Sampling methodologies for adult sea, river and brook lamprey in SAC rivers

Conserving Natura 2000 Rivers

Contents

1 Introduction

This report examines the potential for using standardised sampling methods for adults when assessing sea lamprey (*Petromyzon marinus*), river lamprey (*Lampetra fluviatilis*) and brook lamprey (*Lampetra planeri*) populations in SAC rivers.

An initial examination of methodologies recommended concentrating monitoring effort on the ammocoete life stage (APEM 2001), However, information on the adult life stage is also vital because:

- Sea lamprey ammocoetes are generally recorded at low densities relative to *Lampetra* ammocoetes (Gardiner *et al*., 1995, APEM 2002b, 2002c), making any assessment of stocks based solely on juveniles potentially difficult.

- River and brook lamprey cannot be reliably distinguished in the field at the ammocoete life stage, making additional monitoring of adults necessary to assess the status of each species.

2 Overall objectives

The overall objectives of this report are to:

- Review potential methods for sampling adult lampreys.

- Sssess the feasibility of recording lamprey adults during routine monitoring of population status.

Particular attention has been given to existing structures and operational systems used for monitoring adult salmon (traps and fish counters) which may be able to record adult lampreys with little or no modification.

3 Adult sea, river and brook lamprey behaviour

All three species of lamprey have a life cycle that includes both a sedentary larval (ammocoete) stage and an adult dispersal phase, during which spawning takes place. Both sea and river lamprey are anadromous, undergoing larval development in fresh waters before metamorphosing into adults and migrating downstream to the sea. Adult sea and river lamprey feed parasitically on fish in the marine environment. River lamprey stay within coastal regions and estuaries, while adult sea lamprey generally move further out to sea. Both species remain in the marine environment for at least one year before undertaking a spawning migration into freshwater (Maitland, 2001). In contrast, brook lamprey do not feed as adults and hence spawning is generally considered to be preceded by a relatively short upstream migration to the spawning areas (Thomas, 1962 in Strevens, *in prep*.).

Hardisty & Potter (1971) have drawn attention to a paucity of information on the adult marine phase of anadromous lamprey, and note that it is during the upstream migration and spawning phase that migratory species are most easily observed. This clearly suggests that any attempt to monitor adult sea, river and brook lamprey should focus upon the migration and spawning period when individuals are concentrated. With this in mind a brief review of the adult migratory life stage is presented below for each species.

3.1 Metamorphosis and downstream migration

Metamorphosis refers to the transformation of larval lamprey ammocoetes into adults and typically takes around three months to complete (Swink, 1995, Potter *et al*., 1978, Hardisty & Potter, 1971). The metamorphosis of sea, river and brook lampreys begins in the summer, although the precise timing and duration will vary between catchments and years (Potter *et al*., 1982). Potter *et al*. (1982) noted that many of the morphological changes that occur in river and sea lamprey relate to the development of features allowing them to feed parasitically (dentition and large suckers). The non-feeding adult stage of the brook lamprey does not complete these changes, but undergoes sexual development including the maturation of gonads (Vladykov & Kott, 1979).

The size at which sea lamprey ammocoetes undergo metamorphosis to the adult life stage shows a wide degree of variation, but generally occurs when individuals are between 120-145 mm in length (Bird *et al*., 1994). The timing of the migration of newly metamorphosed lamprey to the sea is variable but generally occurs in the autumn (Davis, 1967), although this may extend into the winter (Bird *et al*., 1994). Swink (1995) noted that the downstream migration of sea lamprey into the Great Lakes was bimodal, with peaks of activity occurring in November and April, the late spring arrivals having previously over-wintered in the substrate of tributaries.

Bird *et al*. (1994) reported that several hundred metamorphosed sea lamprey were caught in a 'Gloucester' eel net on one night in the River Severn at the end of November. The net was laid across the entire width of the river with the mouth facing upstream. No lampreys were caught during either the preceding or following nights. Bird *et al*. (1994) noted that newly metamorphosed adult sea lamprey caught in the lower River Severn were morphologically similar to more mature adults, with a blue-grey dorsal surface and dull white ventral surface. They possessed prominent eyes and a large buccal funnel. The dentition was well developed, consisting of rings of sharp teeth on the oral disc and central tongue, typical of the species. The lamprey caught in late November had a mean length of 182 mm, which suggested that these individuals had been feeding for at least one month prior to their downstream migration. Bird *et al*.

(1994) proposed that these lampreys had previously fed in the estuary but had subsequently been transported upstream, either by strong spring tides or through the migration of salmon upon which the lamprey were feeding (Potter & Beamish, 1977). However, it was also thought possible that the lamprey had been feeding upstream, presumably on upstream resident fish. Bird *et al.* (1994) concluded that the timing of downstream migrations was highly variable and may be interspersed with short periods of feeding in freshwater. The ability of sea lamprey to feed and grow in freshwater has been reported by Potter & Beamish (1977) and is thought have been one of the factors that have enabled freshwater populations to develop in the Great Lakes of North America.

Brook lamprey undergo metamorphosis at lengths between 120 to 150 mm. The initial changes mirror those of river lamprey, but metamorphosis continues until sexual differentiation occurs. Male and female brook lamprey also show morphological divergence, with the male developing a shorter trunk but longer tail and larger oral disc. These differences are thought to enable the female to carry more eggs and allow the male to be more active during nest construction (Potter *et al*., 1982).

River lampreys metamorphose into adults at a smaller size than both sea and brook lampreys, typically measuring between 90 and 120 mm (Maitland and Campbell, 1992). River lamprey will then undertake downstream migration to estuaries between late winter and early summer. Hardisty & Potter (1971) reported that newly transformed young adult river lamprey were caught in elver trawls in the River Severn in April.

3.2 Spawning migration

In Northern Western Europe, the spawning migration of sea lamprey generally occurs in the spring and early summer and shows a more consistent degree of synchronicity than that observed for river lamprey (Hardisty & Potter, 1971). This point is illustrated by data from the River Dee at Chester Weir, where both river and sea lamprey are routinely caught during salmon trapping operations. The sea lamprey catch data reflects this consistent timing of the spawning migration, the main period of activity being May and June (see Figure 1). It is also interesting to note the appearance of a small number of individuals in January.

Both sea and river lamprey spawning runs only occur during the night, with adults being sedentary during the daytime, resting under rocks and riverbanks. Sea lamprey spawning runs on the River Severn and in Eastern Europe have also been associated with particularly dark nights and high water levels (Hardisty & Potter, 1971). Females are attracted to the spawning sites by olfactory signals from sexually mature males who generally undertake the majority of nest building. These olfactory cues are so strong that French fisherman bait lamprey traps with highly prized, sexually mature males.

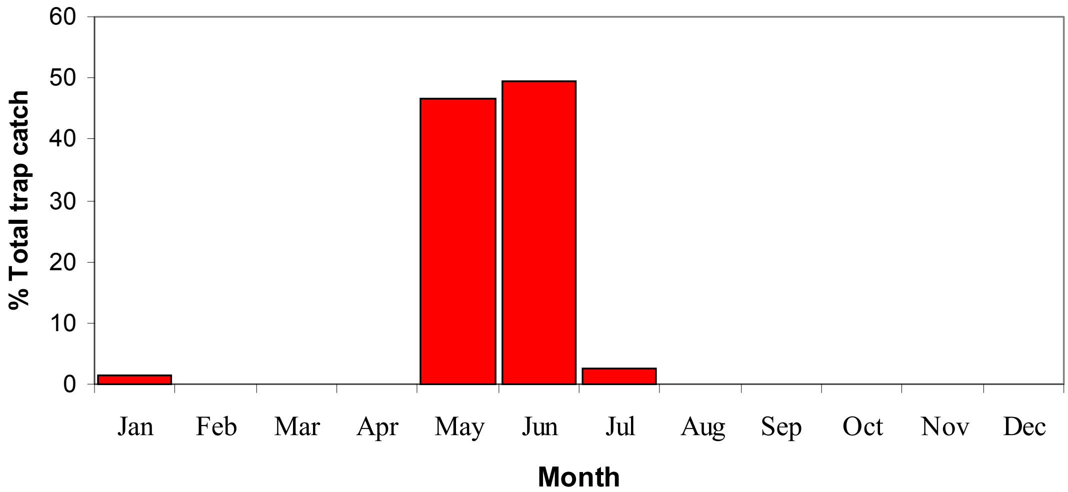

Figure 1. The relative abundance of sea lampreys from recorded trap catches at Chester Weir (n=77, composite data from 1992, 1993, 1997 and 1998. Data courtesy of Nigel Milner/Environment Agency).

Water temperature and high water levels are known to trigger spawning migrations in sea lamprey (Hardisty & Potter, 1971). Optimal water temperatures associated with sea lamprey migration in the Great Lakes were found to range from 10°C to 18.5°C. Skidmore (1959, reported in Hardisty & Potter, 1971) noted an association between temperature and the size of the migration, whereby sudden changes in temperature resulted in a spawning run. This is similar to spawning cues observed for coarse fish, where a sudden period of warm weather, in conjunction with increasing photoperiodicity in the spring, can trigger spawning in coarse fish (Mills 1991). This suggests that spawning runs may be anticipated to some degree. Skidmore (1959) reported that the only correlation observed between the number of upstream migrants and stream volume was negative and associated with a concomitant fall in water temperature. However, these observations were based upon lake populations of sea lamprey, and high water levels are thought to be more important to the migration of sea lamprey in North West Europe. This is consistent with anecdotal evidence from the River Camel where upstream sea lamprey migrations appear to be related to high summer flow levels (T. Jackson, riparian owner, *pers. comm.*). In this comparatively small South West river, sea lamprey spawning appeared to occur infrequently (every four to five years) and was associated with high spring and early summer water levels. In normal dry summer years, no spawning was observed.

Hardisty & Potter (1971) noted that the importance of both relatively high water temperatures and high flow levels in stimulating upstream lamprey migrations may not be mutually exclusive, since different authors have made their observations in different rivers and years. In addition, high water levels may be particularly important in allowing the passage of lamprey over obstacles, giving the appearance of sudden lamprey runs associated with high flow and not increased water temperature.

River lamprey upstream migration generally begins in late summer or early autumn, with a peak in activity recorded on the River Severn around October to November (Hardisty & Potter, 1971). However, Hardisty & Potter (1971) also noted that a spring migration was recorded in Russian rivers and this is consistent with high trap catches of river lamprey recorded in March and April by the Environment Agency on the River Dee in Cheshire (see Figure 2). Catch data shows two main periods of adult river lamprey activity, in spring (March to April) and autumn (August to November, see Figure 2). Autumn migrants are sexually undeveloped whilst spring migrants arrive with mature gonads and may move directly to the spawning site.

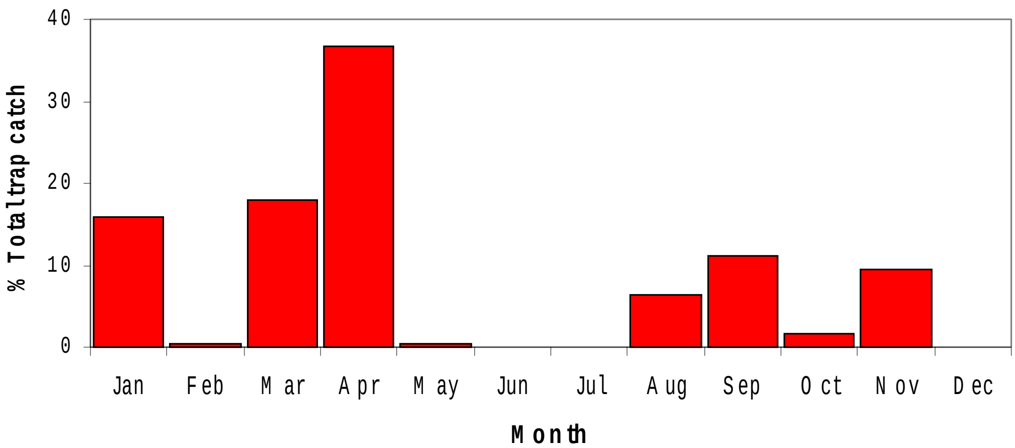

Figure 2. The relative abundance of river lampreys from recorded trap catches at Chester Weir (n=313, composite data from 1992, 93, 97 and 98). Data courtesy of Nigel Milner/Environment Agency).

Brook lamprey spend their entire life cycle within fresh water and therefore long upstream migrations to spawning sites are not undertaken by this species (Hardisty & Potter, 1971). However, brook lamprey do undertake small upstream migrations prior to spawning, the extent of which will depend on stream gradient. This may impact upon the distance ammocoetes drift downstream during development, and spawning habitat availability (Thomas, 1962).

Very few observations of adult brook lamprey migrations have been recorded, although Strevens (*in prep.*) described an unexpected downstream drift of adult brook lampreys immediately prior to spawning. He caught several hundred adult brook lampreys in the Hampshire Avon in fyke nets set overnight. The downstream movement was recorded during an initial trapping study in 1988 and more recently in 1999. On both occasions, the drift started in February and lasted until May, which is consistent with the timing of non-parasitic lamprey migrations to spawning sites reported by Hardisty & Potter (1971). However, the latter were upstream, which was considered to be a mechanism to compensate for the downstream drift exhibited by ammocoetes. Strevens (*in prep.*) considers that the observed spawning migration of brook lamprey may include both a downstream and upstream component, the importance of which should be considered when developing action plans to ensure the favourable conservation status of this species.

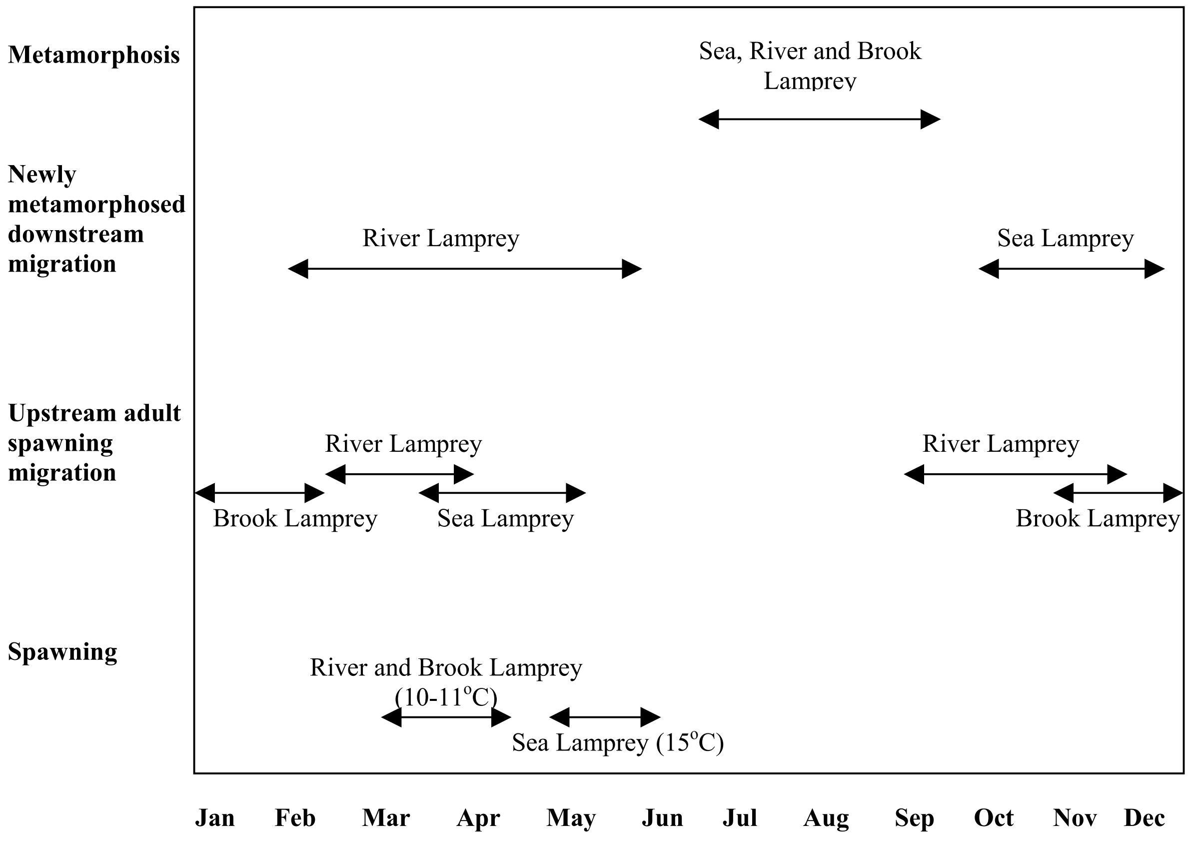

Figure 3. The timing of lamprey metamorphosis, migrations and spawning behaviour. (The temperatures accompanying spawning behaviour refer to water temperature requirements, based upon a review of lamprey behaviour in Hardisty & Potter, 1971).

4 Adult lamprey sampling

Sampling of newly metamorphosed and mature anadromous adult lampreys during migrations has previously been undertaken by electric fishing (Gardiner & Stewart, 1997), trapping (Maitland *et al*., 1994, Morris & Maitland, 1987) and netting (Bird *et al*., 1994). Samples and data have also been collected from adult sea lamprey caught in power station intakes (Maitland *et al*., 1984).

4.1 Trapping

The use of traps to sample adult lamprey may conveniently be split into temporary and permanent. Temporary traps have been installed to target spawning runs and include both the use of nets and specifically designed traps (Tuunainen *et al*., 1980, Morris & Maitland, 1987). Permanent traps have been developed in association with weirs and electric barriers to remove adult sea lamprey in response to the colonisation and decimation of fish stocks in the Great Lakes, North America (Smith, 1971). These traps removed thousands of lampreys but their use was gradually curtailed in the 1950s, as the use of lampricides became more prevalent. Permanent traps in the UK would be based upon existing salmon traps, which are also associated with weirs.

Temporary traps

Traps are used in Finland to harvest the spawning runs of river lamprey from August to February. Sea lamprey are rarely caught since their geographical distribution is limited to the southern edge of Finland (Maitland, 1980). Finnish fishermen use an array of wooden lamprey basket traps built upon trestles, which span and subsequently sample the entire width of the river.The baskets have a wide mouth, which tapers into the trap and acts as a funnel, stopping lamprey from escaping. Although sampling efficiency is not known, sufficient numbers are caught for this species to represent an important source of income for the fishermen, with approximately 2 million individuals caught in 1979.

Modified fyke nets were used to sample the downstream movement of adult brook lamprey in the Hampshire Avon. This was first noted in 1984 as a by-catch in fyke nets set to target the movement of fish (Strevens, *In prep*.). This phenomenon was subsequently targeted with the same fyke net design in 1999. The lampreys were caught in fyke nets placed in mid-stream and orientated to catch fish moving downstream. The fyke nets were originally designed to trap eels but were modified with a particularly small mesh size, enabling them to trap adult brook lamprey. The nets were located in the middle of the catchment and only sampled a fraction of the river discharge. The proportion of the adult migration sampled was unknown and only semi-quantitative data was produced. However, the large number of adults caught (over 400) appears to be indicative of a much larger-scale movement in the catchment as a whole. The traps were emptied twice daily in order to detect diel activity patterns, which showed a marked nocturnal bias. This nocturnal activity is symptomatic of a photophobic response common to all migrating lamprey adults (Hardisty & Potter, 1971) and it has been suggested that the use of searchlights could be used to direct adult lampreys into traps during night movements.

The traps used by Morris & Maitland (1987) were made from a single plastic tube through which drainage holes had been drilled. A detailed design is presented in Figure 4. Lampreys enter the mouth of the tube through a tapering funnel (the outer funnel) placed at the entrance to the trap. This prevents adult lamprey escaping from the trap through the entrance. A second, inner funnel is placed further down the tube, which ensures that trapped specimens are concentrated at the end of the tube and further reduces the chance of escape. When installed, the entrance to the tube should point downstream.

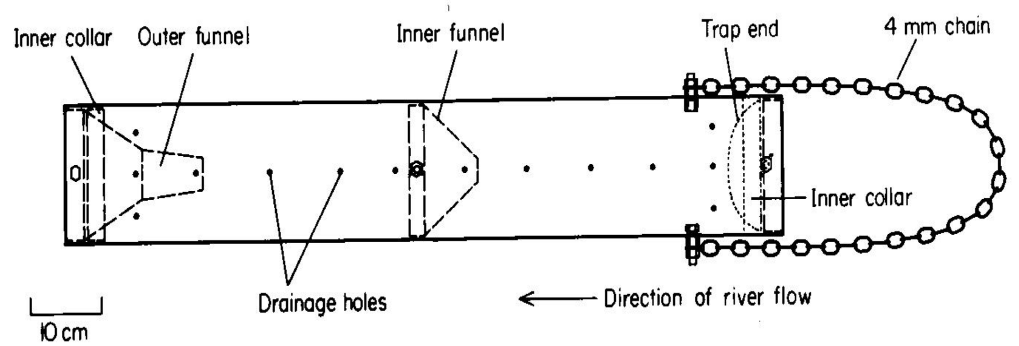

Figure 4. Trap design developed by Morris and Maitland (1987). This particular model has both an outer and an inner funnel. The sampling tubes were made of UPVC domestic waste discharge pipe (approximately 15 cm in diameter).

The traps were fixed to the river bed with 4 mm chain secured to a stake, or a stable feature such as a tree. Morris & Maitland (1987) compared the performance of this trap design, utilising both a single and double inner funnel, to that of two alternative trap designs over two years. The additional traps consisted of a cage (Schudlt & Heinrich, 1982) and barrel with an internal funnel.

An initial comparison of techniques found that the barrel design caught significantly more adult brook lamprey than the cage design. The barrel caught a total of 92 brook lamprey and 2 river lamprey. The barrel design was then compared to the double funnel design described above. The barrel caught 142 brook lamprey and 54 river lamprey, whilst the funnel design caught 284 brook lamprey and 33 river lamprey. These catches were not significantly different. However, the barrel was found to be cumbersome to use, difficult to empty and could only function in areas that were deep enough to ensure that the entrance to the trap was available to lamprey. The tube design was therefore adopted as the preferred sampling method and its catch rate (efficiency) was compared between designs with and without the second internal funnel. The trap with the inner funnel caught 262 brook and 39 river lamprey, whilst the trap without an inner funnel caught only 50 brook and 2 river lamprey, thus confirming the importance of an inner funnel to retain caught individuals.

Adult lampreys may enter the traps either by accident or when they actively seek out cover during the day. They are at their most effective when laid in conjunction with obstructions to migration such as weirs. Morris & Maitland (1987) noted that the trap did not catch any sea lamprey, but this is ascribed to the absence of the species from the Loch Lomond area where their work was undertaken. However, if the design were to be used to target sea lamprey, further consideration should be given to the size of the entrance. A larger entrance might allow the capture of sea lamprey, but would also allow river lamprey to escape. Hence, two sizes of trap may be required to successfully survey for both species, although the latter has not been tested in the field.

Nevertheless, the double funnel trap design is relatively cheap to build and install, and Morris & Maitland (1987) suggest that it could lend itself to the trapping of an entire river width. This could be achieved by laying a series of traps across the river using a chain stretched from bank to bank. However, consideration would need to be given to the impact on other species, particularly migrating salmonids.

Gardiner & Stewart (1997) recommended the trapping of an entire spawning run as the preferred option for estimating the population size of adult river lamprey. However, the authors were not able to pursue this sampling strategy when assessing a population of adult river lampreys moving upstream from Loch Lomond. Targeting the adult spawning run would be particularly difficult for river lamprey, which do not show such a high degree of synchronicity in the spawning migration as that observed for sea lamprey. However, Gardiner & Stewart (1997) did undertake small-scale trapping on the River Endrick in Scotland, based on the design of Maitland & Morris (1989).

The traps were deployed at two sampling sites on the River Endrick and one site on Blane Waters between November 1995 and May 1996. Trap catches were dominated by brook lamprey adults, which contributed 97% of the catch. A total of 186 brook lamprey and 5 dwarf river lamprey were caught in 136 trapping days, which was equivalent to approximately 1.4 and 0.04 lamprey adults per trap day, respectively. Electric fishing over the same sampling period caught 121 adult brook lamprey and a single adult dwarf river lamprey. However, a direct comparison between the two methods is not possible since no details of the electric fishing strategy were given. Only three river lampreys were caught during this survey, two by electric fishing and one in a trap. Normal, non-dwarf river lampreys migrate upstream from the Clyde Estuary and are known to spawn in the River Endrick, although they were previously believed to be uncommon in the river (Gardiner & Stewart, 1997).

Permanent traps and fish counters

The control of sea lamprey in the Great Lakes, North America, initially targeted the upstream spawning migration of adult lamprey with electrical weirs and screens (Smith, 1971). These structures were primarily used to block migration but also included trapping devices. The most effective structures were electromagnetic weirs, which directed adult lamprey into traps without causing downstream obstructions to flow. However, these mechanisms were not species specific and all fish moving upstream were subject to trapping.

Lamprey are not especially strong swimmers and in fast flowing rivers are usually seen moving up the edges of the main channel in relatively shallow water (Hardisty & Potter, 1971). Nevertheless, they are capable of short bursts of intense swimming, punctuated by rest periods when the adults can attach themselves to the substrate with their sucker. In this way adult lamprey are capable of climbing quite high weirs and waterfalls by alternating intense swimming and rest (Applegate, 1950 in Hardisty & Potter, 1971). Applegate (1950) also noted that, when faced with a barrier to upstream movement, adult lamprey first undertook an exploration of the flow regime, presumably looking for the easiest route over the obstruction. Although weirs can act as barriers to movement, adult lamprey are capable of utilising fish passes so, where fish traps are present, the monitoring of adult lamprey will be possible.

Permanent fish traps are used in the UK to assess salmonid spawning migrations and are often associated with weirs. One such fish trap is found on the River Tamar, Devon at Gunnislake (see Figure 6) where anecdotal reports have been made of up to 50 adult sea lamprey being caught in a single night (H. Sambrook, Southwest Water, *pers. comm.*).

An alternative type of physical barrier has been reported by Tuunainen *et al.* (1980) who noted that strongly lit bridges in Finland obstructed the upstream migration of sea lamprey, and that Russian fishermen used lamprey photophobic behaviour to guide migrating adults into traps. However, for this to be used, the impact on other species would need to be considered.

Figure 6. Gunnislake Weir on the River Tamar with the associated fish pass and trap (Cornish side).

Figure 7. Gunnislake Weir – Fish pass entrance (Cornish side).

Anecdotal reports also exist of adult lamprey using a fish pass in the lower reaches of the Hampshire Avon (A. Strevens *pers. comm.*). Two fish passes are present in this particular stretch of river, which has a relatively low flow regime. The older of the passes is not currently maintained as a trap. Adult sea lamprey show a preference for the older structure, presumably reflecting a selection based upon preferential flow.

Adult lamprey catch data has been recorded at a fish pass and trap on the River Dee, as a by-catch of an Environment Agency salmonid trapping programme. Lamprey counts have been maintained since the initiation of the River Dee programme in 1992, except for a 2-year period during the 1990s. A summary of adult sea and river lamprey catch rates is presented in this report (see Section 3.2), but it should be noted that trapping is only undertaken for about 60 % of the time. The data produced is therefore only semi-quantitative since the proportion of adults passing upstream unseen is unknown.

However, the use of a permanent fish trap to monitor adult lamprey populations is likely to be more efficient than a temporary trap, due to the practical difficulties associated with maintaining temporary facilities. It should also be borne in mind that, as traps are frequently associated with weirs, which can be to a greater or lesser extent impassible, they are likely to offer the capability to catch a significant proportion of the whole river run.

Fish traps and passes[1] may also carry fish counters, some of which have an associated video validation system. A typical counter is made up of three parallel metal electrode strips running perpendicular to the flow, often attached to a purpose built structure or occasionally on gauging weirs or across the top of a fish pass. The change in electrical conductivity of water above the electrodes generated by the presence of a fish is detected and recorded by the counter's electronic circuits. A typical electrical signal is produced, allowing downstream migrants to be separated from upstream migrants. The total count over the migration season provides a measure of the spawning run for migratory salmonids.

However, there are a number of potential interferences with the counting system. These include non-target fish movement, water turbulence and electrically conductive debris bridging the electrodes. Of particular relevance to this study is the interference that can be caused by migrating adult lampreys. This can occur in two ways. The uninterrupted passage of lampreys on their way upstream can lead directly to false counts, while sea lampreys can attach themselves to the counter surface via the oral disk, and literally 'sucker' themselves over the surface of the counter. This is thought to be a method of overcoming the flows encountered on such structures, which may be towards the upper end of the spectrum passable by sea and river lamprey respectively. In this situation, the body of the lamprey frequently covers the electrode array, often for extended periods, causing false counts to be generated.

In order to overcome these interferences and validate the upstream migratory fish count, a means of scrutinising counts is often required. Video validation is the preferred method, a video camera mounted above the electrode strips being used to monitor each individual count using infrared photography, as invariably most fish migration takes

[1] Sometimes associated with flow gauging weirs (e.g. on the Eden)

place at night. The video recordings have to be scrutinised manually, and each invalid salmonid count caused by lampreys is removed from the database.

This process was observed during a field visit to the River Tamar between March 14th and 16th 2002. At the Environment Agency Offices in Launceston the process was demonstrated, false counts generated by lamprey being easily identified and species readily confirmed. The validation procedure is being rigorously pursued by the Agency on the River Tamar following its confirmation as an Index River for part of the salmon monitoring requirements. Although the Tamar is not a cSAC river, the extensive (if somewhat laborious) video validation system has been demonstrated to provide a reliable means of obtaining accurate data on the proportion of the adult lamprey run which uses the Cornish fish pass at head of tide. Although the majority of the adult migrating population would be considered to use the pass, an alternative pass (albeit less efficient), is available on the Devon bank. Under high tides lampreys may be able to negotiate this weir directly. Nevertheless, the validation system does offer the possibility of providing good-quality relative abundance data as a by-product of migratory salmonid counts, where such facilities exist.

Trap Efficiency

When considering both temporary and permanent fish trapping facilities, it is important to realise that only in rare cases are they 100% efficient and hence capable of sampling the entire run. In most installations, even with heavily engineered permanent traps, under high flows an unknown proportion of the migratory fish population will by-pass the trap (H. Sambrook, Southwest Water, *pers. comm*). In the case of temporary installations this is more likely. In each case the data produced is at best semi-quantitative since the efficiency of each method is difficult to determine.

Theoretically, the use of two traps, one upstream of the other operated as a mark-recapture experiment, would give a measure of trap efficiency. However, experience of operating this system on the River Wolf (Tamar catchment) indicates that considerable resource is required to have a reasonable chance of success. In addition, it is not possible to correct or correlate catch with nest counts due to the variable number of individuals involved in the process of nest building and spawning at each location or nest.

Nevertheless, the efficiency of trapping methods can be improved by increasing the number of traps in place or creating partial obstructions such as fish fences (bearing in mind the requirements of other species) and through the development of a rationale for sample site selection. However, an unknown proportion of migrating adult lamprey will inevitably avoid capture.

4.2 Spawning nest counts

An indirect assessment of adult lamprey populations can also be made by evaluating spawning activity and counting the number of nests built along a river. For instance

Cochran & Gripentorp (1992) state that adult brook lampreys are readily detected, collected and identified during their aggregation when spawning, and they counted brook lamprey adults during snorkelling surveys which targeted spawning sites.

A survey of the River Eden, Cumbria, was undertaken in 2001 by the Environment Agency, to identify and count the number of spawning nests built by sea lamprey. The identification of nests was carried out visually and was made both from the river bank and from canoes. This wide-ranging survey identified a concentration of spawning nests situated approximately 25 km upstream of the tidal limit at Warwick Bridge. However, this was the first year that such work had been undertaken and a formal methodology has not been established.

Any interpretation of nest counts should take into account the spawning requirements and mating strategy of the targeted species. Brook and river lamprey have similar temperature requirements and therefore spawn at the same time of year (10–11°C around March to April), while sea lamprey require warmer water and spawn later (15°C around May to June). Of particular importance will be the mating strategies employed, such as the numbers of adults associated with nest construction and the ratio of males to females. Brook lampreys spawn in groups and, without knowing how many individuals spawn together, an assessment of the adult population is not possible. Sea lamprey spawn in smaller groups, including a high proportion of single pairs. However, both polygamous and polyandrous mating behaviour occurs, and its frequency will affect nest count interpretations and may vary between catchments in response to environmental factors such as spawning habitat availability.

Given the difficulty of knowing how many adults are associated with individual nests, an assessment of spawning activity can only provide an indirect and therefore relative estimate of adult numbers. In addition, this method of assessing lamprey populations does not give any indication of egg survival or recruitment to the ammocoete life stage. However, knowledge of the geographical distribution of nests may prove to be of importance in targeting downstream areas of suitable nursery habitat for ammocoete sampling. The identification of historical sea lamprey spawning sites on the River Tay and Spey was used to direct sampling effort for ammocoete surveys. However, both of these rivers lie at the northern limits of sea lamprey distribution, resulting in variable spawning runs (Gardiner & Stewart, 1997) and low sea lamprey ammocoete densities (Gardiner *et al*., 1995, APEM 2002b, 2002c).

Finally, it should be remembered that, as with salmonid redd counts, nest counting will be fraught with similar problems relating to river height and turbidity. Furthermore, late spring or early summer spates may flatten nests and render counting extremely difficult if weather conditions are not favourable in any given year. When considering nest counting as part of a monitoring strategy, it is therefore more appropriate to ensure that effort is applied consistently year on year in specifically targeted river reaches where there is a known history of spawning activity (see below). This can then be developed in the light of new sightings or specific walkover surveys if considered necessary.

A more qualitative assessment of adult spawning behaviour can also be provided via the consistent appraisal of spawning activity by ghillies and bailiffs who have local knowledge and regular access to a river. This has been undertaken through the use of questionnaires on the River Spey (Gardiner & Stewart, 1997), and collation of historical spawning data for both the Rivers Spey and Tay (APEM 2001b, 2001c).

5 Conclusions

Five survey techniques have been identified as practical methods for monitoring adult lamprey (see Table 1). These include temporary traps, permanent migratory salmonid traps, fish counters, nest counts and questionnaires. All these techniques can be used to target the lamprey spawning migration and subsequent spawning period when adults are concentrated in the catchment and most easily monitored.

Table 1. Sampling methods appropriate to the monitoring of adult lamprey.

Survey technique	**Availability**	**Requirements**	**Resources**	**Data type**
Temporary traps	Requires installation	Site selection Installation Regular site visits for catch processing	High	Semi quantitative
Fish traps	Currently installed	Regular site visits and catch processing	Low[1]	Semi quantitative
Fish counters	Currently installed	Regular data processing	Low	Semi quantitative
Spawning nest counts	No existing protocol	Walkover survey/canoe survey	Moderate	Indirect, Semi quantitative
Local knowledge		Data collection (questionnaire, interviews)	Low	Anecdotal

[1] In most cases traps will be serviced regularly for migratory salmonid requirements.

Where present, the use of existing fish passes and traps is particularly desirable, since it removes the need to set and visit dedicated trapping facilities specifically for lampreys. However, any integration of adult lamprey and salmonid spawning run monitoring must acknowledge the additional resource required when collecting lamprey data. If trap operation is continuous this is likely to be minimal.

Furthermore, fish counters with video validation offer an excellent opportunity to gather good-quality data at minimal cost. The co-ordination of adult lamprey monitoring with existing migratory salmonid monitoring programmes could prove cost-effective on SAC rivers. However, it should be recognised that many salmonids spawn further up the catchment than sea lamprey, and some fish traps/counters will be placed upstream of lamprey spawning sites (for example, the Corby Coops on the Eden upstream of the main spawning area at Warwick Bridge). Similarly, in the River Spey, lamprey spawning sites are present below the lowest fish passes, and the monitoring of adult activity in these rivers is therefore not currently feasible without investing in specifically constructed facilities.

Temporary trapping, for example using the trap design of Morris & Maitland (1987), is both feasible and practicable, but the resource requirements may be too great to cover the entire migration period and hence limit the ability to obtain data on a reasonable proportion of the adult run. Any adult run data collected must be meaningful and hence a significant proportion of the migration period would need to be covered. Given the practical problems associated with maintaining temporary traps this is probably not a preferred sampling option, although technically feasible for other studies on the biology of the species.

An indirect measure of relative lamprey abundance and/or spawning activity can be provided by counting the number of spawning nests. Similar work is undertaken for salmon, where redd counts are used to provide an indication of the size of spawning stocks. This has been carried out with some success on the River Eden and could provide either an alternative or complementary method of assessing adult lamprey numbers by trapping. However, the use of nest counts to determine adult numbers is currently limited by a lack of knowledge on spawning behaviour and as such can only provide semi-quantitative data.

6 Recommendations

Following the literature review of adult sampling methods and a field visit to the River Tamar fish trap, the following recommendations are proposed for the monitoring of sea and river lamprey adults.

1. Full use should be made of any permanent salmonid fish traps and counters, and their integration into an adult lamprey monitoring strategy should be undertaken wherever feasible.

2. Where available, video validation should be used to count the passage of lamprey over fish passes when validating migratory fish movements.

3. Angling clubs and ghillies should be targeted with a questionnaire requesting current and historical information on lamprey spawning behaviour and distribution.

4. Annual walkover/canoe surveys between May and June should be undertaken to identify spawning sites and count sea lamprey nests. Having located the key spawning

areas, effort can be focused on these stretches to minimise manpower requirements.

5. A proportion of ammocoete sampling sites should be targeted at suitable nursery habitat immediately downstream of spawning sites.

With respect to brook lamprey, the work by Strevens (Strevens, *in prep*.) indicates that targeted temporary trapping of the species may provide valuable data on adult migrations. However, the resource requirements would need to be fully considered bearing in mind that the trapping was undertaken over several months.

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