

AN ANNOTATED BIBLIOGRAPHY OF RESEARCH ON COARSE AND SALMONID FISH (EXCLUDING SALMON AND TROUT) FOUND IN FRESH WATER IN SCOTLAND

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Introduction

Non-salmonid "coarse" fish are widespread and abundant in Scotland (e.g. Maitland & Campbell 1992) but little scientific research has been done on them, compared with the extensive work on the Atlantic salmon (*Salmo salar*) and populations of brown and sea trout (*Salmo trutta*). Nevertheless, coarse fishes interact with salmonids and there is growing concern that unwanted introductions, such as ruffe (*Gymnocephalus cernuus*) in Loch Lomond (see below), are threatening the native fish fauna of Scotland. Some major points about the ecological role of coarse fish in Scotland were made by J.W.T. in a brief article published in *Freshwater Forum*, Vol. 3, No. 1, pp. 20-25, (Coarse fish in Scotland: a threat or a resource?). Here we provide a more extensive annotated bibliography to a full list of species occurring in Scotland, to highlight what is known about them and to indicate potential areas for further research. The list of references brings together published research papers and numerous unpublished theses and reports, including experimental

and laboratory studies conducted in Scotland, although some may not have unique application to the fish fauna in Scottish waters. We have not attempted to include references that are made incidentally in the general literature intended for naturalists.

The bibliography also covers species that occur in fresh water but occasionally or regularly move into or from the sea; these are bass, eel, flounder, goby, lampreys, mullets, shad, smelt, sticklebacks and sturgeon. In addition, to complete the list of freshwater species found in Scotland, we have included the following rare or uncommon members of the Salmonidae about which more needs to be known for Scottish populations: Arctic charr, brook charr, grayling, powan, vendace. As stated above, the bibliography excludes research done specifically on Atlantic salmon and brown and sea trout, and it also excludes rainbow trout (*Oncorhynchus mykiss*). Scientific names for all species listed here follow those advocated by Wheeler (1992).

Some texts in the list of references mention many or all of the species recorded in Scotland (e.g. Mills 1989; Maitland & Campbell 1992) and they are cited only occasionally in the annotated bibliography below. Although the shortage of references on certain species reflects gaps in our knowledge, it does also reflect the varying economic and sporting importance of these species and, in some cases, their relatively recent introduction. Also, it is not possible to review all of the listed references in the brief paragraphs of notes given below. We hope that no-one will be offended by any omission!

Annotated bibliography and list of coarse fish species in fresh water

PIKE, *Esox lucius* L.

Adams 1991; Adams, Brown & Tippet 1990; Adams & Tippet 1991b; Armstrong 1986, 1987; Armstrong, Lucas, Priede & De Vera 1989; Armstrong, Priede & Lucas 1992; Boyd 1975; Campbell, A.D. 1974; Campbell R. N. 1955; Campbell & Williamson 1983; Copland 1956; Forsyth 1954; Hyslop 1976; Lucas 1989; Lucas & Armstrong 1991; Lucas, Priede, Armstrong, Gindy & De Vera 1991; MacKenzie 1975; Maitland 1966c, 1990a; Mills, 1962, 1964, 1968; Munro 1957; Proctor 1980; Robertson 1886; Shafi 1969; Shafi & Maitland 1971a; Tasker 1986; Treasurer 1980a,b, 1988a, 1990a,b,e, 1992b,c; Treasurer & Owen 1991; Treasurer, Owen & Bowers 1992; Whilde 1969.

Mills (1964) estimated that 10% of the smolt run in the River Bran system, Ross-shire, was consumed by pike. The relative infrequency of certain

species of waterfowl in northern Scottish lochs may be due to predation by pike on duck chicks (Treasurer 1980a). Production of pike in Scottish waters has been estimated as 7.8 kg ha⁻¹ in Dubh Lochan, near Loch Lomond, 4.8 lb acre⁻¹ in a single-species loch, Loch Choin (Munro 1957), and 1.2-1.3 kg ha⁻¹ in Lochs Kinord and Davan, Deeside, where the predator-prey relationship of pike and perch in a simple fish system was examined (Treasurer, Owen & Bowers 1992). MacKenzie (1975) recorded 1.89 tonnes of pike from 65 ha Loch Fitty after rotenone treatment. The food of pike has been reported as mainly salmonids and coregonids in Loch Lomond, invertebrates and perch in Dubh Lochan (Shafi 1969; Shafi & Maitland 1971a), invertebrates particularly important in Loch Choin, even in larger fish (Munro 1957), invertebrates and perch in Lochs Kinord and Davan (Treasurer, Owen & Bowers 1992), and invertebrates in Loch Tummel (Campbell 1955).

COMMON CARP, *Cyprinus carpio* L.

Brown 1992; Graham 1976; Maitland 1964.

The common carp has a limited distribution in Scotland. A population of the scaled or "wild" form has been present in Danskine Loch, East Lothian, for several years (Mills 1968; Graham 1976). Some individuals from this population were introduced into Duddingston Loch, mid-Lothian, in the the 1970s. More recently, carp have been introduced to this loch from other sources and also to the Monklands Canal (Brown 1992). A specimen of the leather carp (a cultivated variety of *C. carpio*) was recorded from the Union Canal, Edinburgh, in the late 1960s.

CRUCIAN CARP, *Carassius carassius* (L.).

Adams & Mitchell 1992.

The crucian carp has an even more limited distribution in Scotland than the common carp. Adams & Mitchell (1992) recorded its introduction to Loch Lomond very recently.

GOLDFISH, *Carassius auratus* (L.).

Maitland 1971.

The practice of dumping the poor old goldfish into appropriate water bodies when folk go on holidays is likely to be widespread. However, probably few ever establish spawning populations. Maitland (1971) refers to a population of coloured goldfish in the Forth and Clyde canal and they

probably also occur in the Union canal and a number of ponds and other standing waters.

GUDGEON, *Gobio gobio* (L.).

Downie 1973; Mcintosh 1978; Mann, Mills & Crisp 1984.

Relatively little is recorded on gudgeon in Scotland. It is prey to fish-eating birds (Mills 1964) and larger fish (Maitland & Campbell 1992). Age and growth of gudgeon were examined in the River Tweed (Downie 1973), and growth was found to be good compared with other localities in the British Isles. Food items taken were chironomids, molluscs and crustacean zooplankton. Mann, Mills & Crisp (1984) examined life history strategies of gudgeon at different locations and reported that gudgeon in the River Don, Aberdeenshire, had lower gonadosomatic indices (GSI) compared with fish in the River Frome, Dorset, suggesting lower reproductive output. The age range in the River Don was 1-6 years old and there was variation in annual recruitment.

TENCH, *Tinea tinea* (L.).

Blower 1979; Griffiths 1977; Juppenlatz 1977.

Tench occur in a few small lochs in central and southern Scotland and were introduced into Duddingston Loch in 1969. Limited studies have been made of the biology (Griffiths 1977) and feeding preferences and activity (Juppenlatz 1977; Blower 1979) of tench in Abercairny Loch, Perthshire. It was found that male tench, which grew slower than females in later life, had an average length of 43.2 cm and 1200 g weight at 9+ years of age, while females of the same age were on average 44.5 cm length and 1360 g weight. The main food items in their diet were Cladocera and Diptera.

COMMON BREAM, *Abramis brama* (L.).

Maitland 1966c, 1967b; Adams & Maitland 1991.

The only reproducing populations of bream in Scotland are in Castle Loch, Lochmaben, the River Clyde below Motherwell (Mills 1968) and the River Annan (Adams & Maitland 1991). However, roach x bream hybrids were reported from Loch Lomond (Adams & Maitland 1991) and from Castle Loch (Maitland 1966c, 1967b). Bream were introduced to the Union Canal by Lothian Regional Council on at least one occasion in the 1980s and have also been introduced to the Monklands Canal and the Strathclyde Country Park.

MINNOW, *Phoxinus phoxinus* (L).

Curtis 1979; Kindness 1977; Maitland 1965, 1966c, 1984; Patience 1985.

The distribution of the minnow in Scotland has been well documented (Maitland 1972b) and its widespread distribution is no doubt due in part to its introduction by anglers while using it as live bait for trout (Maitland & Campbell 1992). The density and biomass of the species has been recorded for many streams and rivers (Curtis 1979), often during electro-fishing surveys of salmonid waters (Mills 1970, 1989; Mills, Griffiths & Parfitt 1978). Its feeding relationships with other stream-dwelling fish in the River Endrick have been studied by Maitland (1965). Curtis (1979) studied the growth rates of minnows in some Tweed tributaries and found they lived to four years of age, with sexual maturity being attained during their second year of life.

RUDD, *Scardinius erythrophthalmus* (L).

There appear to be no data on rudd in Scotland. As far as is known, rudd only occurs in a small loch in the grounds of Culzean Castle, Ayrshire.

ROACH, *Rutilus rutilus* (L).

Adams & Maitland 1991; Aldoori 1971,1972; Clout 1972; McIntosh 1978; Maitland 1966c; Mills 1968, 1970, 1971a; Radforth 1940; Scobie 1984; Treasurer 1990c; Whilde 1969.

The roach is fairly well distributed throughout central and southern Scotland (Mills 1968, 1971). Growth rates in a number of waters (Tweed, Humber Reservoir, Loch Lomond, Eden Water, Union Canal and Duddingston Loch) have been investigated using scales (Whilde 1969; Mills 1971a; Aldoori 1972) and opercular bones (Clout 1971; and also Treasurer 1990c, for the most northerly population in the British Isles, in the Gilston Ponds, Moray). An estimate was made by Mills (1971a) of the population density and standing crop of roach >12 cm length (i.e. more than 4 years old) in Humber Reservoir, West Lothian, namely 2,316 acre⁻¹ (937 ha⁻¹) and 371 lb acre⁻¹ (416 kg ha⁻¹). The seasonal diet of the roach in the Humber Reservoir was found to be mainly oligochaetes (Aldoori 1971, 1972). Roach transferred from Humber Reservoir, where their growth rate was slow, to Duddingston Loch, grew rapidly in their new environment because they switched to a diet of molluscs.

CHUB, *Leuciscus cephalus* (L).

Adams, Brown & Tippett 1990; Maitland 1966c.

A reference to this species confirms the introduction of chub to Loch Lomond (Adams, Brown & Tippett 1990) and there is an on-going need to follow its progress and potential impact on the native fish fauna. Chub occur in the Rivers Annan, Kinnell, Kirtle, Sark (Mills 1968) and Border Esk, and there has been an unconfirmed report of chub in the Tweed at Coldstream.

ORFE, *Leuciscus idus* L.

Lyle & Maitland 1992; Maitland & Campbell 1992.

A population of orfe has been recorded in south-west Scotland (Lyle & Maitland 1992; Maitland & Campbell 1992).

DACE, *Leuciscus leuciscus* (L.).

Adams, Brown & Tippett 1990; Brown 1992; McIntosh 1978; Starkie 1976.

Dace have been recorded from the River Tweed and Border Esk (Mills 1968, Maitland 1972b) and more recently from Loch Lomond (Adams, Brown & Tippett 1990) and the Clyde (Brown 1992). The growth, diet and movements of dace in the lower Tweed have been extensively studied by Starkie (1976). Starkie was able to demonstrate a fairly regular movement of dace shoals between two localities in the River Tweed using tags and dyes (Alcian blue) as markers. Juvenile dace were found in some of the lower Tweed tributaries (Oxnam, Eden and Leet Waters) (Mills 1989).

STONE LOACH, *Barbatula* (= *Noemacheilus*) *barbatulus* (L).

Crawford 1979; Maitland 1965, 1966c; Mills 1970, 1989; Mills, Griffiths & Parfitt 1978; Sinclair 1991.

The distribution, density, biomass and length frequencies of the stone loach have been recorded by many workers (Maitland 1965; Mills 1970, 1989; Mills, Griffiths & Parfitt 1979; Crawford 1979; Sinclair 1991), frequently during general electro-fishing surveys. Growth rates of stone loach in the Tweed catchment have been investigated by Crawford (1979) and Sinclair (1991). The feeding habits of the species and its inter-relationships with other stream-dwelling species in the River Endrick have

been studied by Maitland (1965). Limited data on the diet of stone loach in some Tweed tributaries have been recorded by Crawford (1979).

PERCH, *Perca fluviatilis* L.

Adams & Tippett 1990; Boyd 1975; Campbell, A. D. 1974; Campbell, R. N. 1955; Campbell & Williamson 1983; Collette et al. 1977; Dodds-Smith 1982; Findlay 1987; Forsyth 1954; Jenkins & Harper 1980; Jones 1982; Jones & Elphinstone 1983; Koss 1977; Lorn, Pike & Dykova 1991; McPherson 1983; Maitland 1966c; Mills 1962, 1963, 1964, 1965, 1968; Radforth 1940; Rennie 1973; Shafi 1969; Shafi & Maitland 1971b; Spangler et al. 1977; Thorpe 1974, 1977a,b,c; Tozer 1978; Treasurer 1978, 1980b, 1981a,b, 1983, 1988a,b, 1989, 1990b,d,e, 1992a,b,c,d, 1993; Treasurer, Owen & Bowers 1992.

The extensive and comprehensive bibliography on perch reflects, to some extent, the abundance and widespread distribution of perch in Scotland. All stages of the life cycle of perch (eggs, larvae, juveniles, adults) have been closely examined in north-east Scotland, particularly in Lochs Kinord and Davan, Deeside (e.g. Treasurer 1983, 1989; Treasurer, Owen & Bowers 1992). Perch in Scotland normally spawn at the end of April/beginning of May at water temperatures of 10-12°C, with duration of incubation temperature related. Survival during incubation is high, >96% (Treasurer 1983), due to the eggs being shed in a tough strand on vegetation. Mortality of larvae was estimated as 4% day⁻¹ on Deeside (Treasurer 1989), declining to 2% when the larvae metamorphosed to the juvenile period. Adult numbers were 5-10 ha⁻¹ in Lochs Kinord and Davan, biomass 1.0-1.6 kg ha⁻¹, and production 0.2-0.4 kg ha⁻¹, based on population estimates by census of egg strands. In Dubh Lochan, near Loch Lomond, abundance was higher, 1649-1695 perch ha⁻¹ and production 34-39 kg ha⁻¹ (Shafi 1969; Shafi & Maitland 1971b). Growth of perch in Dubh Lochan was slow, the average length at 8 years being <15 cm compared with 23 cm for fish of the same age in Loch Lomond. Thorpe (1977c) developed an exponential model to describe gastric evacuation rate in perch in Loch Leven, Kinross, and estimated daily food consumption in summer as 2-4% of body weight. Perch eat a wide range of invertebrates including Chironomidae, and are also cannibals above a length of 16 cm (Campbell 1955; Treasurer 1989).

RUFFE, *Gymnocephalus cernuus* (L.).

Adams 1991; Adams & Tippett 1990, 1991a,b; Graham 1987; Maitland & East 1989; Maitland, East & Morris 1983; Murphy 1988.

The recent introduction of ruffe to Loch Lomond is affecting the powan in particular (Maitland, Morris & East 1983a; Adams 1991), as the ruffe is a major predator of powan eggs (Adams & Tippett 1991a). However, in contrast, the ruffe has become the commonest prey species, 44% by number, in the diet of pike in Loch Lomond and has relieved predation pressure by pike on powan (Adams 1991).

BULLHEAD, *Cottus gobio* L.

Clelland 1971; Morris 1978; Escott 1984.

Clelland (1971) quoted maximum fork lengths of bullhead in the Gogar Burn, Edinburgh of 58, 84, 96, 105 and 114 mm at age 0+, 1+, 2+, 3+ and 4+ respectively from examination of otoliths. Density of bullheads in the Braid Burn was low compared with other reports for Great Britain, 1.7 fish m^{-2} although biomass was high, 19.9 g m^{-2} (Escott, 1984). Escott estimated average bullhead fecundity of 195 eggs per female and egg density on the spawning ground of 179 m^{-2} with maturation in the second year. Average survival in the Braid Burn was 0.237 year⁻¹ from the egg stage to age 5 years. Maximum age of bullhead in the Braid Burn was 5 years.

Annotated bibliography and list of coarse fish with marine affinities

SEA LAMPREY, *Petromyzon marinus* L.

MacDonald 1959a,b; Maitland 1980 a,b; Smith 1957.

The sea lamprey is recorded from most river systems in Scotland with the exception of the waters north of the Great Glen (Maitland & Campbell 1992) from which it has only been recorded very occasionally (e.g. R. Conon in 1958 by D. H. Mills). Larvae of all three species of lampreys occurring in Scotland may occupy the same habitat types, normally where stream gradient is 1.9-5.7 m km^{-1} . Maitland & Campbell (1992) reported that the only location where the adult sea lamprey is known to feed in fresh water in Great Britain is Loch Lomond. The spawning migration is normally between April and June when the adults move upstream to reproduce (Maitland 1980a), spawning occurring when water temperatures exceed 15°C in late May or June. The duration of larval development in the Inler Burn, Scotland, was reported as at least 5 years (MacDonald 1959a). The ammocoetes are normally found in silty sand in running water but may occur in large lakes, e.g. Loch Lomond (Maitland & Campbell 1992).

RIVER LAMPREY, *Lampetra fluviatilis* (L.).

Lamond 1922; MacDonald 1959a,b; Maitland 1980a,b; Maitland, East & Morris 1983; Maitland, Morris, East, Schoonoord, Van der Wal & Potter 1984; Morris & Maitland 1987; Schoonoord & Maitland 1983.

The river lamprey is widely distributed in Scotland south of the Great Glen (Maitland & Campbell 1992). Spawning is normally in March and April at water temperatures of 10-11°C. Larvae inhabit silt beds in rivers and duration of this phase is normally 3 years (MacDonald 1959a). Metamorphosis is from July to September and downstream migration normally occurs in darkness between March and June (Maitland 1980a).

BROOK LAMPREY, *Lampetra planeri* (Bloch).

Campbell & Williamson 1983; Maitland 1980 a,b; Mills 1962.

The brook lamprey is the most widely distributed species and the smallest of the Scottish lampreys, when mature 13-15 cm. Spawning is normally from March to April at 10-11°C. Following hatching, larvae leave the nest, drift downstream and burrow in silty sand (Maitland 1980a). Larval life is about 3 years' duration in Scotland (MacDonald 1959a). Metamorphosis is from June-September. Adults burrow like ammocoetes but, on temperatures reaching 10°C, migrate upstream to spawning grounds (Maitland 1980a).

COMMON STURGEON, *Acipenser sturio* L.

A rare vagrant from Europe; occasionally enters estuaries in Scotland.

ALLIS SHAD, *Alosa alosa* (L.).

Maitland 1987a; Maitland & Lyle 1990a,b.

Little is known of the biology of Ail is shad and Twaites shad in Scotland, apart from notes on distribution (Maitland 1987a; Maitland & Lyle 1990b).

TWAITE SHAD, *Alosa fallax* (Lacepede)

Maitland & Lyle 1990a,b.

SMELT, *Osmerus eperlanus* (L.)

Hutchinson 1983a,b; Hutchinson & Mills 1987; Maitland & Lyle 1990a,b; Parnell 1838b.

Partly as a result of over-exploitation and pollution, the smelt is limited to

only three river estuaries in Scotland, namely the Cree, Forth and Tay, and it is only in the first-named that there is a population of any size. However, smelt numbers appear to be increasing in the Forth and Tay. The spawning behaviour and growth of the smelt in the River Cree have been studied by Hutchinson (1983b). Recommendations for the management and re-establishment of smelt stocks have been made by Hutchinson & Mills (1987) and for their conservation by Maitland & Lyle (1990a,b).

EUROPEAN EEL, *Anguilla anguilla* (L).

Campbell & Williamson 1979; Cuthbert 1979; Calloway 1977; Hussein 1981, 1983; Hussein & Mills 1982; Jenkins & Harper 1980; Keddie 1988; Mcintosh 1978; Maitland 1966c; Mills 1970; Mills & Hussein 1985; Painter 1978; Reid 1978; Richards 1989; Shafi & Maitland 1972.

The population densities, standing crops and length frequencies of eels in a number of Tweed tributaries have been recorded by Mills (1970), Mills, Griffiths & Parfitt (1978), Mills & Tomison (1985), and Mills & Hussein (1985). Eel densities have also been recorded by other workers surveying other Scottish rivers but do not appear to be published. Age and growth analyses have been undertaken on eels from four Tweed tributaries with differing chemical characteristics and sex ratios recorded (Hussein 1983; Mills & Hussein 1985). The seasonal diet of eels from the same four tributaries was also examined by Hussein (1983). The growth and diet of eels in the River Almond, Midlothian, have been reported (Richards 1989). The prevalence of "cauliflower" disease in four Tweed tributaries (Leet, Eden, Leader and Eddleston Waters) has been described (Hussein & Mills 1982). The parasite fauna of eels from the same four tributaries was investigated by Keddie (1988) and *Acanthocephalus lucii*, *Spinitectus inermis*, *Bothriocephalus claviceps* and *Echinorhynchus ruttiae* were recorded.

THREE-SPINED STICKLEBACK, *Gasterosteus aculeatus* L.

Campbell, R. N. 1979b, 1985; Campbell, R. N. B. 1984; Campbell & Williamson 1979, 1983; Clark 1976; Findlay 1987; Giles 1983; Gillies 1983; Ibrahim 1988; Ibrahim & Huntingford 1989a,b, 1992; Kindness 1977; Kislalioglu & Gibson 1977; Maitland 1965, 1966c; Mills 1965; Rhind 1976; Walker 1985; Whyte 1985; Wright 1990.

Various experimental studies have examined the feeding behaviour and efficiency of sticklebacks (Giles 1983; Wright 1990; Ibrahim & Huntingford 1992). Wide morphological variation in sticklebacks has been described (Campbell 1985).

NINE-SPINED STICKLEBACK, *Pungitius pungitius* (L.).

Campbell 1979b; Campbell & Williamson 1979, 1983.

The nine-spined (ten-spined) stickleback is mainly found in low-lying coastal areas, particularly the Western Isles and the Inner Hebrides, and is not so tolerant of saline conditions as the three-spined stickleback (Campbell & Williamson 1979, 1983).

SEA BASS, *Dicentrarchus labrax* (L.).

There appear to have been no investigations on the distribution and biology of bass in Scotland, which occurs frequently in the Forth judging by records of its appearance in the catches of inshore fishermen. It is also taken by anglers fishing in the Forth in the vicinity of the warm water outfall of Cockenzie Power Station. The bass probably has a much wider distribution and, because of its culinary value, some work on this species would be useful.

COMMON GOBY, *Pomatoschistus microps* (Kroyer).

Healey 1972; Kislalioglu & Gibson 1977.

Healey (1972) described the abundance of the common goby in the estuary of the River Ythan, Aberdeenshire. The maximum life-span was 20 months with all individuals maturing and breeding in their first summer. Maximum lengths and weights were 5.5 cm and 1.5 g respectively. The amphipod *Corophium volutator* and the isopod *Jaera marina* were the main food items.

THICK-LIPPED MULLET, *Chelon labrosus* (Risso).

Campbell & Williamson 1983; Greer 1980.

Greer (1980) found the distribution of the thick-lipped mullet to be chiefly confined to three main coastal areas in southern Scotland, namely the Forth, Clyde and Solway, with few more northerly records, although it does occur in inner Loch Fyne, near Inveraray. Growth in all three areas studied was similar and slow.

THIN-LIPPED MULLET, *Liza ramada* (Risso).

Maitland & Campbell, 1992.

This species, found from central Scotland southwards along the North Sea coast, is smaller than the thick-lipped mullet with range in length of 25[^]10

cm at maturity (Maitland & Campbell, 1992). It is an inshore species found in a variety of shallow-water habitats and penetrating far above the tidal limit into pure freshwater.

GOLDEN MULLET, *Liza aurata* (Risso).

Maitland & Campbell, 1992.

This species is rare in northern waters and is the smallest of mullets found in the British Isles, when mature from 20-30 cm length (Maitland & Campbell, 1992). It is a coastal and estuarine species only present in northern areas during summer, migrating to southern deeper waters in winter. It will penetrate beyond the tidal limits of estuaries. Little is known about the biology and behaviour of this species in the British Isles (Maitland & Campbell, 1992).

FLOUNDER, *Platichthys flesus* (L.).

Alexander 1977; Birnie 1968; Dempsey 1981; Edwarson 1974; Fallon 1980; Kislalioglu & Gibson 1977; McIntosh 1978; MacFarlane 1967; North 1980; Pearson 1985; Radforth 1940; Summers 1974, 1979.

Flounders in the Ythan estuary, Aberdeenshire, of age 0, 1 and 2 years increased in length and weight from April to September but did not grow during winter (Summers 1979). *Males matured at the end of their third year and females in their fourth. Seasonal changes in abundance of flounders on intertidal flats were influenced by a spring immigration of immature fish. 0-group fish entered the estuary in late June/early July, a proportion of fish of age 3 and 4 left the mud flats in July, and a winter emigration of all age classes commenced in October and continued through winter, leaving a population of 0 group and maturing fish.*

Annotated bibliography for freshwater Salmonidae, excluding salmon and trout

GRAYLING, *Thymallus thymallus* (L.).

Anon. 1983; Burns 1976; Calderwood 1898; Gardiner 1989, 1992; Greendale 1975; Kerr 1992; Mackay 1970; Malloch 1910; Mills 1968, 1970, 1989; Mills, Griffiths & Parfitt 1978; Radforth 1940; Ricketts 1984.

The grayling was introduced to Scotland in the nineteenth century and there are several Scottish rivers with important sport fisheries (Mills 1968;

Gardiner 1992). An uneven distribution of grayling in the River Clyde was reported by Mackay (1970), with higher densities only found in large shallow pools with slow currents. Spawning is normally in April in shallow water with moderate current speeds, and on fine gravel (Burns 1976). There are spawning migrations of adult grayling into tributaries in the River Tweed (Mills, Griffiths & Parfitt 1978; Mills 1989). Fastest growth has been recorded, surprisingly, in larger rivers with poor nutrient status, and may be density related (Gardiner 1992). Growth is noted to decline rapidly with age, and maximum size in Scotland is 350-450 mm FL, 500-1100 g at 5-10 years (Gardiner 1992). Further work is required to quantify abundance and production in Scottish waters and potential competition with salmonids.

POWAN, *Coregonus lavaretus* (L).

Adams 1991; Adams & Tippet 1991a,b; Bernard 1980; Brown 1983, 1989; Brown & Scott 1987, 1988, 1990, 1991; Brown, Finnigan & Scott 1991; Brown, Pomeroy & Scott 1986; Cronyn 1969; Copeland 1981; Cowling 1992; Ferguson 1974; Finnigan 1983; Fuller 1975; Fuller & Scott 1976; Fuller, Mason & Fraser 1976; Fuller, Scott & Fraser 1976; Gervers 1954; Halliday 1976; Harvey 1980; Hogg 1980; Hunter 1978; Kissack 1986; Lamond 1922, 1931; Lawson 1979; McCulloch 1981; McEwen 1985; Maitland 1967a, 1969b, 1970a, 1980b; Maitland & Lyle 1990a; Malloch 1910; Miller 1984; O'Connell 1978, 1984; Parnell 1838a,b; Peebles 1974; Pomeroy 1982, 1987, 1991; Rashid 1984; Reid 1982; Rennie 1977; Roberts, Leckie & Slack 1970; Scott A. P. 1974; Scott, D. B. C. 1975, 1979; Scott & Rennie 1980; Scott, Rashid & Yekrangian 1981; Scott, K. J. 1979; Seale 1968; Slack, Gervers & Hamilton 1957; Tahourdin 1970; Yekrangian 1983.

Apart from salmon and trout, the richest bibliography of any Scottish freshwater fish is for the powan, largely due to a concentrated and long research programme by staff and students of St Andrews University. This work covers reproductive biology and hormonal control of reproduction (e.g. Fuller, Scott & Fraser 1976; O'Connell 1984), growth (e.g. Brown 1989; Brown, Pomeroy & Scott 1986), movement (Hogg 1980) and feeding (Pomeroy 1987, 1991). The Scottish populations of powan are confined to Lochs Lomond and Eck. Powan in Loch Lomond are attacked by river lampreys in summer (Maitland 1980b) and are also a common food of pike, although less so since the introduction of ruffe to the loch as this new species is now the most common item in the diet of pike (Adams 1991). However, there is concern regarding the importance of powan eggs in the diet of ruffe (Adams & Tippet 1991 a).

VENDACE, *Coregonus albula* (L).

Knox 1834; Maitland 1966b,c, 1967b; Maitland & Lyle 1990a,b.

The vendace is the smallest of the British and Irish *Coregonus*, with a mean length of 15-20 cm for adults (Maitland 1966c); the colour is silvery white and the back has a greenish-blue sheen. Two populations are historically recorded for Scotland: in Castle Loch, Lochmaben, where vendace apparently became extinct in 1911, and Mill Loch, Lochmaben, where vendace occurred in the 1960s but may now also be extinct (Maitland & Lyle 1991).

ARCTIC CHARR, *Salvelinus alpinus* (L).

Adams, Murray & Huntingford 1992; Barbour 1984; Barbour & Einarsson 1987; Campbell, R. N. 1979a; Campbell & Williamson 1979, 1983; Campbell, R. N. B. 1976, 1982, 1984; Friend 1956; Gardner, Walker & Greer 1988; Hardie 1940; Hartley 1989, 1990; Hartley, McGowan, Greer & Walker 1992; Hartley & Home 1985; Maitland 1983, 1992b; Maitland & Lyle 1990a; Maitland, Greer, Campbell & Friend 1984; Maitland, May, Jones & Doughty 1991; Mills, 1964; Partington & Mills 1988; Walker, Greer & Gardiner 1988.

The status of the Arctic charr in Scotland has been described by Maitland, Greer, Campbell & Friend (1984) and various forms of the species have been recorded (Friend 1956; *Walker, Greer & Gardiner 1988; Partington & Mills 1988*). Age and growth have been studied in three habitats in Scotland (Lochs Doine, Builg and Meallt) by Barbour & Einarsson (1987) and the variation in life history, ecology and resource utilization by the species has been discussed by Barbour (1984). Diet of charr in Loch Luichart has been recorded by Mills (1964) and in Loch Meallt and other Hebridean lochs by Campbell (1976, 1982, 1984). Concern for the future status and conservation of the species, particularly in southern Scotland, and the effect of acid rain on its survival has been expressed (Maitland & Lyle 1991, Maitland, May, Jones & Doughty 1991; Maitland 1992b). Some interest has been shown in the commercial exploitation of charr populations in Highland lochs. Data on stock recruitment, population structure and survival are required, before this occurs.

BROOK CHARR, *Salvelinus fontinalis* (Mitchill).

Maitland & Campbell 1992.

The brook charr was introduced to the British Isles from North America in 1868 (Maitland & Campbell 1992) and there are now several self-

propagating populations in lochs in North-west Scotland, Mull, Perthshire and Tayside. It is distinguished from Arctic charr by alternate dark and wavy lines creating a marbled effect on the back and dorsal and tail fins. Maitland & Campbell reported a study of two self-sustaining populations in hill lochs on the west coast of Scotland. In one loch, spawning took place in the loch itself while, in the other, the adjacent streams served as spawning and nursery areas. The diet of adult brook charr was almost exclusively tadpoles, small frogs and caddis pupae. In the second loch, brook charr were smaller and density higher, the diet comprised benthic invertebrates and adult terrestrial insects. The growth of charr in the lochs was good, considering the poor water chemistry, particularly in the first two years. Where spawning facilities are poor, it appears that brook trout are better at maintaining populations than brown trout. Maitland & Campbell (1992) considered the brook trout to be a vulnerable species that could easily be displaced by brown trout or perch and pike.

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