THE SEA LAMPREY *PETROMYZON MARINUS* (L.), RIVER LAMPREY *LAMPETRA FLUVIATILIS* (L.) AND BROOK LAMPREY *LAMPETRA PLANERI* (BLOCH) IN IRELAND: GENERAL BIOLOGY, ECOLOGY, DISTRIBUTION AND STATUS WITH RECOMMENDATIONS FOR CONSERVATION

F. Igoe, D.T.G. Quigley, F. Marnell, E. Meskell, W. O'Connor and C. Byrne

ABSTRACT

Three lamprey species occur in Ireland: sea lamprey, *Petromyzon marinus* (L.), river lamprey, *Lampetra fluviatilis* (L.) and brook lamprey, *Lampetra planeri* (Bloch). All three species are listed under Annex II of the EU Habitats Directive (Directive 92/43/EEC), thereby requiring member states to designate Special Areas of Conservation (SACs) for their protection.

The juvenile or ammocoete stages of all three species construct burrows in river sediment and feed on organic material. After metamorphosis, both the sea and river lamprey migrate downstream to the sea, where they feed on fish. The brook lamprey does not migrate to the marine environment, and the adults do not feed.

Lampreys are a primitive group of fishes, and they have been little studied in Ireland. However, recent interest in the group, principally driven by their inclusion in the EU Habitats Directive, has led to the initiation of several studies to collect basic information on their ecology in Ireland. This information will provide the basis for the development of meaningful conservation plans for all three species in Ireland.

This paper collates the information resulting from these studies, which should assist in developing appropriate conservation plans for these species.

F. Igoe (corresponding author e-mail: igoe@shrfb.com), Irish Char Conservation Group, 11 Poddle Green, Kimmage, Dublin 12
D.T.G. Quigley, Carrigadrohid Smolts Ltd, Carrigadrohid, Macroom, Co Cork
F. Marnell, National Parks and Wildlife Service, 7 Ely Place, Dublin 2; E. Meskell, National Parks and Wildlife Service, Government Buildings, Nenagh, Co. Tipperary;
W. O'Connor, ECOFACT Environmental Consultants, Tait Business Centre, Dominick Street, Limerick; C. Byrne, Carlow County Council, Co. Carlow.

INTRODUCTION

Lampreys are Ireland's most primitive freshwater fish species, belonging to a group of vertebrates known as the Agnatha, which literally means 'jawless fish'. Their mouth takes the form of a toothed circular sucking disk and they do not have scales or paired fins. The gills open directly to each side of the head, forming seven gill holes in a line behind the eye. Unlike other Irish freshwater fish, there are no gill covers (opercula). Their skeletal structure is formed from cartilage, instead of true bone, and their only nostril is located on top of the head, just in front of the eyes. Superficially, they resemble the European eel (*Anguilla anguilla* L.) in general form and movement (Fig. 1). This similarity has led to colloquial names in Ireland, such as the 'lamprey eel', 'lamper eel' (used in the. Lower Shannon area), or the 'sticky eel' (associated with the River Slaney area).

Renaud (1997) lists 34 nominal lamprey species for the northern hemisphere, only three of which occur in Ireland. In order of size these are: the sea lamprey, *Petromyzon marinus* (L.); the river lamprey, *Lampetra fluviatilis* (L.); and the brook lamprey, *Lampetra planeri* (Bloch). Whether or not the brook and river lamprey are separate species is open to question. Schreiber and Engelhorn (1998) found little notable difference in chromosome number or in nuclear DNA content between the two species. Therefore, it is possible that the river lamprey is an anadromous form of the brook lamprey.

Fig. 1— River lamprey *Lampetra fluviatilis*. Reproduced with the kind permission of Peter Maitland.

Mature adults of the three species are relatively easy to identify by their length and the shape of their dorsal fins (Table 1). The mouth structure, number and development of teeth are also distinctive features (Fig. 2). These diagnostic features, used for identification of adults, are not well developed in juveniles, making them more difficult to distinguish to species level. Gardiner (2003) has recently developed a key for juvenile lamprey, which concludes that diagnostic characteristics still need to be refined further to reliably distinguish brook and river lamprey ammocoetes from each other. Ammocoetes of sea lamprey, on the other hand, are readily distinguishable from those of river or brook lamprey, on account of their different pigmentation pattern and general morphology (Potter and Osborne 1975).

In some European countries, including Spain, Portugal and Finland, lampreys are a prized delicacy. However, in Ireland they have received little culinary attention and are not exploited. The paucity of both published and grey literature specifically relating to the lampreys in Ireland (e.g. Gibson 1953; Kennedy 1960; Kurz and Costelloe 1999; Byrne *et al*. 2000; Meskell 2000; Kelly and King 2001) reflects the absence of an Irish commercial interest in these fishes. Although listed in the Irish Red Data Book (Whilde 1993) as species whose status is 'indeterminate' but requiring attention, it was not until the enactment of the EU Habitats Directive that interest in the group and their conservation in Ireland was renewed. Kelly and King (2001) reviewed the international literature on the three species, concentrating on lamprey general biology, ecology and conservation. The focus of this paper is on material specific to lamprey species in Ireland.

METHODS

Distribution data for the three lamprey species are based principally on information compiled by Kurz and Costello (1999), with some new additions. Kurz and Costello (1999) cautioned that their distribution data may reflect the efforts of interested collectors, rather than the true distribution of lamprey in Ireland. Much of the data were anecdotal, and records with taxonomic detail to species level are mostly derived from adult specimens. Juvenile lampreys are more difficult to identify to species level (Gardiner 2003) and are also less noticeable than adults, due to their burrowing habit. On account of the greater size of the adults, the distribution of sea lamprey presented may more closely reflect the species distribution. Either way, more field data are required to establish if this is the case.

Methods employed to collect information included electrofishing surveys, visual observations from river banks, in-stream snorkelling surveys and

Table 1— Distinguishing features of adult sea, river and brook lampreys. Source Maitland (1972).

Species	*Length*	*Colouration*	*Fins*	*Teeth*
Sea lamprey	>50cm	Back and sides with a marbled pattern	Two distinct dorsal fins	Teeth on the oral disc close together in radiating rows; supraoral dental plate with 2 large teeth. Back and sides with a marbled pattern.
River lamprey	30–40cm	Back and sides of uniform colour	Two distinct dorsal fins	Teeth on the oral disc widely spaced and not in radiating rows; supraoral dental plate with, at most, 1 small tooth. Infraoral lamina with the range 7–10 cusps. Most teeth strong and sharp.
Brook lamprey	12–18cm	Back and sides of uniform colour	Dorsal fins joined	Teeth on the oral disc widely spaced and not in radiating rows; supraoral dental plate with, at most, 1 small tooth. Infraoral lamina with 5–9 cusps. All teeth weak and blunt.

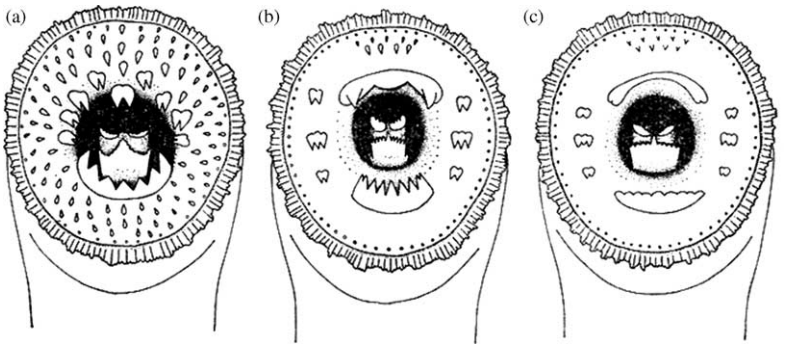

Fig. 2 — Mouth structure of adult lamprey: a) sea lamprey, *Petromyzon marinus*; b) river lamprey, *Lampetra fluviatilis*; and c) brook lamprey, *Lampetra planeri*. Source Maitland (1972).

examination of by-catch from conical nets. Conical nets were used as part of a juvenile glass eel (*Anguilla anguilla*) capture programme, aimed at restocking the species in the River Shannon catchment above the Ardnacrusha dam. Juvenile lampreys were also captured in substantial numbers at times. The aperture of the conical net was a circular metal frame with a diameter of 1.5m. A nylon net (2mm stretch mesh) in the shape of a cone (3m in depth) was attached to the frame. The net was hung from a road or footbridge crossing the lower reaches of tributary channels flowing into the River Shannon, generally on a flood tide, for several hours.

The principal author also contacted people who were thought to have data or anecdotal information on lamprey in Ireland, and this information was used to provide additional supporting material.

DISTRIBUTION OF LAMPREY IN IRELAND

Records for the three lamprey species in Ireland are presented in Table 2. These data are based on information collated by Kurz and Costello (1999), with some additions. As already pointed out, the species distributions are almost exclusively based on adult records. Difficulties arise with the identification of juveniles to species level. Fig. 3 shows the location of some of the better known sea and river lamprey sites.

SEA LAMPREY

Went (1946) stated that sea lamprey are found in all suitable rivers of Ireland and noted that they are particularly common on the River Shannon. Almost sixty years later, the lower Shannon area is still an important location for sea lamprey (Kurz and Costello 1999; F. Igoe, pers. obs.). Other important locations include the River Suir in Clonmel, the River Nore in Kilkenny, the River Moy in Ballina and the River Corrib in Galway. Sea lampreys have also been observed spawning at the head of tide in the River Bann at a place known as the 'Cutts' (W. Crozier, pers. comm.).

Many of these locations are along main river reaches immediately downstream of weirs, where sea lamprey can be found spawning at high densities and are easily observed. There are historical records for a number of locations for which there are no recent records, suggesting a possible decline in the population. For example, sea lamprey were recorded from the River Liffey at Island Bridge in 1906 (O'Riordan 1965). Records also exist for sea lamprey in Lough Corrib (O'Riordan 1965) and its tributaries, such as the Owenriff and Cornamona (Kennedy 1960). However Byrne *et al*. (2000) recently failed to find any sea lamprey during a comprehensive survey of the tributary streams of Lough Corrib, Lough Mask and Lough Carra.

A number of marine records exist for lamprey off the coast of Ireland, most of which are associated with commercial fishing (Table 3). Sea lamprey can travel considerable distances out to sea as illustrated by a record of sea lamprey in a *Nephrops* trawl, off the Porcupine Bank, 230km off the west of Ireland.

RIVER LAMPREY

On account of their smaller size, adult river lamprey are less obvious than sea lamprey to the naked eye, and less information is available on their distribution in Ireland. Known from a number of Irish rivers, their range appears to overlap with that of the sea lamprey. Important populations occur in the rivers Slaney, Mulkear, Barrow, Nore, Blackwater (Co. Cork), Laune and Bonet (Kurz and Costello 1999). They also occur in large numbers in the lower reaches of the River Shannon and its tributaries: populations have been identified recently in the Owenslieve River (F. Igoe, pers. obs.), the Owenogarney (Bunratty) River, the Landstown River and the Rine River,

Table 2— Freshwater locations with positive records for sea, river and brook lamprey. Data are based on Kurtz and Costello (1999) with some updates.

Hydrometric area	*Sea lamprey*	*River lamprey*	*Brook lamprey*	*Lamprey species (unidentified)*
HA 1	Foyle			Foyle
				Finn
HA 5		Lagan[1]		Mourne Beg
HA 6				Castletown
				Fane
HA 7			Lough Bane	
HA 8				Nanny
HA 9			Dodder	Liffey
				Rye
			Liffey	
HA 10		Aughrim		Dargel
				Glecullen
HA 11				Ovenavorragh
HA 12	Slaney	Slaney	Slaney	Slaney tributaries
HA 14	Barrow and tributaries	Barrow and tributaries	Barrow and tributaries	
HA 15	Nore	Nore	Nore	Kings
				Munster
				Dinin
				Owveg
			Srrigle	
			Ballyragget	
			Erkina	
HA 16	Suir	Suir		Suir
				Lingaun
				Clodiagh
				Drish
HA 18	Blackwater	Blackwater	Blackwater	Funsion
				Awbeg
HA 19	Lee		Lee and tributaries	Owennacurra
				Dissour
HA 20				Bandon
HA 22	Laune	Laune	Laune	Flesk
HA 23	Feale*			Feale
HA 24				Maigue
HA 25	Lower Shannon and tributaries	Lower Shannon and tributaries	Lower Shannon and tributaries	
HA 26			Upper Shannon and tributaries	Tributaries of Loughs Owel, Sheelin and others
HA 27	Ennis			
HA 29	Corrib[2]			Tributaries of Lough Rea
HA 30	Corrib[3]		Corrib[4]	
HA 34	Moy			Moy tributaries
HA 35	Lough Gill tributaries	Lough Gill tributaries	Lough Gill tributaries	
	Garavogue	Bonet	Arrow	
HA 36	Erne		Annalee	
HA 38			Clady	
HA 39			Leannan	

[1]Rosell (2002).
[2]At Galway city, downstream of weir.
[3]Records for Corrib pre-date current Galway weir.
[4]Byrne *et al*. (2001).

all in County Clare (reported in this paper). It is likely that they occur in most rivers that allow access to spawning and nursery areas from the sea.

BROOK LAMPREY

Brook lamprey are the smallest lamprey species in Ireland. They are non-anadromous and can complete their entire life cycle above physical barriers that impede upstream migration of anadromous lamprey. However, they may undergo migrations over considerable distances to reach their spawning beds (Hardisty and Potter 1971). Brook lamprey are the most widespread of the three species and are regularly captured during electrofishing surveys (Byrne *et al*. 2001; F. Igoe, pers. obs.) and kick sampling for macroinvertebrates (J. Lucey, pers. comm.). Byrne *et al*. (2001) examined the distribution of brook lamprey in the Lough Corrib catchment and found that they were recorded in 15% (57) of sites surveyed for juvenile salmonids. Although the majority of lamprey were ammocoetes, adults were confirmed for both Lough Corrib and Lough Carra tributaries. Subsequent to the work of Byrne *et al*. (2001), brook lamprey were also confirmed in tributaries of Lough Mask (F. Igoe and M. Kelly, pers. obs.). It is likely that they occur in most catchments through out Ireland.

EXPLOITATION OF LAMPREY IN IRELAND

No commercial fishery exists for any lamprey species in Ireland, although evidence exists to support the contention that lamprey were once harvested for human consumption in former times. In 1187, Giraldus Cambrensis noted in *Topographia Hibernica*, his account of the history and topography of Ireland, that 'The Shannon abounds in sea lampreys. They serve as luxuries for the rich' (O'Meara 1982). Evidence for the existence of river lamprey fisheries also occur for the River Barrow (J. Lucey, in prep.). Went (1946) noted that sea lamprey were taken in quantity when spawning in the River Shannon, and it is known that they were eaten by some local people (T. Finnigan, pers. comm.).

Table 3—Marine records of sea lamprey, *Petromyzon marinus* L., from the Irish coast.

Date	*Location*	*Total length (cm)*	*Weight (g)*	*NMI Reg. No.*[1]	*Notes*
14 June 1988	Porcupine Bank 230km west of Slyne Head, Co. Galway	49.5	158	NMI 7.1991	Caught in Nephrops trawl
24 February 1989	Dingle Bay, Co. Kerry	24.0		NMI 8.1991	Attached to coalfish *Pollachius virens* in gill net
22 May 1989	Owenalondrig River, Lispoole, Dingle, Co. Kerry	25.0		NMI 9.1991	Attached to seatrout *Salmo trutta* in gill net
October 1990	Fenit, Co. Kerry	14.5		NMI 10.1991	Attached to herring *Clupea harengus* in gill net
26 April 1990	16 SW Blasket Islands, Co. Kerry	83.0	910	NMI 21.1994	Went (1949)
6 August 1951	Whitehead, Belfast Lough, Co. Antrim				Deane (1952)
15 March 1973	Dingle Bay, Co. Kerry	68	294		Went (1974)

[1]NMI Reg. No. = National Museum of Ireland Registration Number.

In more recent years, however, exploitation of lampreys in Ireland was carried out for less conventional reasons. During the latter half of the nineteenth century, adult sea lamprey were harvested on their spawning beds and sold to supply universities with specimens for anatomy classes. Several hundred were removed annually for this purpose from tributaries of the lower Shannon (both the Mulkear River at Annacotty and the Kilmastulla River) and from the Plassey section of the main channel (N. Roycroft and P. Barry, ESB, pers. comm.). This practice was discontinued during the late 1980s.

BIOLOGY OF LAMPREY IN IRELAND

JUVENILE LIFE STAGE

The adult lamprey of all three species construct redds — compressions in a gravel or cobble river bed substrate — into which the fertilised eggs are deposited. These tiny white eggs, approximately 1.0–1.4mm in diameter, hatch after about two weeks. The larvae drift downstream and settle in slack areas in sandy substrates that are rich in organic sediment, usually in pools or behind boulders. There they burrow into the substrate, positioning their heads to face upstream and sucking down organic detritus and microorganisms. Both shade and water velocity appear to be important site characteristics (Maitland 1980), and large concentrations of juveniles are sometimes found among aquatic plants (Applegate 1950).

The mouth functions as a filter and is covered by a hood-shaped upper lip. All three species may be found at a single location, although the presence of upstream barriers often limits the upstream distribution of the anadromous species. Larval lamprey are blind, and their external features are rudimentary — the sucker, for example, is incomplete and the teeth are undeveloped. As a result juveniles can be difficult to distinguish from each other (Maitland and Campbell 1992; Gardiner 2003).

Maitland (1980) cites estimates from the literature for the duration of the larval stage of river lamprey and brook lamprey as 3–5 years. Estimates for sea lamprey range from two years (Morkert *et al*. 1998) to eight years (Beamish 1980). Differences in the duration of the larval phase probably reflect differences in latitude and other site factors such as food (Maitland 1980). Hardisty and Potter (1971) suggest that many studies underestimate the duration of the larval phase. Data are not yet available on duration of larval phase for juvenile lamprey in Ireland. Fig. 4 shows length–frequency distribution of lamprey ammocoetes captured in conical nets set on the Bunratty River (Owenogarney River) on a flood spring tide in April 2002. These were most probably river lamprey ammocoetes, as a large number of river lamprey having undergone metamorphosis (transformers) were also taken in the sample.

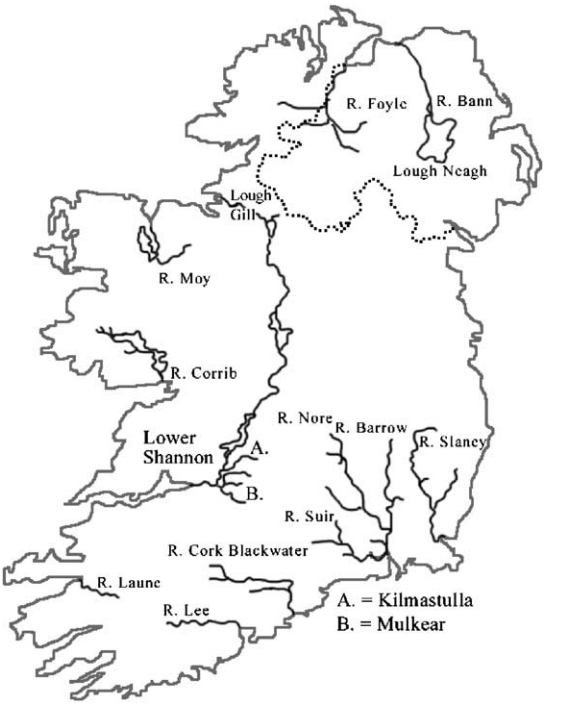

Fig. 3 — Distribution of primary freshwater sites for sea and river lamprey in Ireland.

POPULATION ASSESSMENT OF JUVENILES

A number of techniques have been developed to monitor juvenile lamprey abundance, using hoe methods (Friedl 1995), depletion electrofishing (Pajos and Weise 1994), or and electricity and pump (Bergstedt and Genovese 1994).

Electrofishing is useful as it is relatively quick and can be used in combination with other techniques. Most recent Irish ammocoete records come from electrofishing surveys. However, estimation of population size by electrofishing alone is difficult. In the experience of one of the authors (F. Igoe), juvenile lamprey < 5cm are rarely caught during electrofishing. This means that assumptions such as catch reduction in consecutive electrofishings at one site (Cowx 1983) — required for certain mathematical models used for estimating densities (e.g. Zippin 1958; Seber and LeCren 1967) — may not be appropriate. Fig. 5 shows the catch of lamprey by repeat electrofishing in a 20m stretch of a 2m wide tributary of the Black River, Co. Galway, in the Lough Corrib catchment. Difficulties in getting accurate density estimates using electrofishing

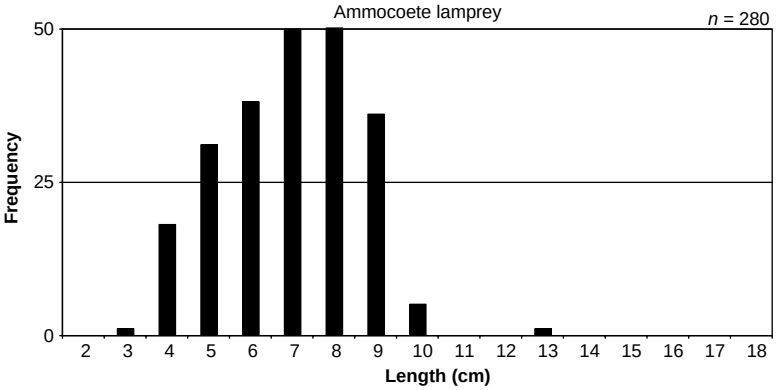

Fig. 4 — Length frequency distribution of ammocoetes or juvenile lamprey taken in conical nets set in the Owenogarney (Bunratty) River on 26 April 2002.

means that quantitative density data are limited for juvenile lamprey in Ireland. Natura (2002) estimated the density of juvenile lamprey by sieving sediment immediately downstream of lamprey spawning sites on the River Shannon at Plassey and found approximately twenty individuals (probably young of that year) per square metre.

METAMORPHOSIS (TRANSITION PHASE)

The development from the juvenile stage to the adult stage is characterised by a metamorphosis or transition period. The eyes become fully developed and the fins and teeth more pronounced. When all of their adult external features are defined, the lamprey are known as transformers or macrophthamia. Fig. 6 gives length data for transformers (river lamprey) caught in conical nets in tributaries of the River Shannon.

ADULT PHASE

Both sea and river lamprey migrate to the sea and feed on other fish species. Brook lamprey, however, remain in freshwater and do not feed as adults. Adult brook lamprey do not differ much in size from larger larvae (Fig. 7).

Adult sea and river lamprey, on the other hand, grow considerably larger than their larval stages on their new fish diet (Fig. 8). Kelly and King (2001) listed twelve known prey fishes of sea lamprey and eight for river lamprey from the published literature. In Ireland, sea lamprey have been recorded attached to herring (*Clupea harengus* L.), sea trout (*Salmo trutta* L.) and coalfish (*Pollachius virens* L.) in the marine environment (Table 3). A sea lamprey was even found attached to a basking shark (*Cetorhinus maximus* Gunnerus) which was

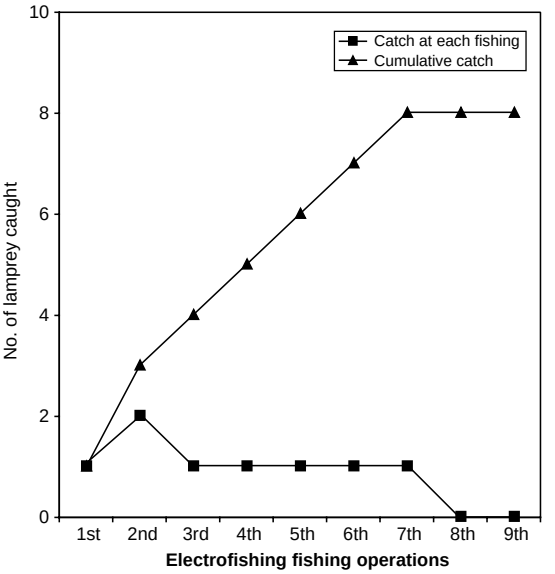

Fig. 5 — Result of a successive removal electrofishing exercise on lamprey capture in a small Irish river (the Black River) on 20 March 1997. The large number of electrofishing operations required illustrates the difficulty in obtaining quantitative data by electrofishing. Modified Byrne *et al*. (2001).

beached at Rosscarbery, Co. Cork (M. Kennedy, pers. comm.).

In freshwaters, lamprey attack marks have also been noted on brown trout in both Lough Conn, the Lee Reservoir (Kennedy 1960) and Lough Derg (W. O'Connor, pers. obs.). Harrod (2001) noted the characteristic disc shaped lamprey marks on 1.12% of pollan (*Coregonus autumnalis* Pallas) sampled in Lough Neagh. These marks were probably inflicted by river lamprey, which were occasionally found entangled in experimental survey nets (C. Harrod, pers. comm.). Maitland (1980) gives a detailed account of lamprey attacks on schelly (*Coregonus lavaretus* L.) in Loch Lomond, Scotland, by a landlocked river lamprey population. Attacks by river lamprey on cisco or vendace (*Coregonus albula* L.) have also been reported in Lake Onega and Lake Ladoga, north-western Russia (Maitland 1980).

SPAWNING MIGRATION OF RIVER AND SEA LAMPREY

The marine phase of river and sea lamprey may last up to several years prior to their return to freshwater to reproduce. The returning lamprey generally move upstream during the hours of darkness (Haro and Kynard 1997), keeping to shaded areas in hours of light and making use of refugia, such as log piles (Kelso and Gardner 2000). On 31 May 1992 and various dates during June 1992, adult sea lamprey were observed on video

migrating through the Borland fish pass at the Ardnacrusha Hydroelectric Power Station in the lower River Shannon (M. O'Farrell, pers. comm.). Greatest activity was noted during late evening (nineteen individuals moving between 20.00 and 21.30hrs (BST)), while little activity was observed during the morning (four individuals moving between 08.00–09.00hrs) or afternoon (two individuals moving between 16.00–17.00hrs) and no activity was observed during the hours of darkness.

Direct observations of river lamprey migrations in Ireland are limited. Mature adult river lamprey were recorded over a 1km stretch of the Owenslieve River (a small tributary of the Fergus estuary) on 15 and 20 March 2001. Information from the UK suggests that the upstream migration of river lamprey may occur over a protracted time period, from September to June (Hardisty and Potter 1971).

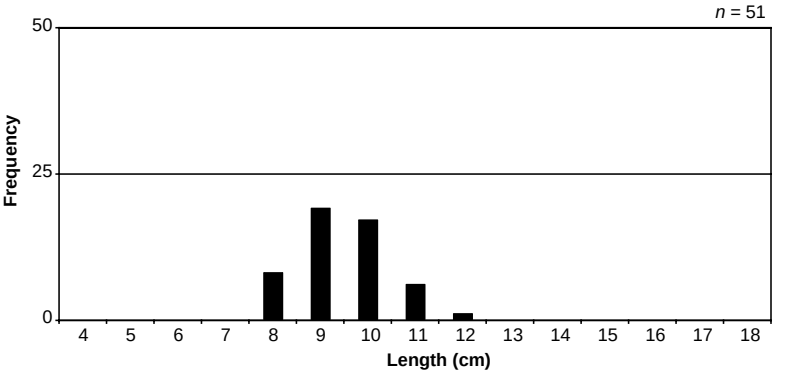

Fig. 6 — Length frequency distribution of a combined sample of transformer river lamprey taken in conical nets in the Rine River on 13 April 2002, 25 April 2002 and 4 January 2003 and the Owenogarney (Bunratty) River on 26 April 2002.

SPAWNING HABITS AND HABITAT OF LAMPREY IN IRELAND

In Ireland, adult sea lamprey first appear over the spawning beds from April onwards. However, mature adults may enter the lower reaches of rivers earlier in the year. For example, adult sea lamprey were observed in the lower reaches of the River Moy at Ballina, Co. Mayo, during February 2001 (B. Kennedy, pers. comm.) and March 2002 and 2003 (S. Neylon, pers. comm.). This may reflect the close proximity of the River Moy at Ballina to the sea.

On the Mulkear River, a tributary of the lower River Shannon, adult sea lamprey are not normally seen over spawning beds until mid-May (F. Igoe, pers. obs.; N. Roycroft, pers. comm.). Commencement of spawning at this time has also been reported for sea lamprey in the lower Shannon main river channel at Plassey, upstream of Limerick city, in the Kilmastulla River, a tributary of the lower River Shannon (P. Barry, pers. comm.) and in the River Suir (A. Culough, pers. comm.) Although the spawning period may span several months, most of the adults have left the spawning beds by early August. The 2002 spawning period for lamprey on the Mulkear River was longer than that normally observed for most years. Sea lamprey appeared over the spawning beds in mid-May 2002. Spawning activity peaked from mid-June to mid-July. However, a small number of individuals were still observed over the spawning grounds in early October. Similarly, late spawners were also reported from the main River Shannon at Plassey (K. Hannon, pers. comm.).

The main spawning site for sea lamprey on the Mulkear River is immediately downstream of Annacotty weir. The area available to lamprey for spawning at this location is limited and all suitable substrate is used. Fig. 9 shows the composition of substrate typically used for redd construction. Redd densities are relatively high and are often adjacent or overlap, forming multiple redds. Video footage taken in 2000 combined with direct observation suggest that the lamprey constructing redds avoided lifting stones from adjacent freshly constructed redds.

Direct redd count data were possible on the Mulkear River in 2001. A total of 136 redds were counted along a 200m (15–20m wide) stretch of the river, immediately down stream of Annacotty weir. These redds were generally confined to the low flow-wetted channel and were 10–39cm below the water surface. Another fifty redds were counted at another location approximately 500m downstream of the weir, where suitable substrate and flow conditions existed. The high densities of redds at these sites suggests that availability of suitable spawning substrates is the limiting factor for this population.

The sea lamprey redds at Annacotty were approximately 1.2m long and 0.8m wide, and the excavated depth ranged from 0.4m to 0.6m. At Annacotty, the sea lamprey usually spawned in pairs, although additional males did at times attempt to partake in the courting ritual. Due to spate conditions and heavy rainfall in 2002, it was not possible to repeat the redd count exercise. However, a snorkelling survey on 18 June 2002 did indicate high densities of adults (420 individuals) along the 200m stretch downstream of the weir and a further six specimens at the second location. A third location was also discovered, which had ten redds. Again, the number of redds directly reflected the availability of suitable spawning substrate material. Data collected from the nearby main River Shannon at Castleconnell

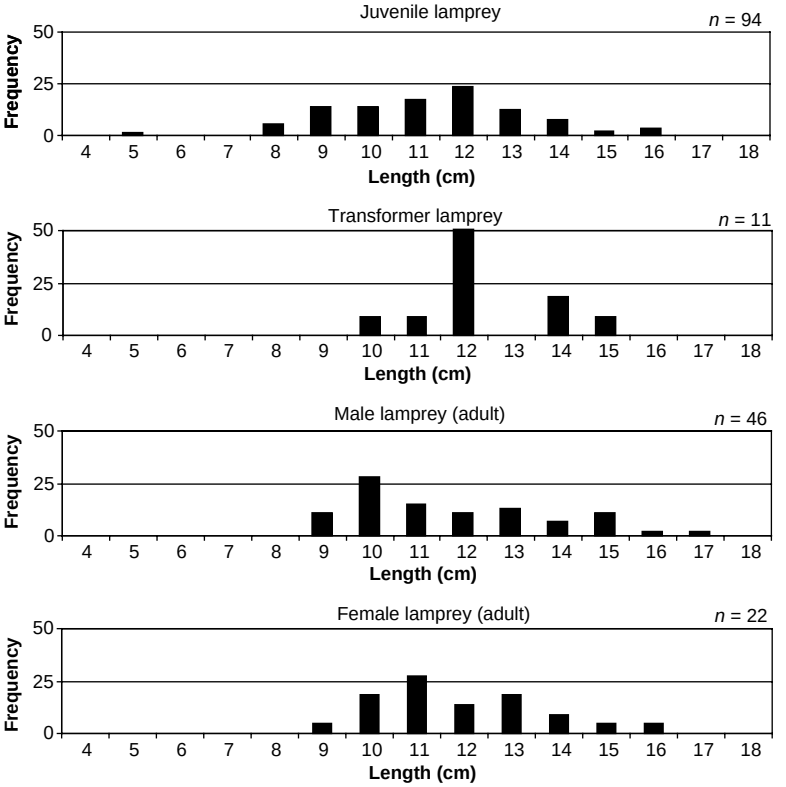

Fig. 7—Relative length frequency for brook lamprey, captured by electrofishing over a three year period (1996–8), in tributary rivers of the Lough Corrib catchment. More detail on these populations can be found in Byrne *et al.* (2001).

indicated that the spawning preferences of sea lamprey and Atlantic salmon, *Salmo salar* L., are similar (Meskell 2000). Not only did they use similar substrates (pebble/cobble), but redds were also made at similar locations. The average river current over sea lamprey redds was 0.35m s^{-1} (range 0.15–0.60m s^{-1}) and the average depth was 0.45m (range 0.20–0.50m). Water temperatures ranged from 15°C to 19°C during spawning.

Very little information is available on the spawning characteristics of river lamprey in Ireland. Large numbers of river lamprey were observed spawning at Annacotty in early May 2000 prior to the arrival of sea lamprey (W. O'Connor, pers. obs.). The Owenslieve River was electrofished on two occasions during March 2002 and returning mature adults were noted from the tidal head up to an impassable barrier, approximately 2km upstream. The majority (60%) of these fish were female.

Brook lamprey spawn in fine gravel usually from March onwards. Males and females congregate over gravel beds and often spawn in clusters or nests over fine gravel (Gibson 1953).

THREATS TO LAMPREY IN IRELAND

The Irish Red Data Book (Whilde 1993) lists the status of lamprey in Ireland as indeterminate. Maitland and Campbell (1992) list the threats to lamprey as water pollution, barriers to migration and habitat degradation. Both Kurz and Costello (1999) and Kelly and King (2001) recommend further collection of field data and collation of records nationally to facilitate conservation efforts.

IMPEDIMENTS TO UPSTREAM MIGRATION

In Ireland the single biggest factor limiting the distribution of anadromous lamprey are upstream barriers. Although the data available to date are limited, the impact of artificial barriers on the distribution of lampreys on a number of major rivers is evident. These barriers take the form of angling and ornamental weirs, derelict mill weirs, hydrological regulating weirs, navigation locks and dams for hydroelectric schemes—especially the large schemes on the Shannon and the River Lee, River Erne and the Liffey. A few case studies are presented to illustrate the impact of weirs on certain rivers.

Byrne *et al.* (2001) carried out a large electrofishing survey in the Lough Corrib catchment, including of 374 sites in 19 major subcatchments. No anadromous lampreys were encountered, despite the availability of suitable water quality and habitat—as evidenced by the distribution of brook lamprey at 15% of sites surveyed. The study was carried out above the regulating weir in Galway city on the River Corrib. Sea lamprey regularly spawn downstream of this weir (S. Hartigan, pers. comm.).

The second example is from the main River Shannon, which is impounded at two locations. Parteen dam diverts most of the main River Shannon discharge along a man-made channel to Ardnacrusha hydroelectric dam (upstream of Limerick city). Some water is allowed down the old river channel and sea lamprey spawn here downstream of Parteen Dam at Castleconnell. They also spawn in the Kilmastulla River, the confluence of which is approximately 50m downstream of the dam. Sea lamprey, however, have never been observed ascending the fish ladder to the main River Shannon at Parteen Dam (P. Barry, pers. comm.). Therefore their only other entry point to the middle and upper Shannon is over Ardnacrusha dam. Fish passage facilities are provided at Ardnacrusha by a Boorland lift. An adjacent boat lift may also facilitate limited passage when in use. Data for the period 1994–7 show that less than fifty adult sea lamprey ascended the Boorland lift (O'Connor 2002) in that period, an average of <17 individuals per annum.

This is a very low figure considering that the River Shannon drains approximately 18% of Ireland. Undoubtedly, upstream migration of anadromous lamprey is also severely impeded by the major hydroelectric dams on the Liffey, River Lee and River Erne.

The third example of impediment to upstream migration of anadromous lampreys by a weir is at the village of Annacotty on the Mulkear River, which is a tributary of the lower Shannon. This weir is at a 35° angle and is 2m high (surface water measurements). The weir is fitted with a Denil fish pass. Baffle boards, which are an essential part of the Denil fish pass design, were not in place between 2000 and 2003, and consequently the fish pass did not function properly. Direct observations were made at the weir in 2001 and 2002. During the height of the spawning activity in 2001, lamprey could be seen attempting to ascend the weir, sometimes as many as 60 individuals at a time. Most made little progress, although attempts at one side of the weir almost proved successful. On one occasion in 2002, in excess of sixteen lampreys were counted propping each other up on the weir. Others dashed and wriggled up this writhing mass in their attempt to surmount the weir. Despite the presence of suitable substrates, a subsequent snorkelling survey upstream of the weir found no evidence of spawning. However, in 2003, baffle boards were fitted to the Denil pass prior to the sea lamprey spawning run. Subsequently, in June of that year, three adult lampreys were noted at Cappamore, upstream of Annacotty Weir (F. Igoe, pers. obs.; Fig. 10). It is unknown whether these lampreys used the Denil pass or managed to negotiate the weir independently. The performance of this pass still needs to be critically appraised. A similar weir impediment also occurs on the River Suir at Clonmel (A. Cullagh, pers. comm.). A snorkelling survey of the River Slaney at Clohamon weir revealed a number of sea lamprey redds downstream of the weir in July 2003 (F. Igoe, pers. obs.). However, lamprey have never been observed ascending the fish pass on this weir (A. Long, pers. comm.).

HABITAT LOSS AND PHYSICAL DISTURBANCE

Physical alterations to river channels associated with flood alleviation schemes can potentially reduce lamprey habitats. The removal of silt in nursery areas can result in direct mortalities of burrowed ammocoetes and/or their displacement. Mortalities are also associated with heavy machinery tracking along the river bed, which crushes juvenile lamprey, as occurred in the Mulkear River (F. Igoe, pers. obs.). Gravel beds used for spawning may also be removed or destroyed following sedimentation by fine silt. Widening or deepening of river channels may also render hydrological conditions unsuitable for lampreys. Removal of woody debris or instream boulders reduces cover for both juveniles and returning adults. The statutory agency with responsibility for flood relief in the Republic of Ireland is the Office of Public Works (OPW). The OPW now regularly consults with the fisheries authorities and the National Parks and Wildlife Service in an effort to minimise impacts of drainage schemes in sensitive areas (M. Collins, OPW, pers. comm.).

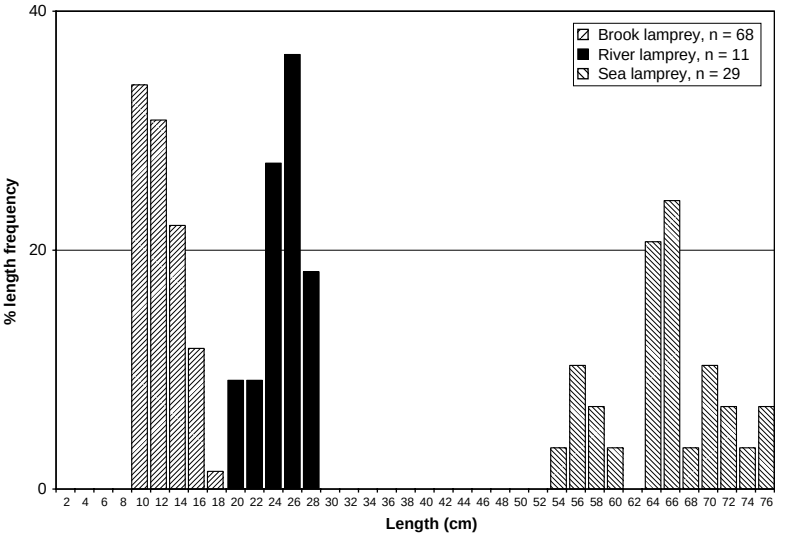

Fig. 8— Comparison of length frequency distribution data typical for the three species in Ireland: brook lamprey, captured by electrical fishing on Lough Corrib catchment (1996–8); river lamprey, from the Owenslieve River, Co. Clare, captured by electrofishing (2002); and sea lamprey, data based on visual length estimates from snorkelling surveys of the Mulkear River, Co. Limerick, and Owenogarney River, Co. Clare (2003).

WATER QUALITY

The impact of water quality, although recognised as a threat to all fishes, has not been quantified for lamprey. However, deterioration of water quality in areas supporting lamprey will inevitably reduce lamprey survival. In North America it is accepted that sea lamprey populations benefit significantly from improvements in water quality. A report by Ferreri *et al*. (1995) concluded that water quality improvement in tributaries of Lake Michigan was actually undermining the effectiveness of lamprey eradication programmes.

DISTURBANCE BY HUMAN ACTIVITIES

Additional threats to sea lamprey include disturbance associated with angling. Reports of anglers kicking lamprey from their redds still occur but are now infrequent. Although no

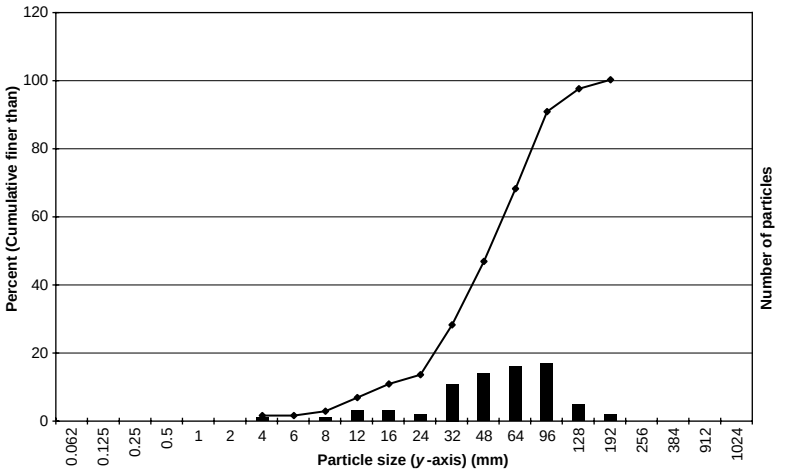

Fig. 9 — Length frequency (columns) and cumulative length frequency (line of diamonds) of substrate particles used by sea lamprey to construct redds at Annacotty, Mulkear River, Co. Limerick, in June and July 2002. Measurements taken along the *y*-axis (Wolman 1954).

statistics are available, it is likely that direct trampling on the redds by anglers may reduce egg survival. Trout egg and pre-emergent fry mortalities can be as high as 96% due to damage caused by wading anglers (Roberts and White 1992).

Stroke hauling of lamprey, particularly sea lamprey, is also practiced in some areas. Stroke hauling is the deliberate foul hooking of fish by dragging a treble hook or other sharp instrument across the body of the fish. The objective is to embed the hook externally. Although not as common as in former years, cases were still being reported from the Mulkear River at Annacotty in 2001 (S. Hasset, pers. comm.).

DISCUSSION

Kirchhofer (1995) described measures needed to conserve lamprey, including addressing the effects of habitat destruction, removing migration barriers, tackling acute pollution to improve water quality, improving and maintaining banks and riparian vegetation and returning engineered channels to a more natural state.

It is apparent from the limited data available at present in Ireland that obstructions to upstream passage need to be addressed in many rivers. Lamprey are notoriously poor swimmers compared to salmonids (Beamish 1974) and have difficulty traversing even the lowest dam. In North America, where sea lamprey are a serious problem for lake trout (*Salvelinus namaycush*) fisheries, low head barrier dams and electrical fields are used to prevent upstream migration to lamprey spawning areas (Hunn and Youngs 1980; Swink 1999; Porto *et al*. 1999). Paradoxically, studies in North America (Kelso and Gardner 2000) aimed at improving the management (i.e. eradication) of sea lamprey as a pest offer valuable information for the conservation of lamprey in Ireland and other European sites where they are considered threatened.

Physical habitat restoration will prove important to lamprey conservation in Ireland, particularly in areas impacted by land drainage, flood relief or channel realignment programmes for infrastructural projects such as road-building. Restoration techniques have been successfully employed for Atlantic salmon and brown trout (O'Grady and Duff 2000) and increased numbers of brook lamprey have been associated with sites in the Lough Ennell and Mulkear River catchments post restoration (F. Igoe, pers. obs.). Friedl (1995) reported similar increases in lamprey (*Endotomyzon marie*) densities after morphological revitalisation of sections of the Gail and Lavant rivers in Austria.

The enactment of the EU Habitats Directive, signed into Irish law in 1997 as the European Communities (Natural Habitats) Regulations, S.I. 94/1997, confers substantial protection on lampreys in Ireland. All three species are listed for protection, and to date there are ten SACs designated for lamprey species. However, site designation alone will not be sufficient to ensure their conservation, and proactive methods (such as tackling barriers and addressing water quality and habitat issues) will be required to ensure their conservation. This applies in particular to the anadromous lamprey species.

This paper has provided new field data, together with information compiled from unpublished reports by some of the authors. Much of the field data presented were collected by the principal author and colleagues while working in the Shannon Regional Fisheries Board, and are specific to the lamprey populations in the lower reaches of the River Shannon area. It is evident from these data that healthy lamprey populations still occur in some areas in Ireland, e.g. in the lower Shannon, and these areas should be prioritised for conservation efforts. Kurz and Costello (1999) concluded that the status of the three lamprey species in Ireland was good, and they suggested that Ireland is in a position to make a positive contribution to the European conservation of these species by protecting these populations. However, before this can be achieved, basic information is required on spawning locations, number of redds, migration patterns and population dynamics: this information is lacking for most Irish river systems. Such data are required

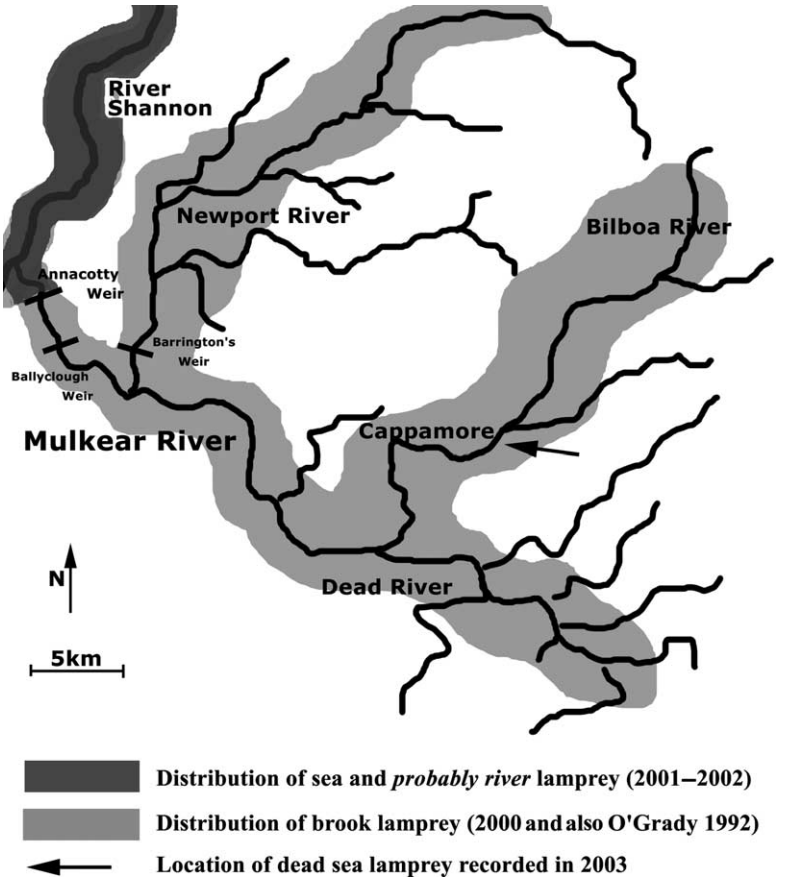

Fig. 10— Distribution of the adults of the three lamprey species on the Mulkear River between 2001 and 2003. The vast majority of anadromous lamprey were restricted the river reach downstream of a single weir at Annacotty in the lower part of the river.

if we are to design conservation protocols that will ensure the continued survival of the three lamprey species in Ireland.

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lamprey in the River Shannon contained in *History and topography of Ireland* written by Giraldus Cambrensis (1146–1223) to our attention.

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