CONSERVATION OF THE IRISH POPULATIONS OF THE POLLAN *COREGONUS AUTUMNALIS*

Robert Rosell, C. Harrod, David Griffiths and T.K. McCarthy

ABSTRACT

The Irish lake populations of pollan *Coregonus autumnalis* Pallas are detached from other Arctic populations and exist at the southern extreme of the range of the species. They are landlocked relics of postglacial colonisation by anadromous forms. In Ireland, pollan exist in atypical habitats and temperature ranges for the species as a whole and are threatened with extinction by a range of potentially detrimental factors, including eutrophication and competition with introduced non-indigenous species. All but one of the four populations is critically endangered. This paper summarises current knowledge of pollan, the status of the four populations and actions proposed to protect and enhance the remaining stocks.

Robert Rosell (corresponding author; e-mail: robert.rosell@dardni.gov.uk), DARDNI, Newforge Lane, Belfast BT9 5PX, Northern Ireland; C. Harrod, Environment Agency, Appleton House, 430 Birchwood Boulevard, Warrington WA3 7WD, England; David Griffiths, School of Environmental Studies, University of Ulster, Coleraine, Co. Londonderry BT52 1SA, Northern Ireland; T.K. McCarthy, Zoology Department, National University of Ireland, Galway.

INTRODUCTION

There are extant populations of pollan (Fig. 1) in Lough Neagh, Lower Lough Erne and Lough Ree and Lough Derg on the Shannon system (Fig. 2). Three of these populations have become severely reduced since 1970. Only Lough Neagh supports a large stock. Consequently, apart from isolated records of presence, absence and rarity, the Lough Neagh stock is the only one to have come under detailed study, and almost all that is known of the biology of the Irish populations of this fish is inferred from studies of this stock.

Over the past two decades, pollan have been reviewed from various perspectives. Ferguson *et al.* (1978) described the taxonomic position arising from genetic studies and the relationship between pollan and other Coregonidae. Wilson (1984; 1993) covered the taxonomic changes and the biology of the Lough Neagh population. Recently, Harrod *et al.* (2001; 2002) have collated data on the status of the four extant populations and proposed possible conservation measures. This paper updates and summarises in a single text the records and observations of the four authors and previous work on the fish. The information in this paper is not intended to be exhaustive; for more detail on specific issues the reader is referred to other original material.

CLASSIFICATION OF POLLAN

The Irish pollan has been repeatedly reclassified over the past two centuries. The early scientific descriptions, which were based on the work of Thompson (1835; 1856), named all pollan *Coregonus pollan*. After a long period of repeated reclassification and doubt over the pollan's identity, protein analysis by starch gel electrophoresis eventually identified pollan as belonging to the Arctic cisco species grouping and settled the classification of pollan as *C. autumnalis* (Ferguson 1974; Ferguson *et al.* 1978). Following this, pollan were described in the literature as *C. autumnalis pollan* Thompson. The currently accepted classification is simply *C. autumnalis* Pallas 1776.

ECOLOGY OF POLLAN

GROWTH AND LIFE SPAN

Pollan in Ireland are a relatively short-lived fish, with most authors (e.g. Twomey 1956; Wilson and Pitcher 1983) encountering fish of up to five years old. The Arctic populations of *C. autumnalis* live much longer (Maitland and Campbell 1993). Rosell (1997) found a specimen of 7+ years old, the oldest recorded Irish *C. autumnalis,* in Lower Lough Erne and concluded that this unusual longevity may have contributed to the persistence of the species at this site. Ageing of pollan is carried out from scales according to methods described by Wilson and Pitcher (1983). Care must be taken not to overestimate age, as there may be summer as well as winter checks in growth (Wilson and Pitcher 1983). Rosell (1997) noted similar checks in Lough Erne fish. These summer checks may be caused by high summer temperature (Dabrowski 1985; Harrod *et al.* 2001). Irish lakes can reach summer surface water temperatures of 18°C–20°C or more in July and August, well above the range at which

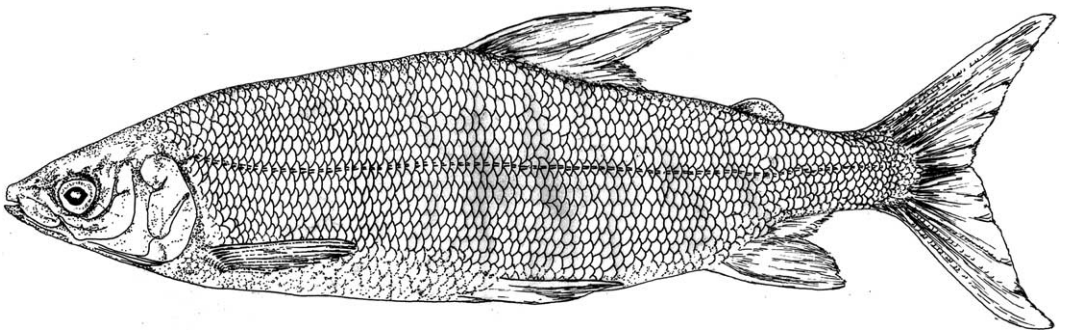

Fig. 1— Pollan, *Coregonus autumnalis*. Drawn by Billy Clarke from a pollan taken from Lough Derg at Killaloe, Co. Clare.

pollan grow effectively (Harrod *et al*. 2001). Of the four Irish lakes containing pollan, only Lower Lough Erne consistently stratifies in summer, providing a deep cold-water refuge for pollan of 14°C or cooler (Gibson 1998). Lower Lough Erne pollan select this refuge when it is available in summer, whereas pollan in Lough Neagh and the Shannon lakes have no choice but to occupy more or less unstratified warm water. Lough Derg can temporarily stratify in some years (J.J. Bowman, EPA, pers. comm.), but with relatively warm (16°C) bottom water.

The Shannon (McCarthy 1997; F. Igoe, pers. comm.) and Lough Neagh pollan (Maitland and Campbell 1993; Wilson 1993) normally attain maximum lengths of around 30cm and weights of 450g, but Lower Lough Erne fish can grow to 38cm, with a maximum recorded weight of 838g (Rosell 1997). Thompson (1856) relays a second-hand report of a specimen weighing circa 2.5lb (1135g) from an unknown source, but it is difficult to assess the accuracy of this report. The largest fish actually seen by Thompson were 12 inches (30cm) long, much the same maximum size as Lough Neagh fish today. The greater growth of Lough Erne fish, noted by Regan (1911) and other authors, may well be associated with the more favourable (colder) thermal regime than in the other lakes. The limited Lough Erne data (Rosell 1997) suggest that female pollan grow faster than males and may live longer.

SPAWNING AND EARLY LIFE HISTORY

Almost all the published literature on the spawning of pollan and its early life history results from studies of Lough Neagh fish (Dabrowski 1981; Wilson 1993). Lough Neagh pollan are mature at 2+ and usually spawn in December. Harrod *et al*. (2002) report a delay in spawning time in 1996–7, associated with reduced size and age at first spawning. Eggs are deposited on rocky or gravely shallow areas of the lake bed. The fry hatch after 416 degree days (Dabrowski 1981), or *about* two months at Lough Neagh temperatures. 0+ pollan reach 7cm by the July of their first summer (Wilson 1993). Interviews with retired commercial fishermen indicate that when Lough Erne pollan were abundant in the 1980s and earlier, spawning and early growth was much the same as described from Lough Neagh, with one-year-old fish reaching a length of 15cm (R. Rosell, pers. comm.).

FEEDING

Wilson (1984) reviews the accounts of pollan stomach content analysis. These and all recent accounts point to pollan being primarily zooplankton feeders, taking mainly copepods and cladocerans, although larger items are taken, including chironomid larvae and *Mysis relicta*, particularly in winter. There have been occasional reports of pollan accidentally caught by anglers using blowfly maggots as bait in the Lower River Bann downstream of Lough Neagh (R. Rosell, pers. comm.). An August 1997 sample of eleven Lough Erne pollan consisted almost entirely of copepods, with a few cladocerans and one juvenile *Gammarus* sp. (R. Rosell, pers. comm.). Bigsby (2000) found *Mysis* to be the dominant pollan food item over winter in Lough Neagh, in line with the findings of most previous studies, but contrary to those of Wilson (1984). Following the atypical capture of many pollan in salmon nets in the Erne estuary following hydroelectric power station construction works in the 1950s, pollan that had been displaced downstream to the Erne estuary ate mainly *Crangon* sp. and gammarids (Twomey 1956).

DISTRIBUTION OF POLLAN

Extant populations of pollan exist in Lough Neagh, in Lower Lough Erne in County Fermanagh, and in Lough Ree and Lough Derg on the main stem of the Shannon system (Fig. 2). Thompson (1856) lists pollan as also existing in Upper Lough Erne, Lough 'Direvragh' (probably Derravaragh) and Lough 'Trom' (possibly Lough Iron on the Inny River

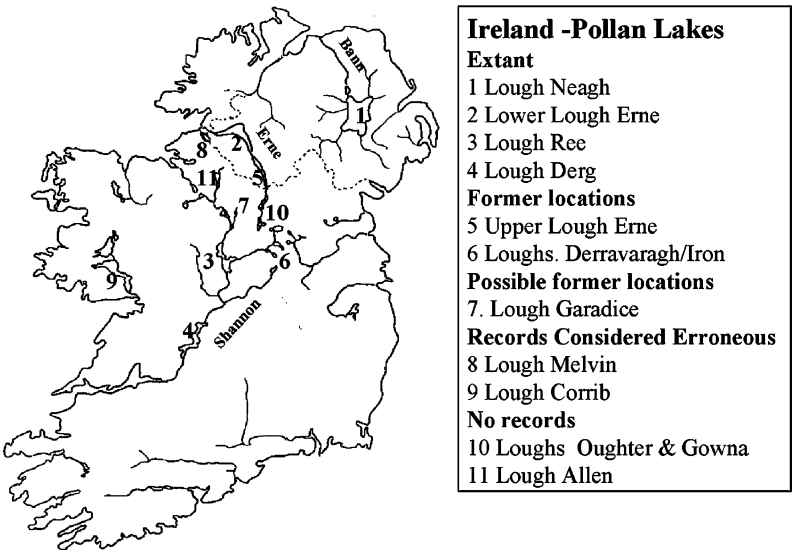

Fig. 2 — The distribution of pollan in Ireland.

between Lough Derravaragh and the Shannon River). One of the authors (Rosell) has received an anecdotal report from eel fishermen that pollan existed in living memory in Garadice Lough on the watershed between the Erne and Shannon systems. It would seem possible from the remaining geographical distribution that pollan once existed at all these additional locations. However, recent netting surveys have not recorded it, and it should be assumed that pollan are no longer present upstream of Lough Ree on the Shannon nor above Lower Lough Erne in the Erne system. It is perhaps surprising that pollan do not seem to have existed (or have never been reported) in Lough Allen, a large lake at the head of the Shannon system, or in Lough Oughter or Lough Gowna in the upper Erne system. Other early reports, including Newland's description of pollan in Lough Melvin (1851) and Yarrell's second-hand account from Lough Corrib (1859), are probably erroneous, on the basis that these lakes would not appear to have altered sufficiently since the 1800s to account for an extinction. Outside Ireland, *C. autumnalis* exists in anadromous forms in Arctic North America (McPhail 1966) and in northern Russia/Asia (Novikov *et al.* 2000). Khozov (1963) noted the presence of four races of omul, then classified as *C. autumnalis*, in Lake Baikal, Siberia, spawning in different affluent rivers. Recently, however, Politov *et al*. (2000) have questioned the classification of the omul and, on the basis of mitochondrial DNA (mtDNA) and isozyme studies, propose that it be reclassified as a separate species, *C. migratorius*. This means that pollan may be the only landlocked form of *C. autumnalis* in existence, which further raises their conservation importance.

Current status of Irish pollan populations

The only remaining abundant population of pollan is in Lough Neagh. Harrod *et al.* (2002) report a 1990s reduction in the size of spawners, indicating some stress on this population. The Shannon lakes and Lower Lough Erne populations are down to 1% or less of total fish biomass (Rosell 1997; Harrod *et al.* 2002) from known former levels of at least 5–9%. Bowman (1998) cites reports of pollan occurring 'in large numbers' in Lough Ree and Lough Derg prior to 1946. In the 1960s, pollan were occasionally abundant, with hundreds per night being taken in flood conditions as a nuisance bycatch in eel nets at the outflow from Lough Derg. (N. Roycroft, pers. comm.). Geraghty (1996) obtained a total of seventeen specimens in January 1996 from these coghill nets (conical-type nets are hung from bridges or specially constructed structures crossing rivers to harvest downstream migrating eel). The present-day recorded catch numbers perhaps three to four specimens per year (F. Igoe, pers. comm.), although eel fishing effort has probably declined and bycatch may not always be rigorously recorded (D. Doherty, pers. comm). Pollan have also been caught in eel nets downstream of Lough Neagh into the Lower River Bann, and they formerly occurred regularly in the River Erne downstream of Lower Lough Erne (Twomey 1956).

Threats and conservation measures

Harrod *et al.* (2001) examined this subject area in detail. The main perceived threats include eutrophication, competition with introduced species and warming of lakes above thermal tolerances. Land drainage and resultant siltation of lakes downstream of drained rivers may also have

had a detrimental impact (Griffiths 1997). It is difficult to separate these impacts to determine their individual effects since several clearly interact (Rosell and Gibson 2000). Eutrophication may favour dominance of roach over pollan: roach have been introduced to the four lakes containing pollan since the 1960s. The effect of eutrophication is not a simple one—Lough Neagh, the site of the largest remaining pollan stock, has a higher trophic status than the three lakes where pollan have declined. There is a view that Lough Neagh is a special case due to its high degree of wind-driven mixing, giving it a limnology more typical of oligotrophic systems (Wood *et al*. 2001). Griffiths (1997) cites several sources indicating that nutrient enrichment of the lakes containing pollan is still increasing, largely due to runoff from intensive agriculture.

Roach, a significant competitor with pollan for zooplankton food, are now the dominant species by biomass component of all lakes containing pollan, while they were absent as recently as 1950 (Rosell 1994; 1997; McCarthy 1997; Harrod *et al*. 2002).

The zebra mussel *Dreissena polymorpha* was accidentally introduced into the Shannon system *c*. 1993–4 (McCarthy and Fitzgerald 1997) and has spread rapidly throughout the navigable reaches of the Shannon/Erne waterways (Minchin and Moriarty 1998; Rosell *et al*. 1999). Within four years of introduction to the Erne system there has been a population explosion of this non-indigenous filter-feeding bivalve, which seasonally clarifies the water column by removal of algae (Maguire *et al*. 2004). The mussels themselves blanket rocky and gravelly areas, including potential pollan spawning ground, and deposit pseudofaeces on them. This organism must be considered as a very real threat to the already reduced pollan population of Lough Ree, Lough Derg and Lower Lough Erne. The zebra mussel has not yet reached Lough Neagh.

Should climate change processes cause temperatures to rise further, this will pose problems for pollan. If realised, the more extreme of the currently projected longer-term increases in annual mean temperatures could eventually dwarf other threats and render management changes to aid conservation redundant. Even relatively small increases in annual average temperatures could have significant impacts. The upper thermal limits for pollan are variably estimated at around 20°C–22°C, and large Irish lakes currently attain summer maxima around 18°C. Harrison *et al*. (2001) predict temperature increases of between 1.2°C and 2.8°C for Ireland by 2080. High summer temperatures already have an effect on the growth of Lough Neagh pollan. The tendency of deep water to deoxygenate when stratified summer conditions occur in pollan lakes clearly reduces the quality of any deep, cool refuge available to pollan. Summer temperatures associated with calm weather have caused some bottom layer deoxygenation in Lough Neagh in most years (Gibson and Stewart 1993). Any climate change resulting in increased summer temperature, along with continuing eutrophication, will clearly exacerbate this problem. Increases in winter temperature could affect pollan spawning behaviour and success. Pollan spawning in Lough Neagh now occurs up to one month later than two decades ago, possibly due to delayed winter cooling (Harrod *et al*. 2002).

A viable commercial fishery still exists for pollan in Lough Neagh, regulated by close season and gill net mesh size and a legal minimum size limit. The Northern Ireland authorities suspended commercial pollan gill net licences in Lower Lough Erne in 1994. At the point of suspension of these licences, the fishery had become uneconomic, but it is unlikely that the fishery played a major part in the population decline. Commercial or semi-commercial fisheries also once existed in the Shannon lakes, and as late as 1959 fisheries legislation provided for a minimum size (20cm) and a close season to protect the spawning season. There are no recent records of any enforcement of this legislation, presumably because pollan have become too rare to repay the effort in fishing for them (F. Igoe, Shannon Regional Fisheries Board, pers. comm). The maintenance of a viable commercial fishery can clearly be a major conservation benefit to pollan, as they have little or no importance as an angler's fish. Once commercial fisheries decline to the point where they are no longer viable, as has happened in Lough Erne, Lough Ree and Lough Derg, there is a real risk that the public perception of the value of pollan may disappear with the fishery. Commercial fishermen may also be a valuable store of information—almost all knowledge on the former habits of pollan in Lower Lough Erne, including spawning areas, the depths at which they are found and their semi-pelagic habit has been recorded as a result of interviews with retired netsmen (Rosell 1997).

Practical conservation measures to date to protect pollan have been restricted to commercial fishery protection measures and monitoring of the Lough Erne population. Pollan have been given a species action plan in the United Kingdom (UK Biodiversity Steering Group 1995), but to date this has not resulted in firm action to, or protection measures for, either the Erne or Lough Neagh populations. In reality, reversal of long-term nutrient enrichment is probably the best hope for preservation of the Erne stock. Since 1995, nutrient levels in Lower Lough Erne continue to rise (Zhou *et al*. 2000). Harrod *et al*. (2001) describe other possible actions including translocation to 'reservoir' sites and artificial rearing for stock augmentation.

CONCLUSION—THE FUTURE FOR POLLAN

It clearly will be difficult to guarantee the future of all the remaining populations of pollan, but there is real value in attempting to do so. Future classification using newly available sensitive DNA-based analyses may yet show important genetic differences between Irish stocks and provide evidence of speciation or genetic divergence since the last glaciation. There is, therefore, a need to preserve all four populations. Other nations in addition to Ireland and the UK may have an interest in analysing global coregonid relationships as a means of gaining an insight into former sea and ice conditions. Such back calculations are no longer academic but may be an important input into models of future climate change.

Some threats to pollan, particularly climate change, are practically impossible to control. The effects of non-native species, such as zebra mussels and roach, once these are introduced, are probably there to stay. However, control of spread of invasive species is technically feasible, as they generally require assistance from humans to gain access to new watersheds. In future, the planners of projects such as the construction or restoration of canals and navigation systems should take into consideration the effects they will have in moving fish and other aquatic organisms between waterways before deciding whether or not to proceed. Eutrophication is probably the main man-induced threat to pollan and is a difficult process to control, let alone reverse, without major public policy change. In Lough Neagh, reduction of phosphorus-driven eutrophication and algal blooms by removing phosphorus from sewage works had some success in the 1970s and 1980s (Wood and Smith 1993). Phosphorous levels began to rise again in the 1990s as a results of increased diffuse phosphorous loading from agriculture (Foy and O'Connor 2002). Prevention of further eutrophication of pollan lakes, or better still their reversion to mesotrophic status, will mean that conservation of biodiversity becomes a matter of public policy priority. While public authorities are now aware of this issue, actions effecting sufficient real positive change have not yet been taken.

REFERENCES

Bigsby, E. 2000 *The interactions between the macro-invertebrates, fish, and diving ducks of Lough Neagh*, Northern Ireland. Unpublished DPhil thesis, University of Ulster.

Bowman, J.J. 1998 The Shannon. In C. Moriarty (ed.), *Studies of Irish rivers and lakes*, 169–89. Dublin. Marine Institute.

Dabrowski, K.R. 1981 The spawning and early life history of the pollan (*Coregonus pollan* Thompson) in Lough Neagh, Northern Ireland. *Internationale Revue der gesamten Hydrobiologie* **66**, 299–326.

Dabrowski, K.R. 1985 Energy budget of coregonid (*Coregonus* spp) fish growth, metabolism and reproduction. *Oikos* **45**, 358–64.

Ferguson, A. 1974 The genetic relationships of the coregonid fishes of Britain and Ireland indicated by electrophoretic analysis of tissue proteins. *Journal of Fish Biology* **6**, 311–15.

Ferguson, A., Himberg, K.-J.M. and Svärdson, G. 1978 Systematics of the Irish pollan (*Coregonus pollan* Thompson): an electrophoretic comparison with other holArctic Coregoninae. *Journal of Fish Biology* **12**, 221–33.

Foy, R.H. and O'Connor, W.C.K. 2002 Managing the effects of agriculture on water quality in Northern Ireland. In P.M. Haygarth and S.C. Jarvis (eds), *Agriculture, hydrology and water quality*, 417–40. Oxford. CAB International.

Geraghty, F. 1996 Studies on smelt, *Osmerlus eperlanus* (L.) and pollan *Coregonus autumnalis pollan* (P.) from the River Shannon, with particular reference to their parasite assemblages. Unpublished BSc (Hons) thesis, University College Galway.

Gibson, C.E. 1998 Lough Erne. In C.E. Moriarty (ed.), *Studies of Irish lakes and rivers,* 237–56. Dublin. Marine Institute.

Gibson, C.E. and Stewart, D.A. 1993 Nutrient cycles in Lough Neagh. In R.B. Wood and R.V. Smith (eds), *Lough Neagh: the ecology of a multipurpose water resource*, 171–201. Dordrecht. Kluwer Academic Publishers.

Griffiths, D. 1997 The status of the Irish freshwater fish fauna: a review. *Journal of Applied Ichthyology* **13**, 9–13.

Harrison, P.A., Berry, P.M. and Dawson, T.P. (eds) 2001 *Climate change and nature conservation in Britain and Ireland: modelling natural resource responses to climate change (the MONARCH project)*. Oxford. United Kingdom Climate Impacts Programme technical report.

Harrod, C., Griffiths, D., McCarthy, T.K. and Rosell, R.S. 2001 The Irish pollan, *Coregonus autumnalis*: options for its conservation. *Journal of Fish Biology* **59** (suppl. A), 339–55.

Harrod, C., Griffiths, D., Rosell, R.S. and McCarthy, T.K. 2002 Current status of the pollan (*Coregonus autumnalis* Pallas 1776) in Ireland. *Archiv für Hydrobiologie: Special Issues Advances in Limnology* **57**, 627–38.

Khozov, M. 1963 *Lake Baikal and its life*. Monographiae Biologicae 9. The Hague, Netherlands. W. Junk.

Maguire, C., Rosell, R.S. and Roberts, D. 2004 The impact of the zebra mussel invasion on the phytoplankton, zooplankton and benthic macro-invertebrate communities in a large Irish lake. *Abstracts of presentations to the 13th international conference on aquatic invasive species*. Sligo. Institute of Technology.

Maitland, P.S. and Campbell, R.N. 1993 *Freshwater fishes*. London. Collins.

McCarthy, T.K. 1997 *Recreational fisheries of Lough Derg, Lough Ree and some adjacent river Shannon habitats: population ecology, parasitology and disease*. A report to the Electricity Supply Board. Galway. University College.

McCarthy, T.K. and Fitzgerald, J. 1997 The occurrence of the zebra mussel *Dreissena polymorpha* (Pallas, 1771) an introduced biofouling bivalve in Ireland. *Irish Naturalists' Journal* **25**, 413–16.

McPhail, J.D. 1966 The *Coregonus autumnalis* complex in Alaska and Northwestern Canada. *Journal of the Fisheries Research Board of Canada* **23**, 141–8.

Minchin, D. and Moriaty, C. 1998 Distribution of the zebra mussel *Dreissena polymorpha* (Pallas) in Ireland. *Irish Naturalists' Journal* **26**, 38–42.

Newland, H. 1851 *The Erne, its legends and its fly-fishing*. London. Chapman and Hall.

Novikov, G.G., Politov, D.V., Makhrov, A.A., Malinina, T.V., Afanisiev, K.I. and Fernholm, B. 2000 Freshwater and estuarine fishes of the Russian Arctic coast (the Swedish-Russian Expedition Tundra Ecology—94). *Journal of Fish Biology* **57** (suppl. A), 158–62.

Politov, D.V., Gordon, N.Y., Afanasiev, K.I., Altukhov, Y.P. and Bickham, J.W. 2000 Identification of paleArctic coregonid fish species using mtDNA and allozyme genetic markers. *Journal of Fish Biology* **57** (suppl. A), 51–71.

Regan, C.T. 1911 *The freshwater fishes of the British Isles*. London. Methuen.

Rosell, R.S. 1994 Changes in fish populations in Lower Lough Erne: a comparison of 1972–3 and 1991–2 gill net survey data. *Biology and Environment: Proceedings of the Royal Irish Academy* **94**B, 275–83.

Rosell, R.S. 1997 The status of pollan *Coregonus autumnalis pollan* Thompson in Lough Erne, Northern Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **97**B, 163–71.

Rosell, R.S. and Gibson, C.E. 2000 Interlinked changes in fish populations and their environments in Lower Lough Erne, Northern Ireland. *Verhandlungen der Internationale Verein für Limnologie* **27**, 2095–9.

Rosell, R.S., Maguire, C.M. and McCarthy, T.K. 1999 First reported settlement of zebra mussels *Dreissena polymorpha* in the Erne System, Co. Fermanagh, Northern Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **98**B, 191–3.

Thompson, W. 1835 Pollan of Lough Neagh. *Proceedings of the Zoological Society of London* **1835**, 77.

Thompson, W. 1856 *The natural history of Ireland, vol. IV. Mammalia, reptiles and fishes, also invertebrata*. London. Henry G. Bohn.

Twomey, E. 1956 Pollan of Lough Erne. *Irish Naturalists' Journal* **12**, 14–17.

UK Biodiversity Steering Group 1995 *Biodiversity: the UK steering group report, Vol. 2. Action plans*. London. HMSO.

Wilson, J.P.F. and Pitcher, T.J. 1983 Age determination and growth of the pollan *Coregonus autumnalis pollan*, of Lough Neagh, Northern Ireland. *Proceedings of the Royal Irish Academy* **83**B, 301–307.

Wilson, J.P.F. 1984 A review of the biology of the pollan *Coregonus autumnalis pollan* Thompson—an endemic Irish salmonid subspecies. *Proceedings of the Royal Irish Academy* **84**B, 123–7.

Wilson, J.P.F. 1993 Pollan. In R.B. Wood and R.V. Smith (eds), *Lough Neagh: the ecology of a multipurpose water resource*. Monographiae Biologicae **69**, 439–50. Dordrecht. Kluwer Academic Publishers.

Wood, R.B. and Smith, R.V. 1993 *Lough Neagh: the ecology of a multipurpose water resource*. Dordrecht. Kluwer Academic Publishers.

Wood, R.B., Andrew, T.E. and Carter, C.E. 2001 Lough Neagh—eutrophic, temperate, shallow—behaving as an oligotrophic, cold, deep lake. *Verhandlungen der Internationale Verein fur. Limnologie* **27**, 2240–2.

Yarrell, W. 1859 *British fishes*. London. Van Voorst.

Zhou, Q., Gibson, C.E. and Foy, R.H. 2000 Long term changes of nitrogen and phosphorus loadings to a large lake in north-west Ireland. *Water Research* **34**, 922–6.

The subvention granted by the National University of Ireland, Galway, towards the cost of publication of papers by members of its staff is gratefully acknowledged by the Royal Irish Academy.