tretiakov, V. (1994). *The freshwater pearl mussels and their relationships with salmonid fish.* VNIRO, Russian Federal Research Institute of Fisheries and Oceanography, Moscow. 104 pp.