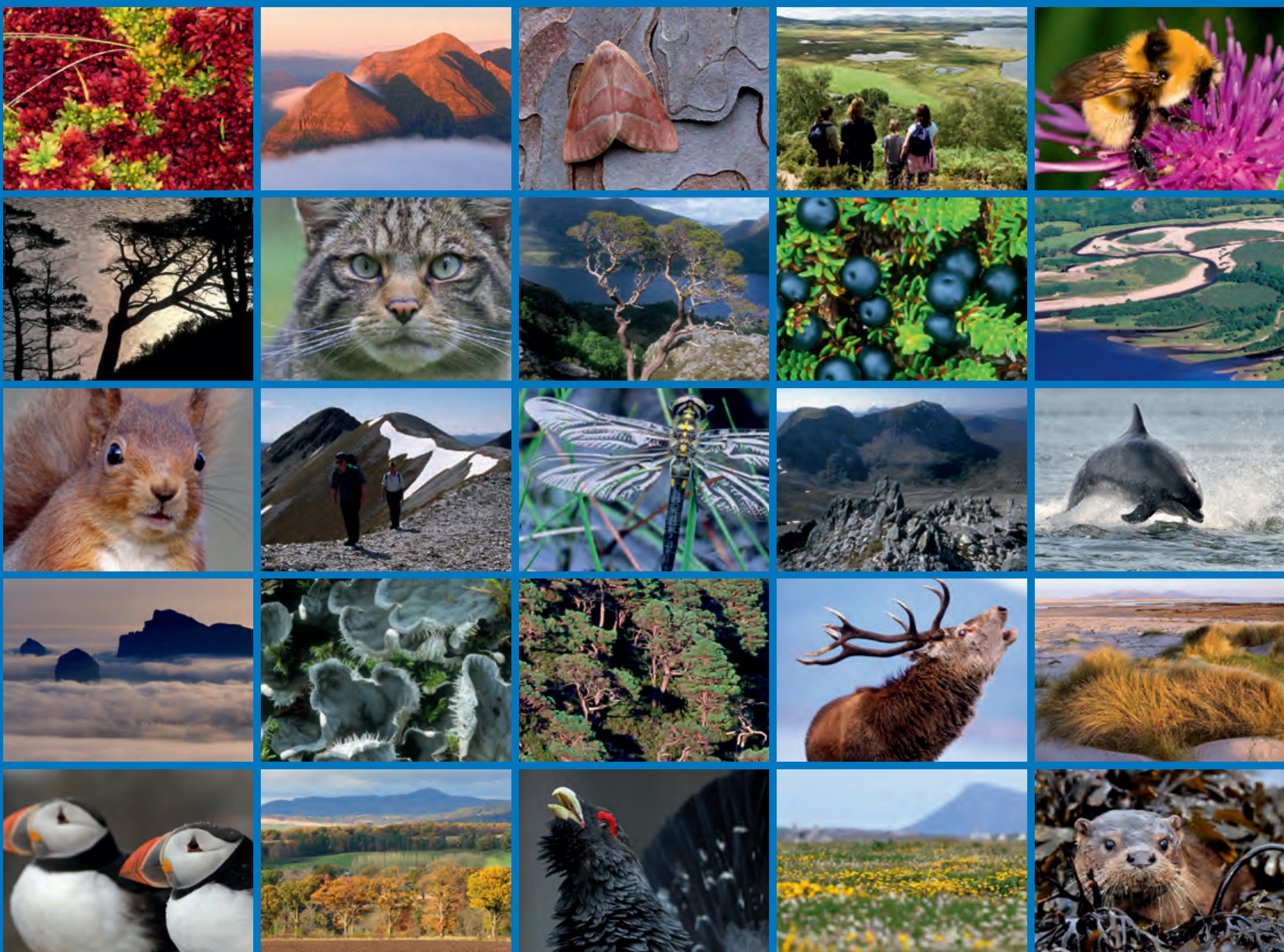
Scottish Natural Heritage
Commissioned Report No. 911

Site condition monitoring of lamprey in the Endrick Water SSSI and SAC 2012



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COMMISSIONED REPORT

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This report should be quoted as:

Bull, C., Perfect, C. & Watt, J. 2016. Site condition monitoring of lamprey in the Endrick Water SSSI and SAC 2012. *Scottish Natural Heritage Commissioned Report No 911.*

SCM Reports

This report was commissioned by SNH as part of the Site Condition Monitoring (SCM) programme to assess the condition of special features (habitats, species populations or earth science interests) on protected areas in Scotland (Sites of Special Scientific Interest, Special Areas of Conservation, Special Protection Areas and Ramsar). Site Condition Monitoring is SNH's rolling programme to monitor the condition of special features on protected areas, their management and wider environmental factors which contribute to their condition.

The views expressed in the report are those of the contractor concerned and have been used by SNH staff to inform the condition assessment for the individual special features. Where the report recommends a particular condition for an individual feature, this is taken into account in the assessment process, but may not be the final condition assessment of the feature. Wider factors, which would not necessarily be known to the contractor at the time of the monitoring, are taken into consideration by SNH staff in making final condition assessments.

COMMISSIONED REPORT

Summary

Site condition monitoring of lamprey in the Endrick Water SSSI and SAC 2012

Commissioned Report No. 911
Project No: 14008
Contractor: CRESS and Waterside Ecology
Year of publication: 2016

Keywords

Brook lamprey; river lamprey; electrofishing; Site Condition Monitoring.

Background

Brook lamprey (*Lampetra planeri*) and river lamprey (*L. fluviatilis*) are primary qualifying features of the Endrick Water Special Area of Conservation (SAC) and are notified features of the Endrick Water Site of Special Scientific Interest (SSSI). This report documents a lamprey survey conducted in 2012 as part of the Site Condition Monitoring programme for the designated site. It describes the distribution and abundance of lamprey, and evaluates the results using Common Standards Monitoring criteria to provide condition assessments for *Lampetra* species.

Main findings

- *Lampetra* larvae were present at all 25 survey sites, exceeding the two-thirds target for favourable condition.
- A single sea lamprey (*Petromyzon marinus)* larva – identified using external features – was found in a sample of larvae collected from the lowermost sampling site on the Endrick Water. This provides only the second record of this species in the designated site in recent years and suggests their continued presence at only a low density.
- The mean *Lampetra* density in optimal habitat was 24.76 larvae / m^2 (σ = 15.60 larvae / m^2). It was 6.56 larvae / m^2 (σ = 3.62 larvae / m^2) in sub-optimal habitat. The catchment mean (all habitat) was 19.56 larvae / m^2 (σ = 8.55 larvae / m^2). All of the mean densities exceeded the favourable condition targets and compare favourably with the results of a survey undertaken in 2008.
- 0+ and 1+ age class larval *Lampetra* were present in most samples together with larger larvae. Age class favourable condition targets were met at all but one of the 25 survey sites.
- Despite appearing to consist of high quality, stable habitat, a sampling site on the lower Blane Water yielded only one cohort of larvae and displayed a marked reduction in larval density when compared with the results of the 2008 survey. The reasons for this change are unclear but the proximity of the site to the confluence with the Garnock Burn suggests that there may be a problem with water quality.
- Young-of-the-year (0+) larvae were most abundant in samples from the Endrick Water between Drymen Bridge and Gartness. This area is thought to be the main spawning area for river lampreys.

- Twenty-three transformers were caught in sites accessible to migratory lampreys. Of these, only two were identified as river lamprey. None of the five transformers caught in the Blane Water was found to be a river lamprey. Eleven transformers caught upstream of the impassable falls at Gartness were identified as brook lamprey.
- Six replacement sampling sites were included in the survey due to either the complete loss of habitat or the significant degradation of it in some of the sampling sites used in the 2008 survey.
- It is concluded that *Lampetra* populations in the Endrick Water SAC and SSSI currently meet favourable condition targets for distribution and density. River lampreys continue to be present in the Endrick Water below Gartness but are less common than brook lampreys. Brook lampreys are present in the area upstream of Gartness. No further information about river lampreys in the Blane Water was provided by this survey.
- No reliable temporal changes in larval abundance were identified when the data were compared to those from the 2008 survey, but localised variation in abundance was encountered. This may have been the result of the small sample sizes at a number of sites or changes in the habitat quality between sampling times.

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1. INTRODUCTION

1.1 Background

Lamprey populations have declined throughout Europe over the last one hundred years, the most dramatic declines being in the anadromous species, i.e. river and sea lampreys (Maitland, 2003). The causes of decline are numerous but are thought to be primarily pollution, barriers to migration, damage to river channels, and land management practices leading to the degradation or loss of spawning areas. All three species of lamprey found in the UK (brook lamprey *Lampetra planeri*, river lamprey *L. fluviatilis* and sea lamprey *Petromyzon marinus*) are listed on Annex IIa of the Habitats Directive and Appendix III of the Bern Convention. The river lamprey is also listed on Annex Va of the Habitats Directive. The Habitats Directive requires EU member states to designate Special Areas of Conservation (SAC) for listed species. While brook and river lampreys are listed as the primary qualifying features for the Endrick Water SAC, sea lamprey are thought to be intermittently present in the system, or present only in very low numbers.

Brook lampreys are widely distributed throughout the Endrick Water and Blane Water catchments, with an established population present in the Endrick Water upstream of the impassable waterfall at Gartness (the *Potts of Gartness*).

River lampreys are confined to the stretch of the Endrick Water that lies downstream of the Potts of Gartness. They have been recorded as far upstream as Dumgoyach on the Blane Water (Maitland, 1994). The river lamprey population of the Endrick Water is of high conservation interest due to the presence of a landlocked form that remains in fresh water for its entire lifecycle and which feeds on fish in Loch Lomond during its adult phase (Maitland, 1994). It is thought that the sea lamprey population of the Loch Lomond area is largely confined to the River Leven which flows from the loch (Maitland, 1994; Gardiner *et al.*, 1995) but that they may be present in the Endrick Water in low numbers. Their presence in the Endrick Water was recently confirmed by the identification of a single larval sea lamprey that was caught during a trapping study (Hume and Adams, 2012).

1.2 Aims and objectives

The purpose of this work was to build upon the results of previous surveys undertaken (Forth Fisheries Foundation, 2004; Loch Lomond Fishery Trust, 2005; Hume, 2011; Watt *et al.*, 2011) to determine the condition of the lamprey populations in the Endrick Water SSSI and SAC by providing a detailed description of the distribution and density of brook and river lamprey. This and the previous surveys also provided information on the presence of sea lamprey in the Endrick Water.

The survey results were evaluated using Common Standards Monitoring (CSM) criteria (JNCC, 2005) to ascertain the site's conservation status and to help inform future casework and management. The survey results were compared with previous assessment data in order to illustrate significant population changes.

2. METHODS

2.1 Selection of survey sites

The geographical extent of larval lamprey survey sites was established during previous SCM work. Surveys have been conducted in three areas:

1. The lower Endrick Water downstream of the impassable waterfall at Gartness. Sampling effort was focussed on the area between Gartness and Drymen Bridge where river lamprey spawning is thought to be concentrated.

2. The upper Endrick Water upstream of Gartness to Low Bridge (NS 6334 8631) above Fintry.

3. The Blane Water between the confluence with the Endrick Water and Dumgoyach.

It was intended to undertake repeat surveys at the locations used in the previous (2008) lamprey SCM (Watt *et al.*, 2011), but the re-surveying of all of these sites was not possible during the autumn of 2012. This was due to the flow and substrate in some survey sites being significantly different to that previously encountered. Where the habitat quality was deemed to be so different that a meaningful repeat survey was not possible, an alternative survey location was identified as close as possible to the original (Table 1).

Table 1. Replacement larval lamprey survey sites

Previous survey site code	New site location	Reason for change
E2	≈ 150 m downstream on the same bank	The conditions had changed and were considered to be completely sub-optimal. The new site provided a greater depth of suitable substrate with an abundance of organic material.
E4	≈ 50 m downstream on the same bank	The substrate had changed to unsuitable mobile sand with occasional small, shallow patches of silt
E9	≈ 30 m upstream on same the bank	The habitat had become marginally sub-optimal
E11	≈ 50 m downstream on the same bank	The substrate had become dominated by coarse sand with occasional small, shallow patches of silt
E17	≈ 150 m downstream on the opposite bank	The substrate had become unsuitable
B5	≈ 100 m downstream on the opposite bank	The habitat had become marginally sub-optimal

2.2 Survey design and timing

The total number of survey sites was based upon the results of the 2008 survey (Watt *et al.*, 2011). Twenty-five sites were sampled. These were split between the Endrick Water (n = 19) and Blane Water (n = 6). Each sampling site was given a unique code (Table 2). The survey consisted of electrofishing optimal or sub-optimal habitat within 100 m long stretches of river (Harvey and Cowx, 2003). When sufficient optimal habitat was present at a site a total of 4 m^2 was electrofished using fully-quantitative methods and quadrat frames (see section 2.3). At sites where the size of habitat patches was limited or a mix of optimal and sub-optimal habitat was present, both habitats types were electrofished using fully-quantitative methods and quadrats and the results for each habitat type were recorded separately. When no optimal habitat was present at a site, a fully-quantitative survey of sub-optimal habitat was undertaken using quadrats. Where, due to obstructions on the channel bed or bank, it was not possible to use quadrats, semi-quantitative timed electrofishing of a measured area of substrate was undertaken (section 2.4).

The main aim of the survey was to obtain larval lamprey density and distribution information for the Endrick Water SSSI and SAC so that a condition assessment of the site could be made according to the CSM Guidance for Freshwater fauna (JNCC, 2005). Temporal and spatial changes in the lamprey population were illustrated by comparing the data with those from previous surveys. An additional aim was to provide data on the distribution of river lamprey in the designated site. This required the species of any transformers caught to be identified. Differentiating river from brook lamprey transformers is easier in late autumn and winter as their external distinguishing features are more easily identifiable at this time (Gardiner, 2003). However, high river flows and low light levels often prevent effective population sampling in late autumn and winter and so, in order to maximise the possibility of catching and correctly identifying transformers the survey was undertaken during late September and early October 2012.

2.3 Quantitative surveys

Quantitative samples were collected by depletion fishing within net frames (*quadrats*) as described by Harvey and Cowx (2003). A quadrat comprised four net walls and an open base of 1 m^2. The apertures of the mesh were <1.0 mm in diameter to prevent larvae from moving into or out of the quadrat. The quadrat was placed on the survey area and pressed into the sediment to seal the base. Generator-powered bankside electrofishing equipment and a single anode ring were used throughout the survey. The anode ring was energised with a pulsed DC for ≈ 20 seconds which was then turned off for ≈ 5 seconds to avoid immobilising the larvae. Electrofishing continued in this way for 2 minutes. A minimum of three two-minute periods of fishing was undertaken in each quadrat. A resting period of 2–8 minutes was applied between each 2-minute period of fishing to allow disturbed silt to settle and water clarity to improve. Larvae were caught using fine-mesh dip nets. The larvae caught during each 2-minute period of electrofishing were kept separately for examination. Quantitative surveys were conducted at 24 sampling sites.

2.4 Semi-quantitative surveys

Where habitat patches were small, steeply sloping, mixed with cobbles or boulders, or situated below overhanging vegetation, it was not always possible to use quadrats effectively and a semi-quantitative approach was taken. Surveyors used the same equipment that was used for quantitative sampling, but energised the anode in pulses of ≈ 20 seconds over an area of suitable sediment until no further larvae emerged. The larvae were captured using fine-mesh dip nets and retained for examination. The area that was electrofished was measured to allow a minimum density estimate to be calculated. Semi-quantitative sampling was conducted at only one sampling site (E19).

Table 2. Electrofishing sites on the Endrick Water and Blane Water

Code	River	Habitat	NGR	Bank	Location
E1	Endrick	optimal	NS 45280 88077	left	Mains Farm, bottom of left bend opposite mature beech and oak tree on other bank.
E2	Endrick	optimal	NS 46853 87555	left	On main stem at end of relict meander channel that is now a connected backwater area
E3	Endrick	optimal	NS 47128 87246	right	≈ 300 m downstream of Drymen Bridge where river closest to road, alder on opposite bank
E4	Endrick	optimal	NS 47908 87084	left	Inside bend , directly opposite edge of woodland area on far bank
E5	Endrick	optimal	NS 48071 86984	right	Downstream of Drumquhassle, 30 m upstream of edge of woodland
E6	Endrick	optimal and sub-optimal	NS 48246 86716	left	Drumquhassle, at end of fence-line below riffle area
E7	Endrick	optimal	NS 48487 86194	right	Gaidrew, marginal strip just downstream of sharp right hand bend, earth cliff on opposite bank
E8	Endrick	optimal	NS 48975 85867	left	Downstream of Dalnair, eddy at downstream end of fenced paddock
E9	Endrick	optimal	NS 49814 85862	left	30 m upstream of point where power lines cross river, small field drain enters
E10	Endrick	optimal	NS 50182 85504	left	≈ 200 m downstream of Blane Water confluence, eddy with fallen tree
E11	Endrick	optimal and sub-optimal	NS 50268 85504	right	≈ 100 m downstream of Blane Water confluence downstream of wooden stakes in channel
E12	Endrick	optimal	NS 50387 85958	left	At footbridge with quadrats located immediately downstream and upstream beneath riparian trees
E13	Endrick	optimal and sub-optimal	NS 51122 87797	left	≈ 300 m upstream of Killearn Bridge at drainage ditch, large boulder midstream
E14	Endrick	optimal and sub-optimal	NS 52843 87800	left	70 m downstream of Ballochruin Bridge, along margin downstream of riparian bushes
E15	Endrick	optimal and sub-optimal	NS 53510 88180	right	≈ 800 m upstream of Ballochruin Bridge, 50 m up from bend, top of site at corner of wood
E16	Endrick	optimal and sub-optimal	NS 56260 88370	right	Dalfoil, eddies on outside of left bend, immediately upstream and downstream of ditch
E17	Endrick	optimal and sub-optimal	NS 59591 88379	right	Just downstream of riffle on outside of left bend in backwater eddy feature
E18	Endrick	optimal	NS 61290 87410	right	Knockraich, eddy by road junction beneath large beech tree
E19	Endrick	optimal and sub-optimal	NS 62798 86549	right	Bogside, 10 m downstream of overhead cables in marginal strip under riparian trees
B1	Blane	optimal and sub-optimal	NS 50619 85252	left	≈ 40 m upstream of bridge on inside of left bend
B2	Blane	optimal and sub-optimal	NS 50657 84951	left	10 m upstream of Carnock Burn confluence in eddy beneath alder
B3	Blane	optimal and sub-optimal	NS 51321 84200	right	Downstream of Moss Bridge, large eddy on apex of u-shaped bend
B4	Blane	optimal	NS 51809 82653	right	≈ 700 m downstream of Quinloch Bridge in large eddy on right bank
B5	Blane	optimal and sub-optimal	NS 51808 82480	left	600 m downstream of Quinloch Bridge in eddy on outside of right bend
B6	Blane	optimal and sub-optimal	NS 51844 82405	right	Quinloch, large eddy below mature ash tree

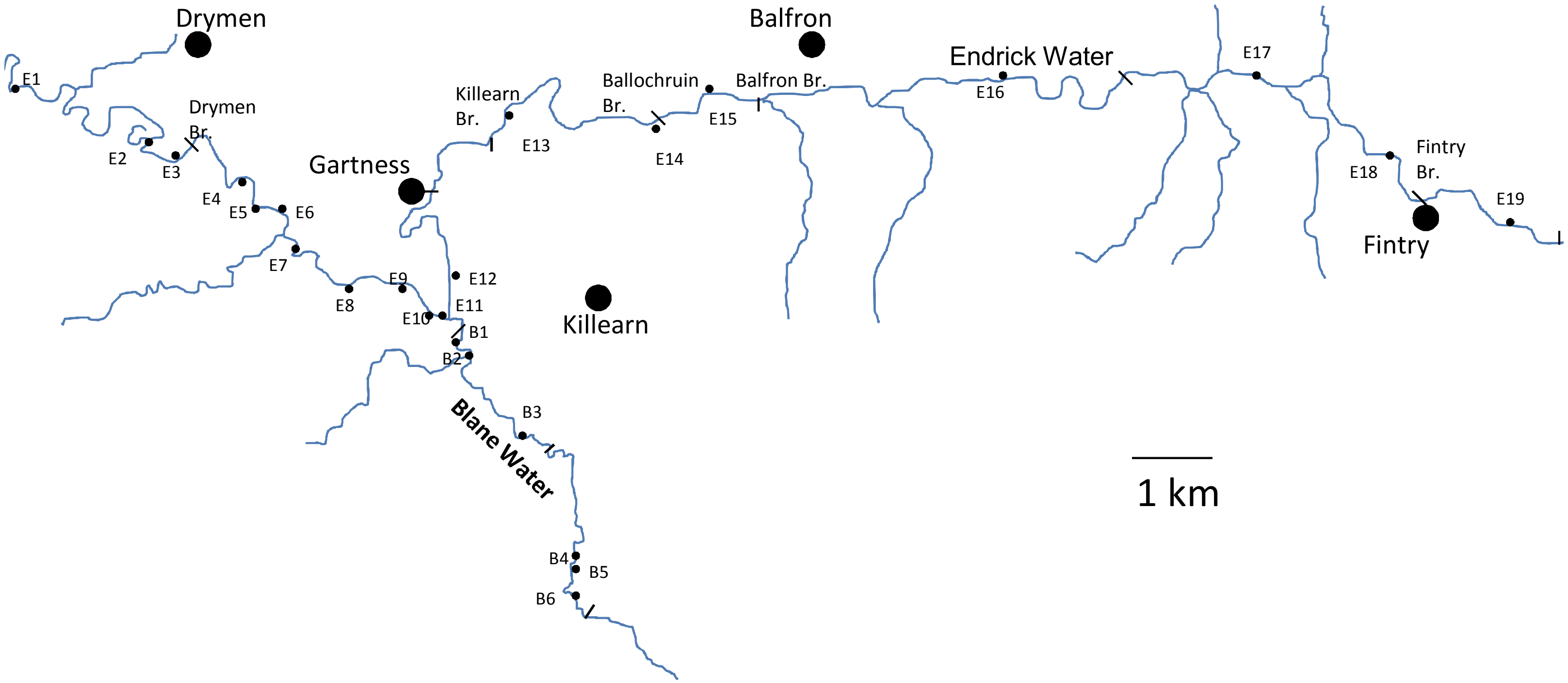


Figure 1. Electrofishing sites on the Endrick Water and Blane Water

2.5 Lamprey processing and identification

Larval lamprey were identified, counted, measured (total length in millimetres) under anaesthetic, and returned to the sample area. River and brook lamprey larvae cannot be reliably differentiated (Gardiner, 2003). The total length and eye length of *Lampetra* transformers were measured and surveyors made field identifications based on colour and morphology. The eye length of river lamprey transformers is typically 2.4–2.9% of body length; it is typically < 2.4% in brook lamprey. Transformers with a total length > 120 mm are most likely to be brook lamprey, but it cannot be assumed that shorter *Lampetra* transformers are river lampreys. Other useful features for identification are the greater silvering, inconspicuous lateral line organs on the head, and lateral flattening of river lamprey transformers (Gardiner, 2003). With practice, sea lamprey larvae can be distinguished from river and brook lampreys in the field by examining the patterning and colouration of the oral hood and caudal fin (Gardiner, 2003).

2.6 Site and habitat data

The habitat at each sampling site was classified as optimal or sub-optimal according to the criteria set out in APEM (2002). Optimal habitat is defined as stable fine sediment or sand ≥ 15 cm deep, low water velocity and the presence of organic detritus. Sub-optimal habitat is defined as shallow sediment, often patchy and interspersed among coarser substrate. The additional variables recorded at each site are described in Table 3 and full data are presented in the appendices.

Table 3. Habitat variables recorded at survey sites

Variable	Description
Sampling site	
Watercourse	Name of river or stream
Site location	Description and NGR to aid future site identification
Bank	Left or right bank (looking downstream)
Water body at survey area	
Wetted width	Wetted width (m) of water body at survey site
Depth	Average and maximum depth (m) of water body at survey site
Land use and bankside vegetation	Classification of riparian zone (arable, broadleaf woodland, etc.)
Downstream obstructions	Is the site accessible to migratory lampreys?
Lamprey habitat unit	
Location	Is the habitat in an eddy, along a margin, etc.
Total area	Total area (m^2) of habitat suitable for larval lamprey
Longevity	Is habitat unit permanent, semi-permanent or ephemeral?
Shade	% shade (canopy) at site
Sampling point details	
Water depth	Water depth (m) at sampling point
Shade	% shade (canopy) at sampling point
Substrate composition	% by volume using Wentworth scale
Sediment depth	Depth (cm) of soft sediment at sampling point
Woody debris	absent, present or abundant
Flow	Description of flow at sampling point
Aquatic vegetation	% cover of emergent, floating or submerged macrophytes
Habitat quality	Optimal or sub-optimal

Notes about the stability of habitat patches were taken and their likely persistence was considered in association with the main factors that had caused the deposition of suitable substrates. Habitat patches were then classified as either being *permanent* (i.e. the patch was unlikely to be significantly changed or lost within ten years), *semi-permanent* (i.e. the patch was likely to be significantly altered or lost within 1–10 years, or *ephemeral* (i.e. the patch was likely to be significantly altered or lost within one year). The electrofishing equipment used, voltage, water temperature and conductivity were recorded and photographs taken at all survey sites. These data and photographs are given in the Appendices.

2.7 Larval density calculation

Larval lamprey density was calculated for each quadrat in fully quantitative sites using depletion methods. All larval lamprey densities are presented as no. m^{-2} (Appendix 3). Depletion estimates were calculated using the Zippin depletion method (Zippin, 1958). When the 95% confidence intervals around a calculated mean density estimate was ≥ 0.5 x mean value, the depletion-based density estimate was rejected and a minimum density was calculated (total number of larval lamprey caught divided by the area (1 m^2) of the quadrat).

The minimum larval lamprey density was calculated for each semi-quantitative site by dividing the number of larval lamprey caught (n) by the area (m^2) that was fished. All larval lamprey densities are presented as no.m^{-2}. The mean densities for optimal and sub-optimal habitat were calculated using pooled data from quantitative and semi-quantitative samples respectively.

2.8 Age class analysis

A larval lamprey length-frequency distribution was derived for each survey site to allow the population's age structure to be determined (Appendix 4). Possible age classes were identified for the three survey areas of the catchment – the Endrick Water above Gartness, the Endrick Water downstream of Gartness, and the Blane Water – using the Bhattacharya method in the FiSAT Stock Assessment Tools programme (Gayanilo *et al.*, 2005). This calculates a separation index (SI) for cohorts identified by visual decomposition of the length distributions. A SI > 2 is indicative of significant separation between age cohorts. Several authors have recently applied this methodology to larval lamprey populations in UK rivers (Nunn *et al.*, 2008; Watt *et al.*, 2011; Bull and Watt, 2012). The size overlap of older age classes – due to slowing in growth (Hardisty, 2006) – restricted any attempt to separate cohorts other than the 0+ and 1+ age classes. The number of age classes present at individual survey sites were then inferred from the FiSAT derived age groups for the relevant area.

2.9 Assessment of site condition

The CSM Guidance for Freshwater fauna (JNCC, 2005) sets out targets for the assessment of favourable condition for lamprey interest features. The larval lampetra population targets relevant to this study are given in Table 4. All of these targets were used in the site condition assessment of the Endrick Water's lamprey population.

Table 4. Lamprey Favourable Condition Table (after JNCC, 2005)

Attribute	**Target**
Distribution	Lampreys should be present at not less than 2/3 of survey sites
Density	Optimal habitat > 10 larvae m^{-2} Overall catchment average > 5 larvae m^{-2}
Population age structure	For samples of > 50 larvae three size (age) classes should be present For samples of ≤ 50 larvae at least two size (age) classes should be present

3. RESULTS

3.1 Lamprey distribution

Larval *Lampetra* were encountered at every survey site in the Endrick and Blane Waters. This exceeded the 2/3 favourable condition target and suggests that *Lampetra* continue to be widely distributed in the designated site. Larvae > 120 mm total length were found at 22 of the 25 sites.

A single sea lamprey larva was recorded at site E1 on the Endrick Water. Its identification was based on the examination of external characteristics in the field (Plate 1).

Thirty-four *Lampetra* transformers were recorded during the survey. They occurred in seven of the sampling sites on the Endrick Water and three on the Blane Water (Table 5). Transformers were present in each of the three sampling areas but none was recorded in any of the sampling sites downstream of E8 (midway between Gartness and Drymen Bridge in the lower Endrick Water sampling area). Whilst the transformers identified as brook lamprey were widely distributed, only two specimens (from sampling sites E10 and E11 in the section of the Endrick Water between Gartness and Drymen Bridge) were identified as river lamprey transformers on the basis of eye length measurements (Figure 2). This method confirmed the initial field identification of these two specimens which used external characteristics (Plate 2).

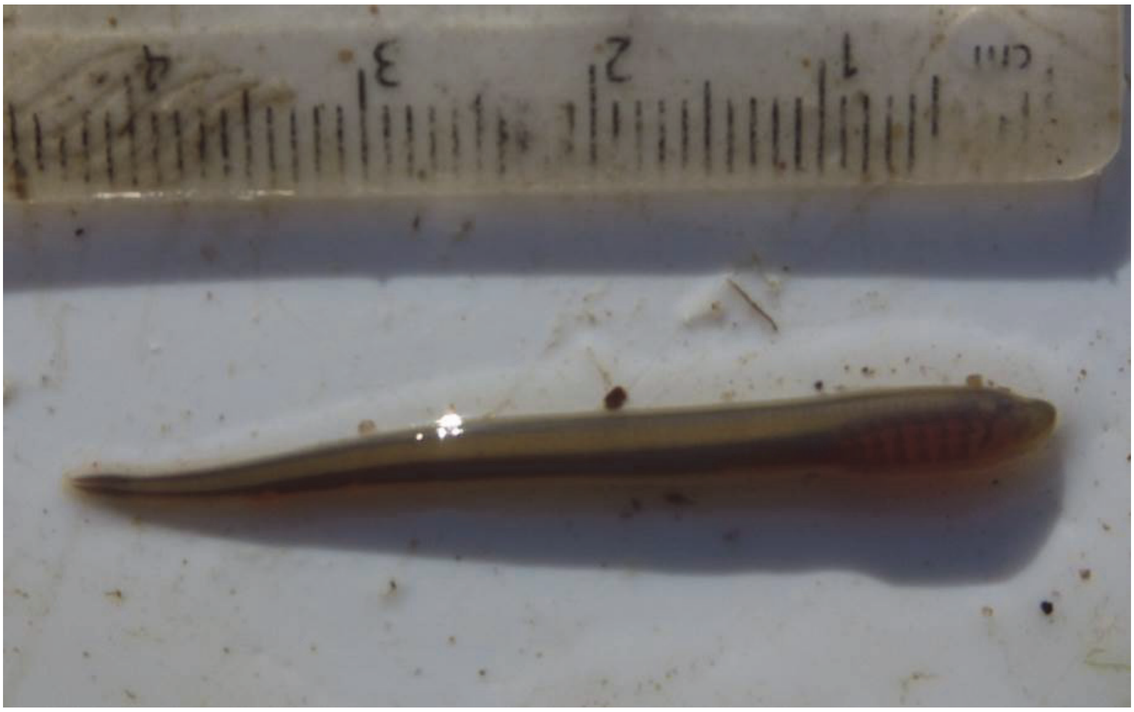


Plate 1. The larval lamprey (43 mm total length) sampled from site E1 and identified as a sea lamprey ammocoete on the basis of the pigmentation pattern on the oral hood and caudal fin

Table 5. The number of lamprey transformers caught during the 2012 survey

Site	**Transformers**	
	Brook	**River**
E8	1	–
E10	3	1
E11	6	1
E12	2	–
E13	9	–
E15	1	–
E16	5	–
B1	2	–
B2	1	–
B6	2	–
All sites	**32**	**2**

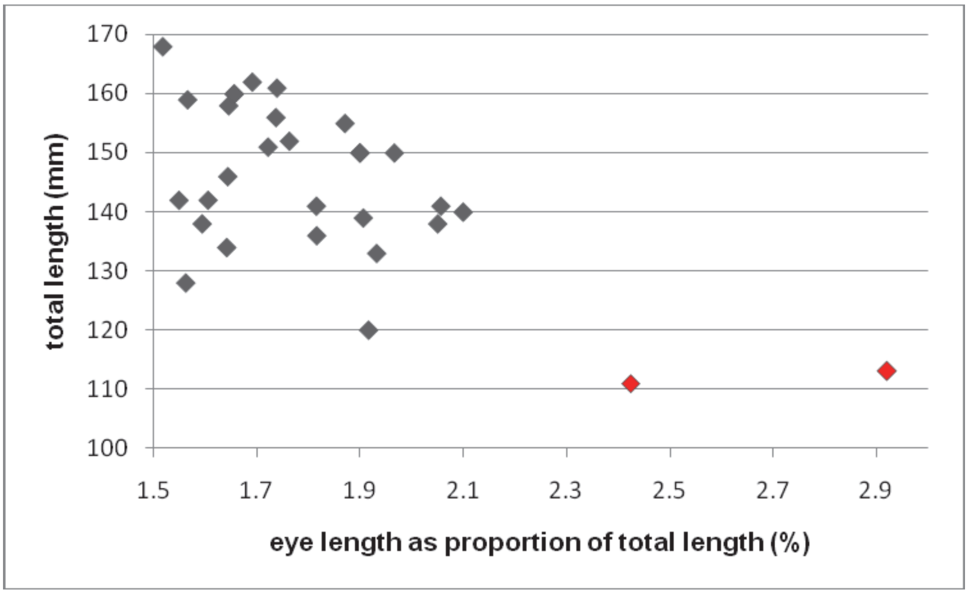


Figure 2. Total length and eye length of Lampetra *transformers. Dark symbols indicate brook lamprey and red symbols indicate river lamprey identified by eye length measurement and external features.*

Plate 2. Lampetra *transformers from site E11 illustrating the differences in body size, colouration and eye size that distinguish brook lamprey (top) from river lamprey (bottom)*

The brook lamprey transformers caught in the Upper Endrick Water (upstream of Gartness) were significantly larger than the *Lampetra* transformers caught in the lower Endrick Water (downstream of Gartness) (mean length 153 mm (σ = 12.27 mm) and 140 mm (σ = 9.04 mm) respectively: $t = 3.07$, $df = 24$: $p = 0.005$). This size difference illustrates the inclusion of smaller river lamprey transformers in the sample taken from the Endrick downstream from the impassable waterfall at Gartness. The five transformers caught in the Blane Water were of intermediate body length (mean = 140 mm, σ = 9.86 mm), but the small sample size prevented reliable statistical comparison with the groups of transformers caught in the Endrick Water areas.

3.2 Larval lamprey density

A total of 2,007 larval *Lampetra*, one larval *Petromyzon*, and 34 transformers were caught during the survey (Table 6). The mean density of larval *Lampetra* caught in the 24 optimal habitat sampling sites was 24.76 m^{-2} (σ = 15.60). This exceeded the favourable condition target of 10 m^{-2}. The maximum density recorded in an optimal habitat sampling site was 66.86 m^{-2} (sampling site E4); the minimum density was 2.34 m^{-2} (sampling site B2). The maximum density recorded for a single quadrat sample was 88 m^{-2} at site E4.

The larval lamprey densities recorded for the eleven sub-optimal sampling sites were consistently lower than those for optimal sampling sites, the mean of 6.56 m^{-2} (σ = 3.62 m^{-2}) being nearly four times smaller. The only exception was that recorded for sampling site E6 where the density in both optimal and sub-optimal habitat was similar (mean density 16.5 m^{-2} and 15.48 m^{-2} respectively). Densities at seven of these 10 locations equalled or exceeded the catchment average target of 5 ammocoetes per m^{-2}. The overall catchment average, which was generated by combining the densities from the optimal and sub-optimal sampling sites, was 19.56 m^{-2} (σ = 8.55 m^{-2}); this greatly exceeded the favourable condition target of 5 m^{-2}.

Table 6. Larval lamprey density estimates for optimal and sub-optimal sampling sites

Site code	**Survey date**	***Lampetra* (n)**		***Petromyzon* larvae (n)**	***Lampetra* density (no. m^{-2})**	
		Larvae	**Transformers**		**Optimal habitat**	**Sub-optimal habitat**
E1	10/10/2012	24	–	1	5.75	–
E2	10/10/2012	93	–	–	25.48	–
E3	10/10/2012	135	–	–	35.25	–
E4	09/10/2012	213	–	–	66.86	–
E5	09/10/2012	88	–	–	22.50	–
E6	04/10/2012	59	–	–	16.50	15.48
E7	04/10/2012	88	–	–	23.47	–
E8	09/10/2012	116	1	–	30.84	–
E9	08/10/2012	118	–	–	35.56	–
E10	08/10/2012	178	4	–	55.77	–
E11	19/09/2012	48	7	–	18.44	3.07
E12	08/10/2012	170	2	–	53.28	–
E13	20/09/2012	21	9	–	11.61	3.54
E14	20/09/2012	37	–	–	13.78	5.00
E15	20/09/2012	93	1	–	29.84	9.22
E16	28/09/2012	95	5	–	25.67	–
E17	27/09/2012	70	–	–	22.28	5.07
E18	27/09/2012	116	–	–	35.21	–
E19	27/09/2012	23	–	–	16.00	7.00
B1	19/09/2012	57	2	–	15.59	–
B2	19/09/2012	8	1	–	2.34	–
B3	04/10/2012	29	–	–	15.38	4.67
B4	28/09/2012	50	–	–	12.91	–
B5	01/10/2012	56	–	–	17.07	7.00
B6	01/10/2012	32	2	–	11.76	5.50
Mean (σ)					**24.76 (15.60)**	**6.56 (3.62)**

The highest larval lamprey densities (35.91 m^{-2}, σ = 18.36 m^{-2}) were recorded in optimal habitat sampling sites in the Endrick Water between Gartness and Drymen Bridge; lower densities (22.16 m^{-2}, σ = 15.03 m^{-2}) were found in the three optimal habitat sampling sites downstream of Drymen Bridge. Similar densities to those encountered downstream of Drymen Bridge were recorded for the six optimal habitat sampling sites in the inaccessible area of the Endrick Water upstream of Gartness (22.06 m^{-2}, σ = 8.77 m^{-2}). (See Table 7).

Table 7. Larval lamprey density estimates for four areas within the Endrick Water SSSI and SAC

Area	**Sampling site**	**Mean larval *Lampetra* density (no.m^{-2})**	
		Optimal habitat (σ)	**Sub-optimal habitat (σ)**
Endrick Water downstream of Drymen Bridge	E1–E3	22.16 (15.03)	–
Lower Endrick Water (Drymen Bridge to Gartness)	E4–E12	35.91 (18.36)	9.28 (8.78)
Upper Endrick Water (Gartness to Low Bridge)	E13–E19	22.06 (8.77)	5.97 (2.20)
Blane Water (confluence with Endrick Water to Dumgoyach)	B1–B6	12.51 (5.34)	5.72 (1.18)
Kruskall-Wallis test results		**H = 10.02 df = 3; p = 0.018**	**H = 0.0 df = 2; N.S**

The optimal habitat larval lamprey densities in the Blane Water were considerably lower than those in the three Endrick Water sampling areas (Table 7). The habitat in the Blane Water was often considered to be only marginally optimal, with patches of anoxic sediment present and indicated by the release of gas bubbles when disturbed. The lowest larval density was recorded in sampling site B2, despite the surveyors considering that the habitat provided optimal conditions with permanent, stable substrate. This low occupancy rate – five times lower than any other density recorded for the Blane Water – is difficult to explain as the physical habitat appeared to be of high quality and spawning habitat was present. Sampling site B2 was located immediately beside the confluence of the Carnock Burn with the Blane Water; one possibility is that a localised change in environmental conditions (e.g. water quality) may have originated in the Carnock Burn and led to the deterioration of the habitat in the sampling site.

The results of the Kruskall-Wallis test for difference between the mean larval *Lampetra* densities in optimal habitat for the different parts of the designated site (Table 7) suggested that it was statistically significant. No statistically significant difference was found when the larval densities for sub-optimal habitat were compared, but the relatively low number (n = 10) of sub-optimal habitat values available for comparison means that the test result should be treated with caution.

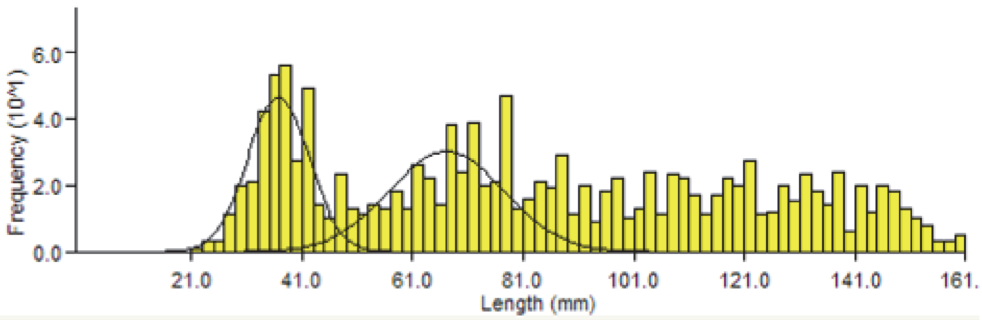
As no sub-optimal habitat was sampled downstream of Drymen Bridge, a comparison could only be made between the sub-optimal habitat larval lamprey densities in the accessible area between Drymen Bridge and Gartness and those from sites sampled upstream of Gartness. As with the densities found in optimal habitat, the sub-optimal habitat densities were on average higher in the accessible area downstream of Gartness than in the area upstream of the waterfall, although due to small sample sizes and high inter-sampling site variability, the difference was not statistically significant.

3.3 Larval lamprey size and age structure

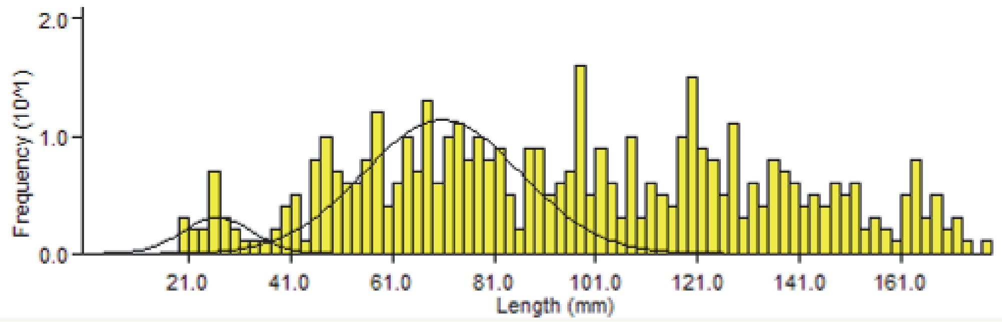
Young of the year (0+) larvae were widespread and were encountered at 22 of the 25 sites sampled. The 0+ larvae were particularly strongly represented at sites E2 and E3 below Drymen Bridge, and at sites E4, E5 and E8 between Drymen Bridge and Gartness. No 0+ larvae were encountered at site E13 in the upper Endrick Water or in sites B2 and B3 in the lower Blane Water. The mean length of the presumed 0+ year class in the upper Endrick Water sampling sites was smaller than that of the lower Endrick Water and the Blane Water, suggesting that growth during the summer of 2012 for this year class may have been slower in the upper Endrick Water area than elsewhere (Table 8 and Figure 3). The difference in growth between the areas was not apparent when the lengths of the presumed 1+ year class larvae were considered.

Table 8. Mean length (mm) and calculated separation index (SI) for lamprey cohorts

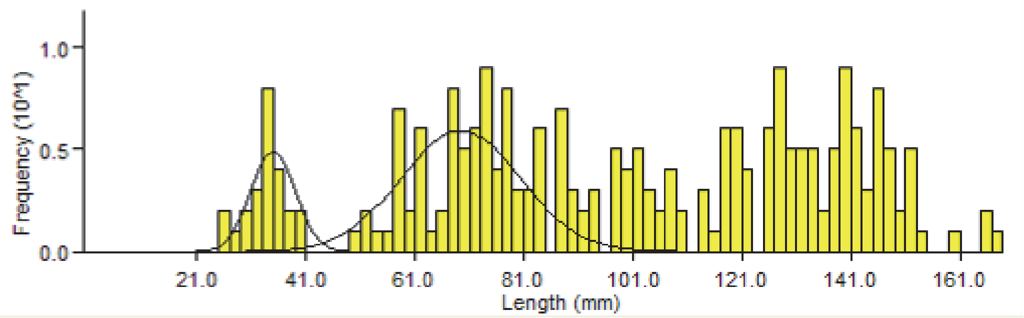
Area	**Mean length (σ)**		**SI**
	0+ year class	**1+ year class**	
Endrick Water (downstream of Gartness)	36.71 (5.59)	67.06 (10.39)	2.68
Endrick Water (upstream of Gartness)	26.64 (6.90)	70.75 (15.34)	3.30
Blane Water	34.96 (4.07)	69.43 (10.97)	3.00



Lower Endrick Water (downstream of Gartness)



Upper Endrick Water (upstream of Gartness)



Blane Water

Figure 3. FISAT length-frequency plots for larval Lampetra

Twenty-four of the 25 sampling sites met the *number of age classes present* targets given in the CSM Guidance for Freshwater fauna (JNCC, 2005). The age class information has been used to give an indication of feature condition (Table 9). Only one site (B2) in the lower reaches of the Blane Water did not meet the targets and this was because of the lack of more than one age class in the small sample of larvae caught (n = 9).

Table 9. Larval Lampetra *age classes and indicative feature condition per sampling site*

Site	Sample size (n)	Size range (mm)	Number of age classes	Feature condition
E1	25	34–97	2	favourable
E2	93	30–160	≥3	favourable
E3	125	22–155	≥3	favourable
E4	213	28–160	≥3	favourable
E5	88	30–150	≥3	favourable
E6	59	26–143	≥3	favourable
E7	88	24–153	≥3	favourable
E8	117	24–155	≥3	favourable
E9	118	35–160	≥3	favourable
E10	182	28–151	≥3	favourable
E11	55	26–142	≥3	favourable
E12	172	27–152	≥3	favourable
E13	30	84–175	2	favourable
E14	37	39–168	≥3	favourable
E15	94	28–178	≥3	favourable
E16	100	19–150	≥3	favourable
E17	70	56–147	≥3	favourable
E18	116	33–136	≥3	favourable
E19	23	32–111	2	favourable
B1	59	25–150	≥3	favourable
B2	9	51–159	≥1	unfavourable
B3	29	71–168	≥2	favourable
B4	50	31–165	≥3	favourable
B5	56	34–166	≥3	favourable
B6	34	29–160	>3	favourable

4. DISCUSSION

The CSM targets for density and distribution were met, but the target for age structure was not, due to a site (B2) on the Blane Water not containing the minimum two or more age classes (see Table 10). The reasons for the reduction in larval density and the presence of only a single cohort at site B2 were undetermined, but the low density and absence of 0+ larvae at this site was unusual as the sediment appeared to be stable and rich in organic matter and the habitat was considered to be optimal. Sampling conditions (water depth and light level) were favourable and capture efficiency was high. The absence of 0+ larvae could have been the result of a localised event that diminished the suitability of this area for the settlement of emerging larvae or which prevented the successful recruitment of this year class. In 2008 the results from the site condition monitoring at same site (B2) indicated that ≥ 3 year classes were present in a sample of 181 larvae (Watt *et al.*, 2011).

The CSM criteria for lamprey spawning, habitat, and water quality are not covered by this report.

Table 10. Lampetra *condition assessment for the Endrick Water SSSI and SAC*

CSM target	Survey result	Target met?
Lampreys should be present at not less than 2/3 of survey sites	Lampreys present at all sites	Yes
Density in optimal habitat > 10 larvae.m^{-2}	Optimal habitat 24.76 m^{-2}	Yes
Catchment average density > 5 larvae.m^{-2}	Catchment average 19.56 m^{-2}	Yes
For samples of > 50 ammocoetes three size (age) classes should be present	At least three age classes present in all cases.	Yes
In samples of ≤ 50 ammocoetes at least two size (age) classes should be present	At least two age classes present in all but one site	No

The presence of a larval sea lamprey in the lowermost sampling site on the Endrick Water is only the second record of this species in the watercourse. The first confirmed larval sea lamprey in the Endrick Water was reported by Hume and Adams (2012); the larva was caught in March 2012 in a trap designed for adult lampreys. The larval sea lamprey during this study was identified by examining only its external features, i.e. its buccal hood and caudal fin pigmentation patterns (Gardiner, 2003); no count of myomeres was made before the specimen was returned to the water alive. Counting the myomeres may have helped confirm the genus, but it was not practical to do so in the field. Killing and retaining the larva was undesirable because of the scarcity of the species. Taverny *et al*. (2012) suggest that genotyping tests are necessary to distinguish the genus of larval lamprey < 60 mm long. But the experience of this report's authors, gained during several surveys of Scottish rivers, suggests that external features can be used with confidence to identify larvae as small as 20 mm long. However, without myomere counts or genotyping evidence it must be stated that the identification of this small (43 mm total length) larva as a sea lamprey cannot be unquestionably confirmed.

The possibility of catching larval sea lamprey during surveys that use conventional electrofishing apparatus in shallow, marginal habitat may be limited. It has recently been suggested that larval sea lamprey may show a preference for substrate in water that is deeper than 2 m (Taverny *et al.,* 2012). Previous surveys of Scottish rivers have typically encountered low densities of larval sea lamprey in optimal habitat compared to those of brook and river lamprey, even when sampling has been in close proximity to known spawning areas (Bull and Watt, 2012). Further investigations would be needed to establish the distribution of sea lamprey in the Endrick Water SSSI and SAC. These could include spawning surveys in early summer (e.g. Igoe *et al.*, 2004) to determine the locations and relative abundance of adult spawning activity. The use of larval drift sampling (Derosier, 2001) could provide supplementary information. Both spawning surveys and larval drift sampling have been used successfully in the River Teith SAC to provide spatial information on sea lamprey habitat use (C. Bull *unpublished data*).

River lampreys in the Endrick Water are unable to migrate upstream of Gartness. They have previously been reported as far upstream as Dumgoyach in the Blane Water (Gardiner and Stewart, 1997). The relative contribution of river lamprey to the overall larval density in these areas can only be inferred by the presence of transformers as it is not possible to differentiate between the larvae of brook and river lamprey.

Similar numbers of brook lamprey transformers were recorded from the same number of sampling sites upstream of Gartness during the 2008 survey (Watt *et al.*, 2011) and this survey (18 and 16 transformers respectively) indicating the stability of the population. However, the number of transformers caught in the areas of the Endrick Water and Blane Water that are accessible to both brook and river lamprey differed between the survey dates.

During the 2008 survey 52 transformers were caught downstream of Gartness and in the Blane Water; six of which were identified as river lamprey and five of these were caught in the Blane Water. Far fewer transformers were caught in the 2012 survey: only 19 were caught in sites downstream of Gartness, two of which were identified as river lamprey, and none was found in the Blane Water. Both the 2008 and 2012 survey were conducted at the same time of year (September and October) and exactly the same identification criteria were used to determine the presence of river lampreys.

The reason for the change in the number of transformers caught in the Endrick Water upstream of Gartness, the Endrick Water downstream of Gartness, and the Blane Water in the 2008 and 2012 surveys is unknown. Unseasonably high water levels during the summer of 2012 may have accounted for the reduction in the number of transformers encountered: scouring flows may have altered lamprey habitat in the middle reaches of the Endrick Water where the channel appears to be more dynamic than it is upstream. Lamprey transformers tend to be found along the less stable margins of larval lamprey habitat where sediment and coarse organic material give way to sand or coarser substrate (C. Bull and J. Watt, pers. obs.). It is possible that this edge habitat was more affected by the prolonged and numerous floods experienced in 2012 than the more stable and protected inner area of sediment where younger larvae concentrate. This might have resulted in the displacement of transformers from habitat in the middle reaches of the Endrick Water to habitat in the lower reaches that it was not possible to sample.

The lower numbers of river lamprey caught may also be the result of the flow conditions in 2012. It appears that the populations of river lamprey in the Endrick Water SSSI and SAC are subject to natural cycles of abundance, with corresponding changes in their spatial distribution possibly being influenced by flow conditions during spawning migrations. Whilst some studies have confirmed the presence of river lamprey in the Blane Water (Maitland, 1994; Gardiner & Stewart, 1997; Watt *et al.*, 2011), others have reported their absence (Gardiner & Stewart, 1999) and, during surveys in 2004, the Forth Fisheries Foundation recorded only one river lamprey transformer in their Blane Water sampling sites. Hume (2011) reported the results of adult lamprey trapping that was undertaken 2009–2010 at Drymen Bridge: 90% of the adult lampreys encountered were brook lamprey and 10% comprised the two morphotypes of river lamprey known to inhabit the Endrick Water. In

2005, similar trapping carried out by the Loch Lomond Fisheries Trust (LLFT, 2005) recorded lower numbers but a higher proportion (27%) of river lamprey.

The lamprey surveys that have been carried out in the Endrick Water SSSI and SAC (Gardiner *et al.*, 1995; McEwen and Gardiner, 2001; Forth Fisheries Foundation, 2004; Loch Lomond Fishery Trust, 2005; Watt *et al.*, 2011) can be used to illustrate longer term trends in larval abundance in the catchment (Table 11).

Table 11. Larval lamprey densities (no. m^{-2}) from surveys of the Endrick Water SSSI and SAC (n = number of samples)

Study	Survey area			
	Downstream of Drymen Bridge	**Drymen to Gartness**	**Above Gartness**	**Blane Water**
Gardiner *et al.*, 1995	1.40 (σ = 0.80, n = 2)	61.10 (σ = 51.90, n = 2)	–	–
McEwen and Gardiner, 2001	–	–	44.10 (σ = 34.00, n = 13)	–
Forth Fisheries Foundation, 2004	1.20 (σ =1.20, n = 2)	15.20 (σ = 7.20, n = 6)	7.20 (σ = 6.60, n = 5)	13.30 (σ = 9.00, n = 3)
Loch Lomond Fisheries Trust, 2005	1.50 (σ = 1.90, n=2)	–	–	–
Watt *et al.*, 2011*	3.70 (σ = 3.50, n = 3)	18.80 (σ = 21.30, n = 9)	13.90 (σ = 12.10, n = 7)	15.80 (σ = 22.50, n = 6)
Bull *et al.,* 2016*	22.16 (σ = 15.03, n = 3)	22.59 (σ = 13.57 (n = 9)	14.01 (σ = 5.48, n = 7)	9.12 (σ = 3.26, n = 6)

*combined optimal and sub-optimal data

Whilst comparisons of the data in Table 11 should be treated with caution because the methods and sites used in each survey were not consistent, some trends were apparent. Lower larval lamprey densities than those recorded in the 2001 survey were again recorded upstream of the Potts of Gartness during the 2012 survey, whereas in comparison with those recorded in the 2004 and 2011 surveys, slightly increased densities were recorded in the middle reaches between Gartness and Drymen Bridge where sampling methods were most comparable. The larval lamprey densities recorded downstream of Drymen Bridge in 2012 were considerably higher than any previously recorded. Whilst this may be indicative of increased larval lamprey settlement or survival in this area, the result should be treated with caution. The number of sampling sites was low and so the result will be sensitive to localised variations in larval lamprey density; data from additional sites would be needed to determine if this was indeed a local trend.

During the 2012 survey, every effort was made to use previously sampled locations with stable, high quality habitat patches. This approach enabled a more detailed comparison to be made between the larval lamprey densities found in optimal habitat sites that were sampled both in 2008 and 2012 (Table 12).

Table 12. Optimal habitat larval Lampetra *density (no. m^{-2}) by sampling site 2008 and 2012*

Site code	2008*	2012	Difference
E1	2.30	5.75	3.45
E3	10.30	35.25	24.95
E5	27.70	22.50	-5.20
E6	4.50	16.50	12.0
E7	42.00	23.47	-18.53
E8	16.70	30.84	14.14
E10	22.30	55.77	33.47
E12	10.50	53.28	42.78
E13	2.50	11.61	9.11
E14	3.80	13.78	9.98
E15	34.30	29.84	-4.46
E16	16.00	25.67	9.67
E18	37.70	35.21	-2.49
E19	8.00	16.00	8.00
B1	18.80	15.59	-3.21
B2	80.50	2.34	-78.16
B3	10.00	15.38	5.38
B4	6.30	12.91	6.61
B6	12.30	11.76	-0.54

*Watt *et al.*, 2011

The overall sampling effort in the 2008 and 2012 surveys was remarkably similar: 1960 lampreys were caught during the 2008 survey and 2007 in the 2012 survey.

A comparison of the larval lamprey densities recorded in the optimal habitat sampling sites used in 2008 and 2012 indicated that there was no significant change in the status of the larval lamprey populations in the Endrick Water SSSI and SAC between the two surveys (paired t-test between larval densities at 19 repeat survey optimal habitat sites: $t = -0.63$, $n = 19$, $p = 0.535$ n.s.). An area based comparison (i.e. a comparison using the groups of sites that were electrofished between Drymen Bridge and Gartness, above Gartness, and in the Blane Water) yielded the same outcome: the results of all of the paired t-tests were not significant and none of the areas exhibited a change in population status. This comparison does however mask some local changes in larval lamprey population density, such as the reduction recorded at site B2 in the lower Blane Water and the increase in two of the middle Endrick Water sites (E10 and E12).

Previous Endrick Water lamprey survey reports have documented changes in in-stream habitat between the sampling period that they cover and the preceding sampling period; these changes mean that replicating surveys exactly is impossible (Watt *et al.*, 2011). In-stream habitat changes that occurred between the 2008 (Watt et al., 2011) and this survey meant that five new Endrick Water sites (26% of the total Endrick Water sites) and one new Blane Water site (17% of Blane Water sites) had to be used during the latter. Establishing new sites was necessary because either the habitat patch sampled during the 2008 survey had disappeared, or it had changed so significantly that a comparison with the 2008 data would not have been possible. Whilst it was not possible to determine exactly how long the new sites used during this survey had been present for, nor how long they had been occupied by larval lamprey, the surveyors did note that some patches had been formed since the 2008 survey. The length of river over which new sites were needed (between site E2 and E17) suggested that the larval lamprey habitat is subject to considerable change.

The same dynamic forces that necessitated sampling at several new locations will also have had some effect on the other survey locations; they will have altered the quality of the larval lamprey habitat and so led to variability amongst and between the repeat survey site results. The somewhat arbitrary description of *optimal* or *sub-optimal* quality given by surveyors to a habitat patch cannot fully account for subtle variations in substrate composition, as variables such as organic content or substrate structure or stability cannot be easily determined by visual inspection alone. With larval abundance closely linked to the physical characteristics of habitat (Almeida & Quintella, 2002; Malmqvist, 1980), subtle differences in quality and stability are likely to have accounted for higher rates of larval lamprey occupancy both within and between sampling locations. This variation in habitat quality was indicated by the relatively high intra-site variability in larval lamprey density, i.e. the variation in larval lamprey density between the quadrats electrofished at a site. Individual quadrat densities are given in Appendix 3.

The impression formed during the 2012 survey of the Endrick Water was that the highest densities of larval lamprey were found in mixed silt and sand deposits that were trapped amongst large woody material in marginal areas. This habitat typically contained a layer of fine sand and silt together with some coarse (> 1 mm) particulate organic material that was often < 10 cm in depth and lay on top of a firmer coarse sand bed. These habitat patches were often small, isolated features along the channel margins and were flanked by larger expanses of more mobile sand, gravel and, in some places, firm earth and mud. It should be noted that the sediment depth and characteristics of many of the habitat patches that contained a high density of larval lampreys were either at the lower limit of the criteria for *optimal* habitat (APEM, 2002) or accorded more with the criteria for *sub-optimal* habitat (APEM, 2002) with sediment < 15 cm deep. The functional importance of the large woody material in such areas of mobile bed appeared to be reflected in larval occupancy rates, especially in the reaches of the Endrick Water between Gartness and Drymen Bridge. Here the accumulations of woody material may have offered greater local stability to the bed substrate as the structures were frequently anchored in the stream bed. This will have led to localised reductions in water velocity and the deposition of organic particles from the water column and promoted larval lamprey settlement. The decomposition of the woody material may also have supplemented the organic content in adjacent habitat patches and increased their suitability for larval lamprey settlement.

During the course of the survey the water levels in the Endrick Water and Blane Water fluctuated in response to unseasonably high precipitation. The electrofishing in sites E6 and E7, and in several of the upper Blane Water sites, was undertaken in slightly elevated flow conditions. This may have reduced the electrofishing catch efficiency and prevented the surveyors from gaining access to habitat in deeper water but, as the larval density and age structure results generally align well with those of the 2008 survey, the elevated flow conditions were not considered to have adversely affected the quality of the survey.

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APPENDIX 1: WATER BODY AND LAMPREY HABITAT DETAILS RECORDED AT ELECTROFISHING SITES

Site code	Bank	Habitat quality	Water body at survey area								Lamprey habitat				
			Width (m)	Depth (m)		Land use		Vegetation		Downstream obstructions	Location	Area (m)	Longevity	Shade (%)	Woody debris
				Mean	Max.	Left bank	Right bank	Left bank	Right bank						
E1	left	optimal	20	1.0	2.0	IP	TH	IP	TH	none	margin	>50	permanent	0	present
E2	left	optimal	25	0.5	1.0	IP	IP	IP	IP	none	eddy	<10	permanent	0	none
E3	right	optimal	11	1.0	2.0	RD	IP	BL	TH	none	margin	10–50	permanent	0	present
E4	left	optimal	10	0.5	1.0	IP	IP	IP	IP	none	margin	10–50	permanent	0	present
E5	right	optimal	15	0.5	0.5	IP	IP	IP	IP	none	eddy	10–50	permanent	0	none
E6	left	optimal and sub-optimal	8	0.5	1.0	IG	IG	IG	IG	none	margin	<10	permanent	0	none
E7	right	optimal	12	0.5	1.0	IP	IP	IP	IP	none	margin	<10	permanent	0	present
E8	left	optimal	12	0.6	1.5	IP	IP	TH	IP	none	eddy	<10	permanent	10	present
E9	left	optimal	10	0.5	1.0	RP	RP	RP	RP	none	margin	<10	permanent	0	present
E10	left	optimal	15	0.3	0.8	BL	IP	BL	IP	none	eddy	<10	permanent	50	present
E11	right	optimal and sub-optimal	12	1.0	2.0	BL	IP	BL	IP	none	margin	<10	semi-permanent	0	none
E12	left	optimal	10	0.5	1.0	IP	IP	IP	IP	none	eddy	<10	permanent	0	present
E13	left	optimal and sub-optimal	10	1.0	1.5	BL	RP	RP	RP	Potts of Gartness	margin	<10	permanent	0	present
E14	left	optimal and sub-optimal	15	0.5	1.2	BL	RP	BL	RP	Potts of Gartness	margin	<10	permanent	50	present
E15	right	optimal and sub-optimal	12	0.5	1.0	RP	BL	MH	BL	Potts of Gartness	margin	<10	permanent	90	abundant
E16	right	optimal and sub-optimal	10	0.4	1.0	IG	BL	IG	BL	Potts of Gartness	eddy	10–50	permanent	50	none
E17	right	optimal and sub-optimal	10	0.4	0.6	IG	RP	BL	BL	Potts of Gartness	eddy	10–50	semi-permanent	90	abundant
E18	right	optimal	8	0.5	1.5	IG	BL	BL	BL	Potts of Gartness	eddy	10–50	permanent	90	abundant
E19	right	optimal and sub-optimal	7	0.3	0.5	IG	BL	IG	BL	Potts of Gartness	margin	<10	semi-permanent	90	present
B1	left	optimal and sub-optimal	12	1.0	2.0	IG	BL	IG	BL	none	margin	10–50	permanent	0	none
B2	left	optimal and sub-optimal	8	1.0	1.0	IG	IG	IG	IG	none	eddy	10–50	permanent	60	none

B3	right	optimal and sub-optimal	3	1.0	2.0	RP	RP	RP	RP	none	eddy	10–50	permanent	0	none
B4	right	optimal	5	0.6	1.2	RP	RP	RP	RP	none	eddy	<10	permanent	20	none
B5	left	optimal and sub-optimal	4	0.7	1.0	IG	IG	IG	IG	none	eddy	<10	permanent	0	present
B6	right	optimal and sub-optimal	4	0.5	1.0	IG	IG	IG	IG	none	eddy	<10	permanent	10	present

Vegetation: BL – broadleaf trees; IG – improved grassland; RP – rough pasture; MH – moorland heath; TH – tall herbs

APPENDIX 2: MICROHABITAT AT ELECTROFISHING SITES

Site code	Bank	Habitat	Water depth (m)	Flow	Shade %	Sediment composition					Sediment depth (cm)	Woody material	Aquatic vegetation cover (%)		
						HO	SI	SA	GR+PE	CO+BO			Emergent	Floating	Submerged
E1	left	optimal	0.30	slow	0	30	70	0	0	0	10–20	present	0	0	5
E2	left	optimal	0.30	slow	0	30	60	10	0	0	30	none	20	0	10
E3	right	optimal	0.20	slow	0	30	50	20	0	0	20–25	present	0	0	0
E4	left	optimal	0.20	slow	0	30	50	20	0	0	20	present	0	0	0
E5	right	optimal	0.30	slow	0	30	70	0	0	0	20	none	0	0	10
E6	left	optimal and sub-optimal	0.30	slow	0	10	40	50	0	0	10–15	none	0	0	0
E7	right	optimal	0.20	slow	0	10	30	60	0	0	15	present	0	0	0
E8	left	optimal	0.40	slow	0	10	80	10	0	0	25	present	5	0	0
E9	left	optimal	0.30	slow	0	20	50	30	0	0	15	present	0	0	0
E10	left	optimal	0.10	slow	50	20	40	40	0	0	15	abundant	0	0	0
E11	right	optimal and sub-optimal	0.30	slow	0	10	20	60	10	0	10–15	none	0	0	0
E12	left	optimal	0.40	slow	20	20	60	20	0	0	15	present	0	0	0
E13	left	optimal and sub-optimal	0.25	slow	0	20	30	50	0	0	5–15	present	0	20	50
E14	left	optimal and sub-optimal	0.35	slow	20	20	50	30	0	0	10–15	present	0	0	0
E15	right	optimal and sub-optimal	0.20	slow	90	30	50	20	0	0	5–15	abundant	0	0	0
E16	right	optimal and sub-optimal	0.35	slow	100	10	60	30	0	0	10–20	none	0	0	0
E17	right	optimal and sub-optimal	0.30	static	90	40	30	10	20	0	10–15	abundant	0	0	30
E18	right	optimal	0.30	slow	90	30	50	20	0	0	20	abundant	0	0	0
E19	right	optimal and sub-optimal	0.30	slow	90	20	40	30	10	0	10–15	present	0	0	0
B1	left	optimal and sub-optimal	0.30	slow	0	30	70	0	0	0	10–20	none	0	0	0
B2	left	optimal and sub-optimal	0.30	slow	60	20	70	10	0	0	10–20	none	0	0	0
B3	right	optimal and sub-optimal	0.30	slow	0	20	70	10	0	0	10–15	none	0	0	0
B4	right	optimal	0.35	slow	20	10	40	50	0	0	20	none	0	10	10

B5	left	optimal and sub-optimal	0.40	slow	0	40	40	20	0	0	10–15	present	0	0	0
B6	right	optimal and sub-optimal	0.30	slow	10	30	40	30	0	0	5–15	present	0	0	30

Sediment composition: HO – high organic; SI – silt; SA – sand; GR+PE – gravel and pebble; CO+BO – cobble and boulder

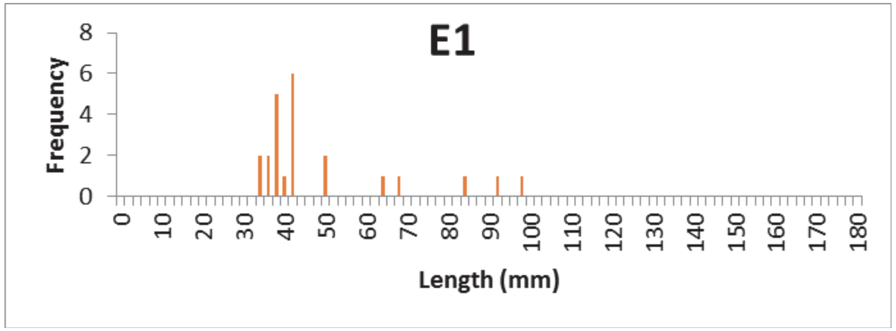
APPENDIX 3: NUMBER OF LARVAL *LAMPETRA* CAUGHT BY QUADRAT AND RUN DURING THE 2012 SURVEY

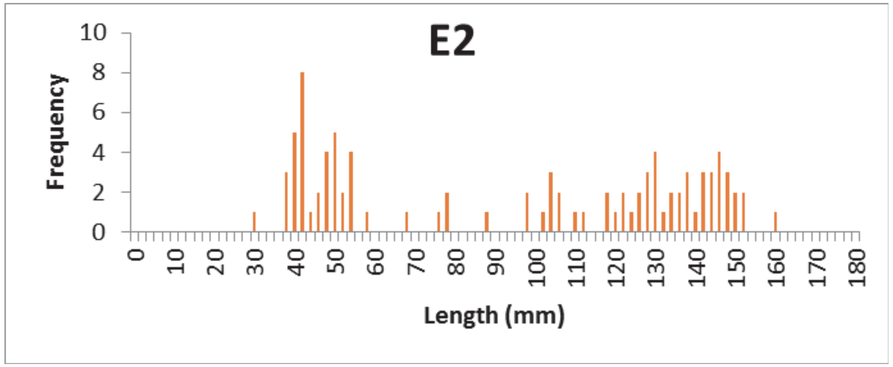
Site	Habitat quality	Quadrat no.	Run						Calculated density per m²
			1	2	3	4	5	6	
E1	optimal	1	3	0	0	–	–	–	3
E1	optimal	2	1	4	1	–	–	–	6*
E1	optimal	3	4	2	1	–	–	–	7
E1	optimal	4	4	2	1	–	–	–	7
E2	optimal	1	8	9	4	–	–	–	21*
E2	optimal	2	10	7	5	–	–	–	22*
E2	optimal	3	13	10	4	–	–	–	34
E2	optimal	4	15	5	3	–	–	–	25
E3	optimal	1	21	9	5	–	–	–	39
E3	optimal	2	26	9	3	–	–	–	40
E3	optimal	3	11	4	3	–	–	–	20
E3	optimal	4	16	14	4	–	–	–	42
E4	optimal	1	21	17	14	8	–	–	88
E4	optimal	2	28	14	7	–	–	–	56
E4	optimal	3	34	18	8	–	–	–	68
E4	optimal	4	22	15	7	–	–	–	55
E5	optimal	1	12	9	10	5	–	–	36
E5	optimal	2	21	7	7	4	–	–	29
E5	optimal	3	8	4	2	–	–	–	16
E5	optimal	4	5	2	2	–	–	–	9
E6	optimal	1	7	3	2	–	–	–	14
E6	optimal	2	14	4	2	–	–	–	21
E6	optimal	3	8	6	0	–	–	–	15
E6	sub-optimal	4	7	4	2	–	–	–	15
E7	optimal	1	13	8	2	–	–	–	25
E7	optimal	2	10	5	3	–	–	–	21
E7	optimal	3	13	2	1	–	–	–	16
E7	optimal	4	14	9	8	–	–	–	31*
E8	optimal	1	20	5	4	–	–	–	31
E8	optimal	2	19	10	10	0	–	–	39*
E8	optimal	3	9	8	3	–	–	–	20*
E8	optimal	4	16	9	4	–	–	–	34
E9	optimal	1	13	0	2	–	–	–	15*
E9	optimal	2	15	10	2	–	–	–	30
E9	optimal	3	29	15	13	–	–	–	78
E9	optimal	4	18	1	0	–	–	–	19
E10	optimal	1	19	9	5	–	–	–	38
E10	optimal	2	23	25	7	–	–	–	74
E10	optimal	3	24	8	7	–	–	–	44
E10	optimal	4	29	15	10	–	–	–	67
E11	optimal	1	5	4	1	–	–	–	10*
E11	sub-optimal	2	2	1	0	–	–	–	3
E11	optimal	3	5	3	4	5	1	0	21
E11	optimal	4	12	7	5	–	–	–	24
E12	optimal	1	30	17	12	–	–	–	78
E12	optimal	2	14	15	7	0	–	–	36*
E12	optimal	3	23	14	10	–	–	–	65
E12	optimal	4	18	7	5	–	–	–	34
E13	optimal	4	13	3	0	–	–	–	14
E13	optimal	3	7	1	1	–	–	–	9

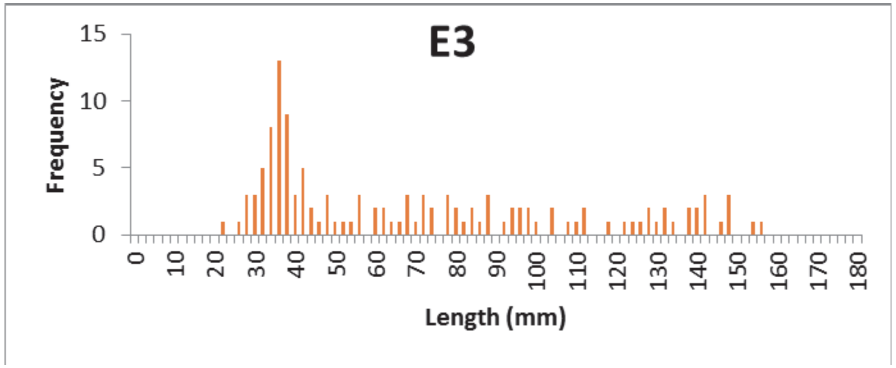
E13	sub-optimal	2	3	1	0	–	–	–	3
E13	sub-optimal	1	4	0	0	–	–	–	4
E14	optimal	1	11	2	2	–	–	–	16
E14	optimal	2	9	0	1	–	–	–	12
E15	sub-optimal	1	7	1	1	–	–	–	9*
E15	optimal	2	12	5	2	–	–	–	20
E15	optimal	3	28	9	2	–	–	–	40
E15	optimal	4	18	5	4	–	–	–	29
E16	optimal	1	15	2	1	–	–	–	18
E16	sub-optimal	2	9	1	2	–	–	–	13
E16	optimal	3	29	9	3	–	–	–	42
E16	optimal	4	22	5	2	–	–	–	30
E17	sub-optimal	1	4	1	0	–	–	–	5
E17	optimal	2	15	5	1	–	–	–	22
E17	optimal	3	13	1	0	–	–	–	14*
E17	optimal	4	20	8	2	–	–	–	31
E18	optimal	1	20	3	1	–	–	–	24
E18	optimal	2	6	5	8	3	2		29
E18	optimal	3	13	9	4	–	–	–	32
E18	optimal	4	13	16	10	3	–	–	55
B1	optimal	1	7	5	1	–	–	–	15
B1	optimal	2	9	4	1	–	–	–	15
B1	optimal	3	8	7	0	–	–	–	16
B1	optimal	4	15	2	0	–	–	–	17
B2	optimal	1	1	0	0	–	–	–	1*
B2	optimal	2	3	0	0	–	–	–	3
B2	optimal	3	1	0	0	–	–	–	1*
B2	optimal	4	2	2	0	–	–	–	4*
B3	optimal	1	11	3	1	–	–	–	15
B3	sub-optimal	2	7	0	0	–	–	–	7
B3	sub-optimal	3	3	0	0	–	–	–	3
B3	sub-optimal	4	1	3	0	–	–	–	4*
B4	optimal	1	17	3	0	–	–	–	22
B4	optimal	2	4	1	2	–	–	–	7
B4	optimal	3	10	5	0	–	–	–	15
B4	optimal	4	5	2	0	–	–	–	7
B5	optimal	1	14	5	2	–	–	–	22
B5	optimal	2	4	1	2	–	–	–	7
B5	optimal	3	6	3	2	–	–	–	11
B5	optimal	4	11	5	1	–	–	–	18
B5	sub-optimal	5	4	0	0	–	–	–	4
B6	optimal	1	13	2	2	–	–	–	18
B6	sub-optimal	2	6	0	0	–	–	–	6
B6	optimal	3	8	1	0	–	–	–	9
B6	sub-optimal	4	2	0	0	–	–	–	2

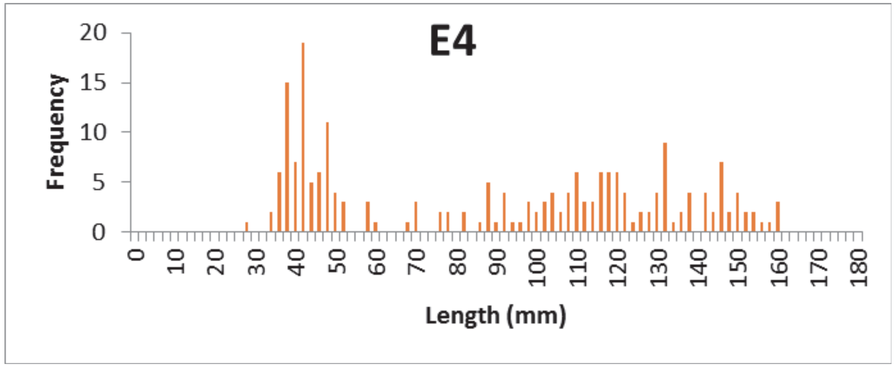
* Calculated minimum density estimate.

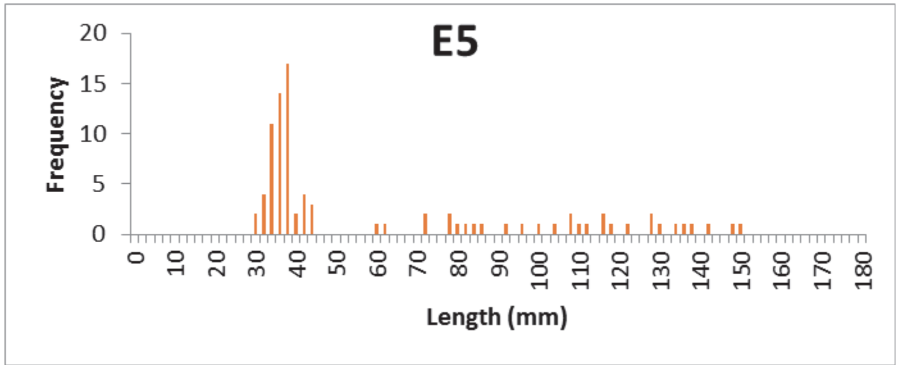
APPENDIX 4: LENGTH FREQUENCY PLOTS FOR LARVAL *LAMPETRA* AT INDIVIDUAL SURVEY SITES

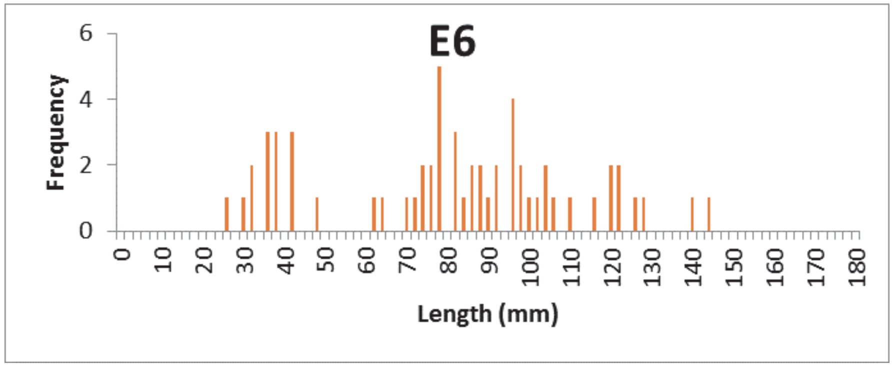


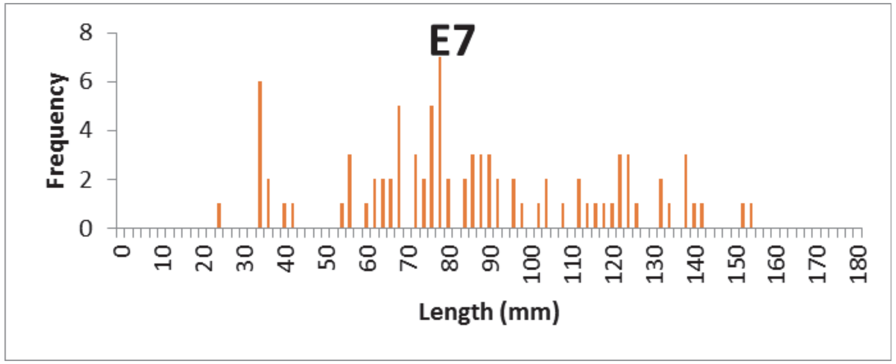


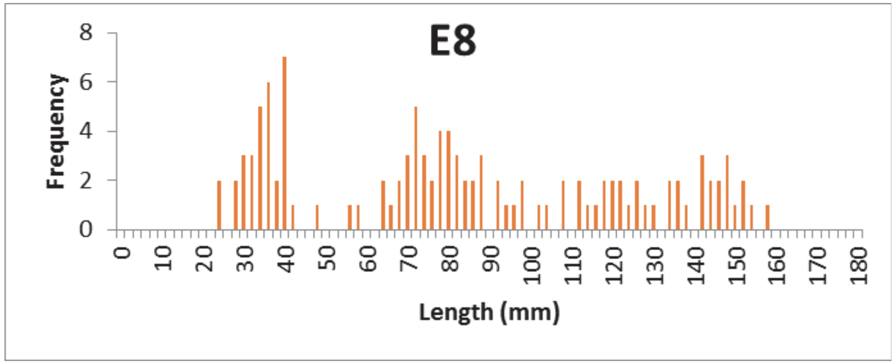


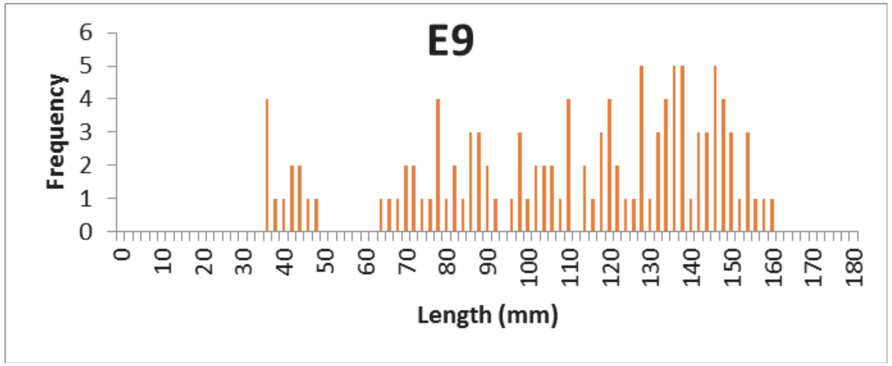


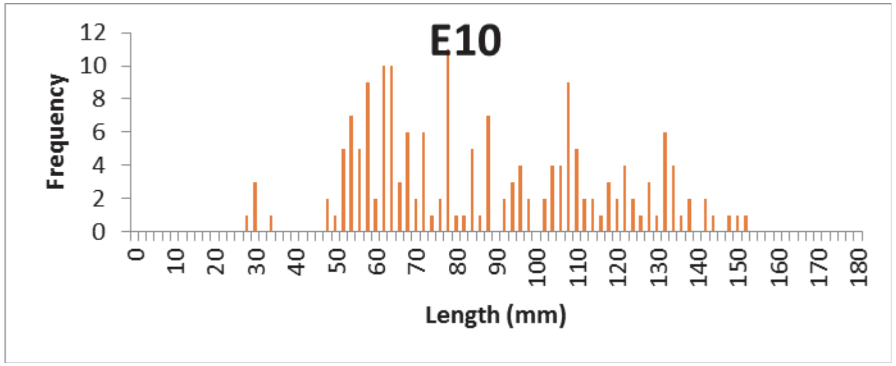


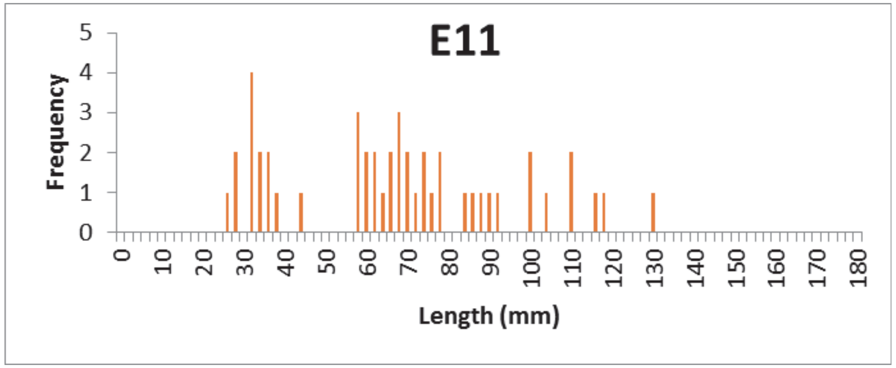


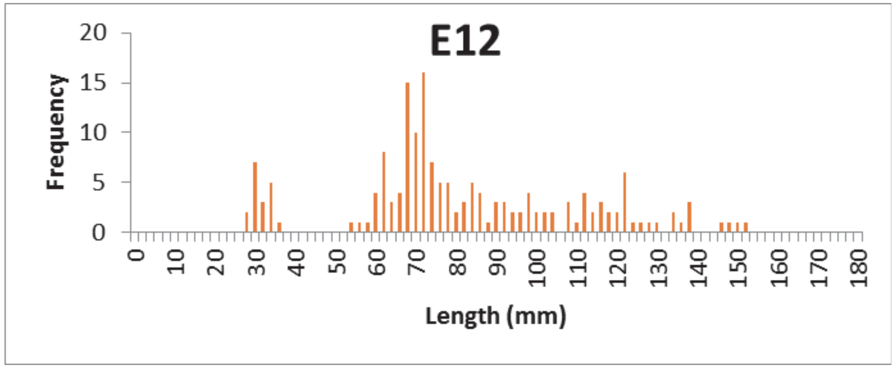

E7
Frequency
Length (mm)

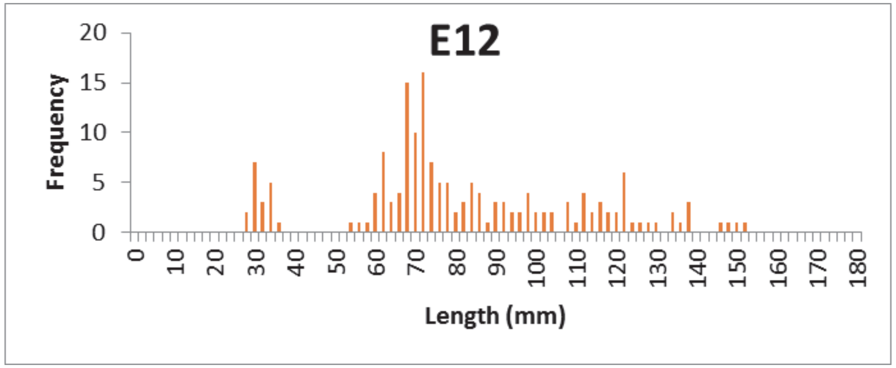

E8
Frequency
Length (mm)

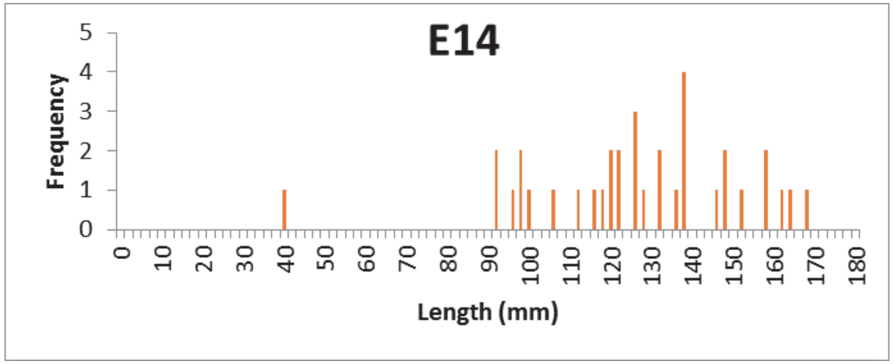

E9
Frequency
Length (mm)

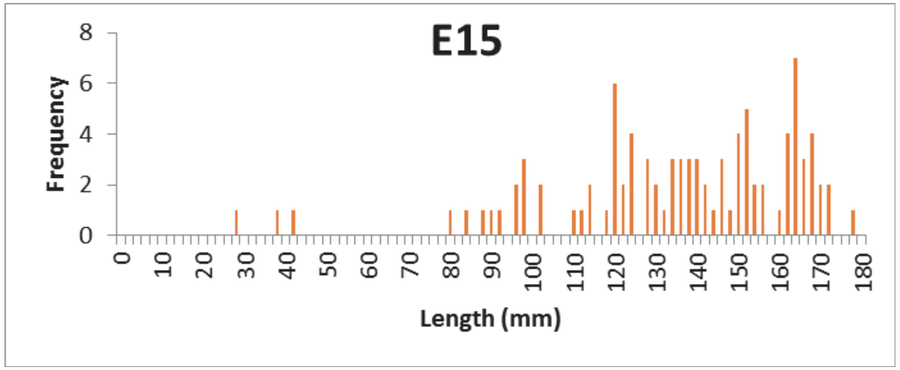

E10
Frequency
Length (mm)

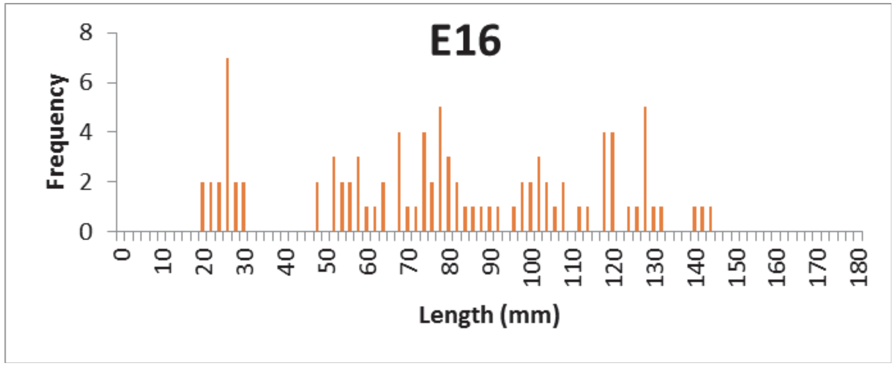

E11
Frequency
Length (mm)

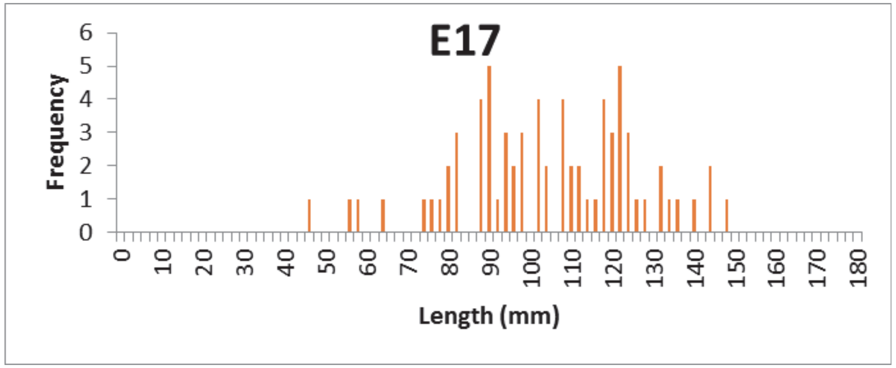

E12
Frequency
Length (mm)

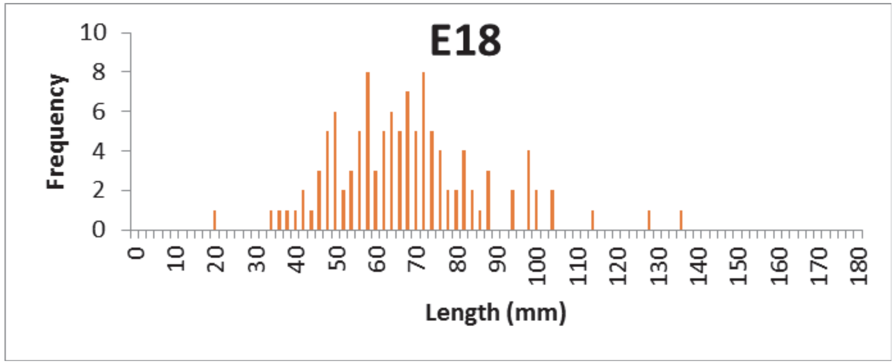

E12
Frequency
20
15
10
5
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

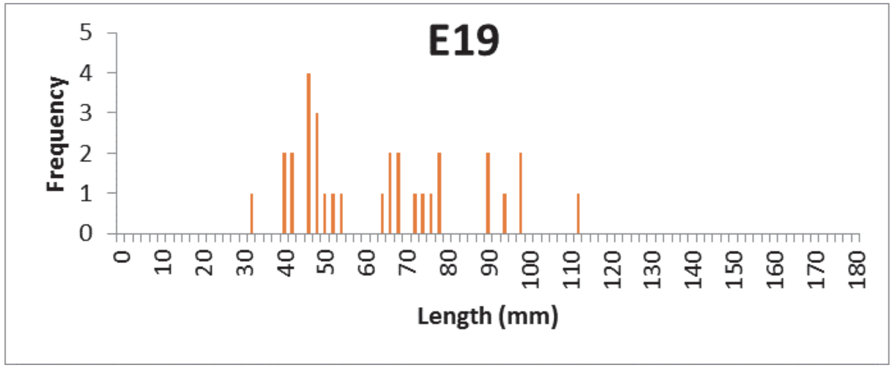

E14
Frequency
5
4
3
2
1
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

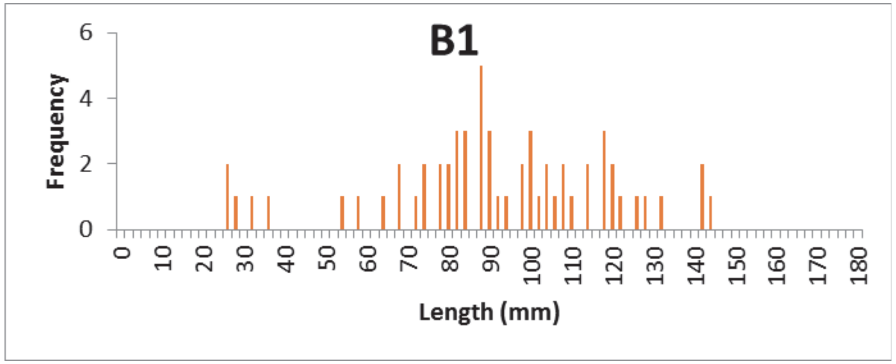

E15
Frequency
8
6
4
2
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

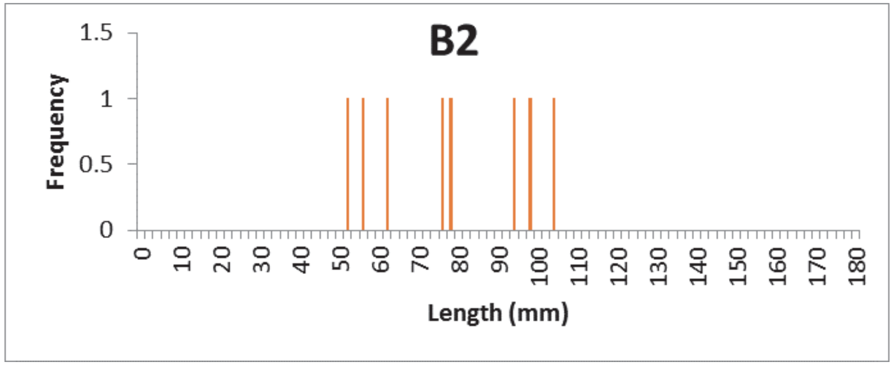

E16
Frequency
8
6
4
2
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

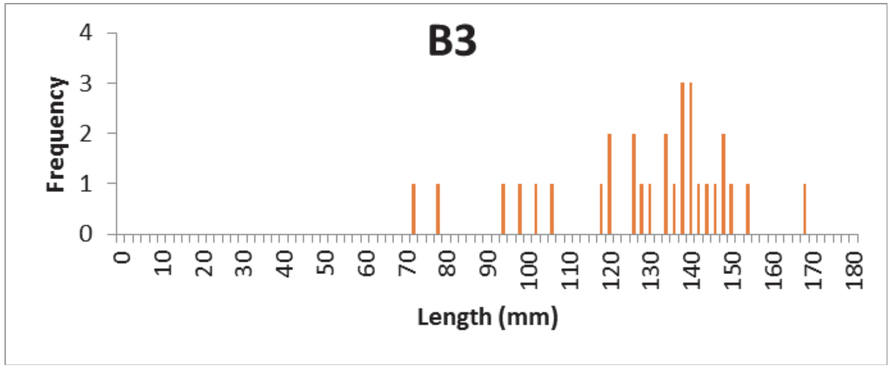

E17
Frequency
6
5
4
3
2
1
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

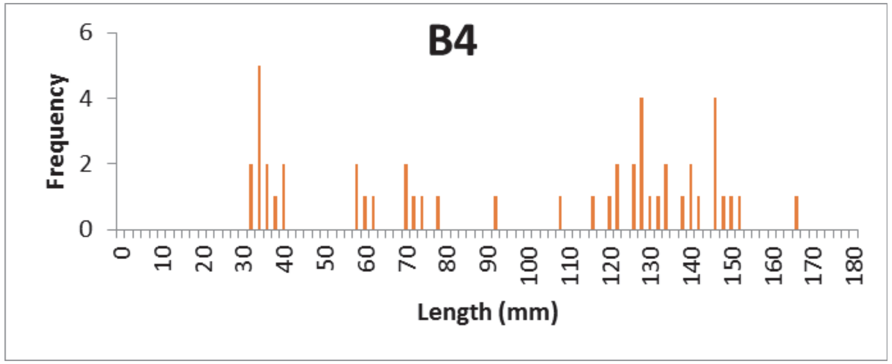

E18
Frequency
10
8
6
4
2
0
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

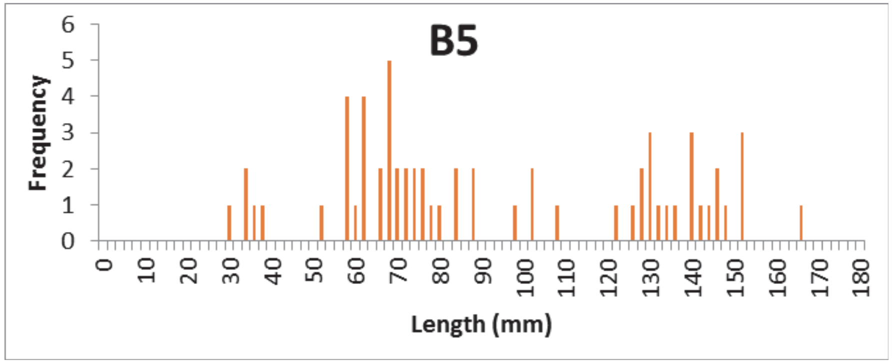

E19
Frequency
0 1 2 3 4 5
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)

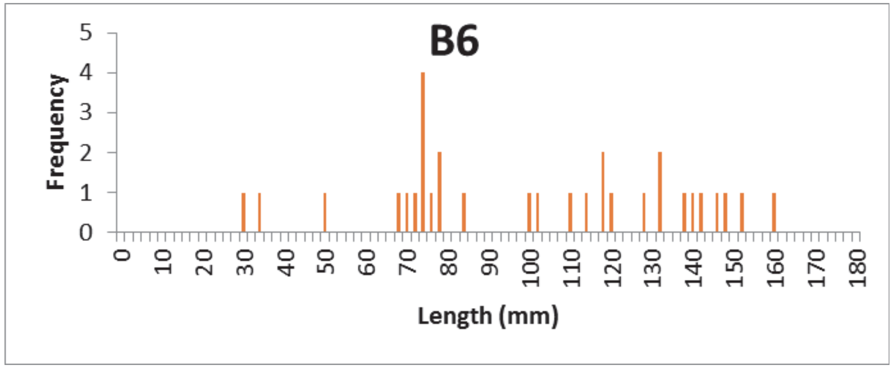

B1
Frequency
0 2 4 6
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)


B2
Frequency
0 0.5 1 1.5
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)


B3
Frequency
0 1 2 3 4
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)


B4
Frequency
0 2 4 6
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)


B5
Frequency
0 1 2 3 4 5 6
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Length (mm)


B6
Frequency
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Length (mm)

APPENDIX 5: ELECTROFISHING SITE PHOTOS


Site E1 from upstream


Site E2 from downstream


Site E3 from upstream


Site E4 from upstream


Site E5 from upstream


Site E6 from upstream


Site E7 from downstream


Site E8 from downstream


Site E9 from upstream


Site E10 from upstream


Site E11 from upstream


Site E12 from downstream


Site E13 from downstream


Site E14 from downstream


Site E15 from downstream


Site E16 from upstream


Site E17 from upstream


Site E18 from downstream


Site E19 from upstream


Site B1 from upstream


Site B2 from downstream


Site B3 from upstream


Site B4 from downstream


Site B5 from upstream

Site B6 from downstream

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ISBN: 978-1-78391-384-8

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