Analysis of fluvial migration of the Irish pollan *Coregonus autumnalis*, using Sr:Ca ratios of otolith

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**ABSTRACT**

The Irish pollan *Coregonus autumnalis pollan* (Pallas, 1776) is a unique and an endangered fish species endemic to the island of Ireland. However, there is little information available regarding the life history and migration of the species. The migratory history of the *C. autumnalis pollan* was examined for the first time in terms of strontium (Sr) and calcium (Ca) uptake in the otolith, by means of wavelength dispersive X-ray spectrometry on an electron microprobe. The Sr:Ca ratios measured along a transect from the core to the otolith edge showed consistently low Sr:Ca values, averaging from $1.0 \times 10^{-3}$ to $1.4 \times 10^{-3}$. The results suggested the non-anadromous (fluvial) life history styles of the Irish pollan *C. autumnalis pollan*, although the Arctic cisco *C. autumnalis* is typically an anadromous fish in low productivity river and coastal systems.

1. Introduction

*Coregonus* is a diverse genus of fish of the salmon family (*Salmonidae*). The Irish pollan *Coregonus autumnalis pollan* (Pallas, 1776) is a unique and an endangered fish sub-species endemic to the island of Ireland. 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 on the classification of pollan as *C. autumnalis* (Fergusson 1974; Fergusson et al. 1978). Following this, pollan were described in the literature as *C. autumnalis pollan* Thompson. Many authors currently simply classify the Irish pollan at a species level as *C. autumnalis* (Pallas, 1776) (Rosell et al. 2004).

The recorded distribution of the Irish pollan is limited to five loughs (lakes) in Ireland, Lough Neagh, Lower Lough Erne, Lough Derg, Lough Ree and Lough Allen, and in some cases the rivers discharging from them (McCarthy and Blaszkowski 2006; Harrison et al. 2010). Of these lakes, only Lough Neagh is known to support a large stock, contributing approximately 25% of the total fish community (Harrod et al. 2002). Populations in three of the other lakes have undergone significant declines since 1970 (Rosell et al. 2004). Due to their restricted geographic range and decline in numbers, pollan are afforded a high conservation status; they are listed in Annex V (‘Animal and plant species of community interest whose taking in the wild and exploitation may be subject to management measures’) of the EU Habitats Directive (Council of the European Communities 1992) and are classified as ‘Endangered’ in the Irish Red Data Book (Whilde 1993) and the IUCN Red List of Threatened Species (Frehof and Kottelat 2008).

The Arctic cisco *C. autumnalis* is typically an anadromous fish in low productivity river and coastal systems of arctic Russia, Canada and Alaska (McPhail 1966; Morrow 1980; Novikov et al. 2000). The only non-arctic populations occur in Ireland. The Irish pollan is relatively short-lived, and the populations typically consist of classes spawning two to three times a year (Harrod et al. 2001). In Ireland, it is considered a landlocked relict, following post-glacial colonization of the anadromous *C. autumnalis*. However, little information is available on the life history, local movements, migration and habitat use of *C. autumnalis* in Ireland.

Recent studies have indicated that based on variations in the strontium (Sr) to calcium (Ca) ratios in otoliths, the migratory history of salmonid fish can be reconstructed (e.g. Arai et al. 2002, 2004, 2005; Arai and Morita 2005; Umatani et al. 2008, Honda et al. 2010, 2012). Strontium concentrations are one to two orders higher in seawater than in freshwater (Campana 1999), and the Sr:Ca ratio in otoliths is positively correlated with the salinity of the ambient water (Campana 1999; Arai 2002). Thus, this technique might also be applied to reveal the diverse migratory pattern of *C. autumnalis*.

2. Material and methods

A total of five Irish pollan were collected as the bycatch using coghill nets of the European silver eel fisheries in the River
Shannon, Killaloe, Ireland, between 22 and 29 November 2006 (Figure 1). Three white-spotted char *Salvelinus leucomaenis* (Linnaeus 1758), collected by set nets at Otsuchi Bay, northern Honshu Island, Japan, between 20 and 31 May 2006, were also examined for comparison purposes. Fork length (FL) and body weight (BW) were measured.

Sagittal otoliths were extracted from each fish, embedded in epoxy resin (Epofix, Struers, Copenhagen, Denmark) and mounted on glass slides. The otoliths were then ground to expose the core, using a grinding machine equipped with a diamond cup wheel (Discoplan-TS, Struers), polished further with 6 µm and 1 µm diamond paste on an automated polishing wheel (Planopol-V, Struers). Finally, they were cleaned in an ultrasonic bath and rinsed with deionized water prior to examination.

For electron microprobe analyses, all otoliths were Pt–Pd coated by a high vacuum evaporator. All specimens were used for ‘life history transect’ analysis of Sr and Ca concentrations, which were measured along a line down the longest axis of each otolith from the core to the edge using a wavelength dispersive X-ray electron microprobe (JEOL XJA-8900R, Jeol, Tokyo, Japan), as described in the previous reports (Arai et al. 2002, 2005). Calcite (CaCO$_3$) and strontianite (SrCO$_3$) were used as standards. The accelerating voltage and beam current were 15 kV and 1.2 × 10$^{-8}$ A, respectively. The electron beam was focused on a point 10 µm in diameter, with measurements spaced at 10 µm intervals.

### 3. Results and discussion

FL and BW of *C. autumnalis* ranged from 107 to 153 mm and from 8.5 to 21.3 g, respectively. FL and BW of *S. leucomaenis* ranged from 300 to 322 mm and from 402 to 533 g, respectively.

The Sr:Ca ratios measured along a transect from the core to the otolith edge of five specimens of *C. autumnalis* showed consistently low Sr:Ca values, averaging from 1.0 × 10$^{-3}$ to 1.4 × 10$^{-3}$ (Figure 2(A–E)). The Sr:Ca ratios along the life history transect in three specimens of *S. leucomaeni* showed a low Sr:Ca ratios phase from the core to the point 1600–1700 µm distant (phase L), averaging from 1.4 × 10$^{-3}$ to 1.6 × 10$^{-3}$ (Figure 2(F–H)). Thereafter, the ratios increased sharply, being higher than 5.0 × 10$^{-3}$ (Figure 2(F–H)).

It is noteworthy that Sr:Ca ratios along the life history transect in the otoliths of Irish pollan *C. autumnalis* revealed for the first time the typically non-anadromous (fluvial) life history styles. This difference was true for the otolith of an individual Irish pollan that did not have seawater life history. The anadromous type in *S. leucomaenis* showed a clear high Sr:Ca ratio around the edge of the otolith as an indication of a downstream migration to a marine environment. Salinity is quite different among ambient environments such as marine and freshwaters. Sr:Ca ratios in the otoliths of the fish have been positively correlated to ambient salinity (Campana 1999; Arai 2002, 2010). Thus, the difference in Sr:Ca ratio fluctuation patterns along the life history transect between fluvial *C. autumnalis* and anadromous *S. leucomaenis* was probably due to salinity effects.

Pollan are entirely lacustrine and non-anadromous (even though all the populations have access to the ocean within 100 km); they can mature early and at a small size (1+ year, 210 mm) (Harrod et al. 2001). In the present study, we did not study pollan samples at the maturation size or the larger specimens more than 200 mm in FL. Therefore, we cannot exclude the possibility that these pollan specimens are simply too small or young to initiate the anadromous migration. Further study is still indispensable to verify whether the Irish pollan is entirely lacustrine (non-anadromous) or not.

Generally, the Arctic cisco *C. autumnalis* inhabits low productivity river systems in Arctic Canada, Alaska and Russia (Morrow 1980; Novikov et al. 2000). These northern populations are anadromous, making long downstream migrations as juveniles to offshore feeding grounds and returning upstream to spawn as adults (Gallaway et al. 1983). The Irish pollan populations are found far to the south of the species’ typical range and each population has been isolated from conspecific populations probably since the last glaciation (Ferguson et al. 1978), giving adequate time for genetic differentiation in a group renowned for its phenotypic (Lindsey 1981) and genotypic (Vuorinen et al. 1991) plasticity. Coexistence of fluvial and anadromous life history styles are known to occur in other salmonid fish (Kubo 1980; Myers 1984). The coexistence of those life history styles might result from the success of both alternative styles to maximize individual fitness. In salmonids such as the masu salmon *Oncorhynchus masou*, the Atlantic salmon *Salmo salar* and the Arctic char *Salvelinus alpinus*, the decision regarding sea-run or freshwater residence is made depending on individual growth history, sex and ambient environmental conditions (Kubo 1980; Dalley et al. 1983; Myers 1984; Strand and Heggerget 1994). In *O. masou* and *S. salar*, only faster growing males become freshwater residents, while slower growing individuals become anadromous. However, only larger individuals become anadromous in *S. alpinus*. In *Salmo trutta*, a smaller individual became anadromous in the present study. Therefore, proximate mechanisms of divergence between alternative life history styles appear to be species specific among salmonid fish. To confirm the detail flexible life history patterns in *C. autumnalis*, analysis of the otolith Sr:Ca ratio needs to confirm the migratory type correctly, and the fluctuation pattern of the Sr:Ca ratios as an index of the life history should be compared among species and among habitats.

The Irish pollan *C. autumnalis* are detached from other Arctic populations and exist at the southern extreme of the range of the species (Harrod et al. 2001). They might be landlocked relics of post-glacial colonization by anadromous forms. In Ireland, pollan exist in typical habitats and temperature

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**Figure 1.** The Irish pollan *C. autumnalis* collected in the River Shannon, Killaloe, Ireland (119 mm in FL).
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 (Rosell et al. 2004). The present and previous studies found that the Irish pollan is highly restricted to reside in freshwater environments throughout its whole life and it occurs in only five large lowland loughs in Ireland. During recent decades, the pollan loughs have undergone cultural eutrophication as a consequence of phosphorus inputs from discharges of municipal waste and agricultural activities (Harrod et al. 2001). Therefore, prevention of further eutrophication of pollan loughs, or better still their reversion to mesotrophic status, is needed to conserve this unique salmonid fish. The lakes have been affected by a variety of introduced invasive species, such as zebra mussels (McCarthy et al. 1997), which may also be adversely affecting the trophic ecology and spawning areas of pollan. Some recent observations, such as the discovery of pollan in the upper Shannon and Lough Allen by McCarthy and Blaszkowski (2006), may be indicative of occasional upstream migration and potential natural range extension within river systems. The discovery of a juvenile pollan in silver-phase European eel (*Anguilla anguilla* (L.) fishing (J. Dalton pers. comm.) in the upper River Erne in 2015, well upstream of its nearest lake habitat, might also reflect an exploratory within-river migration. It may be that in former times downstream movements of pollan occurred in the Rivers Shannon and Erne, though development of hydroelectric dams now limits possible returns upstream. Twomey (1956) recorded that pollan were frequently caught by estuarine salmon fishermen prior to construction of hydropower dams immediately upstream from the estuary.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**

Arai T. 2002. Migratory history of fishes: present status and perspectives of the analytical methods. (in Japanese with English abstract). Jpn J Ichthyol. 49:1–23.

Arai T. 2010. Effect of salinity on strontium:calcium ratios in the otoliths of Sakhalin taimen, *Hucho perryi*. Fish Sci. 76:451–455.

Arai T, Kotake A, Aoyama T, Hayano H, Miyazaki N. 2002. Identifying sea-run brown trout, *Salmo trutta*, using Sr:Ca ratios of otolith. Ichthyol Res. 49:380–383.

Arai T, Kotake A, Kitamura T. 2005. Migration of anadromous white-spotted char, *Salvelinus leucomaenis* in northern Japan, as revealed by otolith Sr:Ca ratios. Fish Sci. 71:731–737.

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**Figure 2.** Transects of otolith Sr:Ca ratios measured with a wavelength dispersive electron microprobe from the core to the edge in the Irish pollan *C. autumnalis* (left, A–E) and the white-spotted char *S. leucomaenis* (right, F–H). Each point represents all data for every 10 µm. The number of left indicates fish number.
Arai T, Kotake A, Morita K. 2004. Evidence of downstream migration of Sakhalin taimen, *Hucho perryi*, as revealed by Sr:Ca ratios of otolith. Ichthyol Res. 51:377–380.

Arai T, Morita K. 2005. Evidence of multiple migrations between freshwater and marine habitats of white-spotted char, *Salvelinus leucomaenis*. J Fish Biol. 66:888–895.

Campana SE. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Mar Ecol Prog Ser. 218:263–297.

Council of the European Communities. 1992. Council directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild flora and fauna. Official J Eur Comm. 206:7–50.

Dalley EL, Andrews CW, Green JM. 1983. Precocious male Atlantic salmon parr (*Salmo salar*) in insular Newfoundland. Can J Fish Aquat Sci. 40:647–652.

Ferguson A. 1974. The genetic relationships of the coregonid fishes of Britain and Ireland indicated by electrophoretic analysis of tissue proteins. J Fish Biol. 6:311–315.

Ferguson A, Himberg KJM, Svärdson G. 1978. Systematics of the Irish pollan (*Coregonus pollan* Thompson): an electrophoretic comparison with other Holarctic Coregoninae. J Fish Biol. 12:221–233.

Frehof J, Kottelat M. 2008. *Coregonus pollan*. In IUCN 2016. IUCN red list of threatened species. Version 2016.3. [accessed 2016 Dec 20]. www.iucnredlist.org.

Gallaway BJ, Griffiths WB, Craig PC, Gazey WJ, Helmericks JW. 1983. An assessment of the Colville River Delta stock of Arctic Cisco – migrants from Canada? Biol Pap Univ Alaska. 21:4–23.

Harrison AJ, Kelly FL, Rosell RS, Champ TWS, Connor L, Girvan JR. 2010. First record and initial hydroacoustic stock assessment of pollan *Coregonus autumnalis* Pallas in Lough Allen, Ireland. Biology and Environment: Proc R Irish Acad. 110:69–74.

Harrod C, Griffiths D, McCarthy TK, Rosell R. 2001. The Irish pollan, *Coregonus autumnalis*: options for its conservation. J Fish Biol. 59(Suppl. A):339–355.

Harrod C, Griffiths D, Rosell RS, McCarthy TK. 2002. Current status of the pollan (*Coregonus autumnalis* Pallas 1776) in Ireland. Arch Hydrobiol Spec Issue Adv Limnol. 57:627–638.

Honda K, Arai T, Kobayashi S, Tsuda Y, Miyashita K. 2012. Migratory patterns of exotic brown trout, *Salmo trutta*, in south-western Hokkaido, Japan, on the basis of otolith Sr:Ca ratios and acoustic telemetry. J Fish Biol. 80:408–426.

Honda K, Arai T, Takahashi N, Miyashita K. 2010. Life history and migration of Sakhalin taimen, *Hucho perryi*, caught from Lake Akkeshi in eastern Hokkaido, Japan, as revealed by Sr:Ca ratios of otoliths. Ichthyol Res. 57:416–421.

Kubo T. 1980. Studies on the life history of ‘masu’ salmon (*Oncorhynchus masou*) in Hokkaido (in Japanese with English abstract). Sci Rep Hokkaido Salmon Hatchery. 34:1–95.

Lindsey CC. 1981. Stocks are chameleons: plasticity in gill rakers of coregonid fishes. Can J Fish Aquat Sci. 38:1497–1506.

McCarthy TK, Blaszkowski M. 2006. Pollan *Coregonus autumnalis* Pallas in Lough Allen and the upper River Shannon. Irish Nat J. 28:269–271.

McCarthy TK, Fitzgerald J, O’Connor W. 1997. The occurrence of the zebra mussel *Dreissena polymorpha* (Pallas 1771), an introduced biofouling freshwater bivalve in Ireland. Irish Nat J. 25:413–416.

McPhail JD. 1966. The *Coregonus autumnalis* complex in Alaska and Northwestern. J Fish Res Board Can. 23:141–148.

Morrow JE. 1980. The freshwater fishes of Alaska. Anchorage: Alaska Northwest Publishing Company.

Myers RA. 1984. Demographic consequences of precocious maturation of Atlantic salmon, *Salmo salar*. Can J Fish Aquat Sci. 41:1349–1353.

Novikov GG, Politov DV, Makhrov AA, Malinina TV, Afanasiev KI, Fernholm B. 2000. Freshwater and estuarine fishes of the Russian Arctic coast (the Swedish–Russian Expedition ‘Tundra Ecology – 94’). J Fish Biol. 57 (Suppl. A):158–162.

Rosell R, Harrod C, Griffiths D, McCarthy TK. 2004. Conservation of the Irish populations of the pollan *Coregonus autumnalis*. Biology and Environment: Proc Roy Ir Acad. 104:67–72.

Strand R, Heggerberget TG. 1994. Growth and sex distribution in an anadromous population of Arctic char in Northern Norway. Trans Am Fish Soc. 123:377–384.

Thompson W. 1835. Pollan of Lough Neagh. Proc Zool Soc London. 1835:77.

Thompson W. 1856. *Coregonus pollan* Thompson. Proc R Irish Acad. 110:69–74.

Twomey E. 1956. Pollan of Lough Erne. Irish Nat J. 12:14–17.

Umatani Y, Arai T, Maekawa K. 2008. Variation in migratory history of Dolly Varden in a stream with an artificial dam in the Shiretoko Peninsula, Hokkaido, Japan. Environ Biol Fish. 83:37–44.

Vuorinen J, Naesje TF, Sandlundt OT. 1991. Genetic changes in a vendace *Coregonus albula* (L.) population, 92 years after introduction. J Fish Biol. 39(Suppl. A):193–201.

Whilde A. 1993. Threatened mammals, birds and fish in Ireland. Irish Red Data Book 2: Vertebrates. Belfast: HMSO.