Caithness District Salmon Fishery Board

The Crown Estate

Baseline Survey of Juvenile Salmonids in the Rivers of Caithness, 2013.

A.F. Youngson and J.H. Webb

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Contents

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Summary

1. Twenty-two locations in the major rivers of Caithness - Forss, Thurso, Wester, Wick, Dunbeath, Berriedale and Langwell - were electric-fished in low water conditions in Sept/ Oct, 2013. Overall, the sites covered an altitude range from 9 to 250m.

2. Trout fry were absent at 13 of the 22 survey sites, infrequent at six and relatively abundant only at Cnoc-glas (Forss), Rumsdale (Thurso) and Gobernuisgach (Berriedale) - all high altitude sites. Trout parr were relatively abundant only at the same three sites but more widely distributed than fry, being absent at only five sites.

3. With the exception of the three sites noted above, spawning by trout is probably uncommon in the vicinities of the survey sites and the number of trout and their distribution is probably constrained by lack of recruiting fry.

5. Salmon fry and parr were present at all the survey sites. Densities (ie. number per square metre) of fry or parr were classified by comparison with reference values proposed by Godfrey (2005).

6. By comparison with the appropriate reference values, 14 comparisons of salmon fry densities were classed as “excellent/ very good”, four as “good/ average” and four as “low/ poor”.

7. By comparison with reference values, salmon parr densities (all age-classes combined) were classed as “excellent/ very good” for 12 sites, “good/ average” at seven and “low/ poor” at three.

8. Six of the seven “low/ poor” classifications for fry or parr were associated with an “excellent/ very good” classification for the other group. This indicates either variation in the strength of spawning year classes near the sites, or the tendency of some sites to provide suitable habitat for fish only at the smaller fry stage or as larger parr.

9. Only at Barrock Mill (Wester) were densities classed as “poor” for both fry and parr.

10. A classification system was developed based on the biomass of salmon fry (ie. the total mass per square metre). An underlying relationship between altitude and biomass was identified by editing the set of sites to exclude those where habitat was classified as unfavourable for fry.

11. The relationship between altitude and biomass can be used as a basis for classification. The merits of this approach are that it (1) factors out the effect of altitude, (2) factors in fish size and density-dependent growth, (3) uses more of the data to provide more precise assessments, and (4) reduces reliance on comparisons with data acquired in previous years for different sites by different operators.

12. Higher altitude sites were found to support lower biomasses of fry. Allowing for altitude, fry densities at Dalemore (Thurso) and Dalganachan (Thurso) were anomalously high. However, biomass values were not anomalous because the fish were very small. This indicates that the growth of fry had been impaired due to intense competition and, therefore, that these sites were near saturation.

13. The Dalnagleton (Thurso), Bilbster (Wick), The Clow (Wick) and Barrock Mill (Wester) sites contained lower biomasses of fry than expected for their altitude.

14. At Dalnagleton, low biomass was attributable to inferior growth of fry but at Bilbster, The Clow and Barrock Mill, low biomass was attributable to low density of fry, probably because of lack of spawning nearby.

15. An absolute value for site status cannot be provided since scrutiny of densities using Godfrey's (2005) approach and the biomass classification system are both comparative.

16. Classification of sites according to fry biomass identifies weaknesses in the approach based on Godfrey's data that result in its under-rating some sites and over-rating others.

17. Biomass density of fry was calculated from fry density values reported for a previous survey of some of the Caithness rivers conducted for SNH in 2004. In 2004, average fry biomass density was around 60% of the 2013 value.

18. Parr of four age–classes were present, hatched in the years 2009-2012. The frequency of the age-classes varied among sites but, overall, one-year-old (hatched in 2012) and two-year-old (hatched in 2011) parr were most frequent.

19. In many cases, the scales of parr showed checks in growth for the current year. These were probably the result of the unusually high water temperatures experienced in 2013. The frequency of checks varied among sites from zero to 100%.

20. The emigration of smolts determines the age-class structure, density and probably the size of residual 2+ and older parr. However, 1+ parr are probably not affected in this way since one-year-old smolts are not likely to occur in Caithness conditions. Site assessments for parr were therefore focussed on the density and biomass of the 1+ age-class.

21. Lower altitude sites tended to support higher densities of 1+ parr. However, the relationship was non-linear and densities at sites below around 70 m altitude were less than predicted from the progression of values for sites between 70 and 250 m.

22. The site at Barrock Mill (Wester) contained 1+ parr at extremely low density and the fish were very large.

23. The density of 1+ parr at Braemore (Berriedale) was atypically high. However, because the fish were relatively small the biomass at the site was not atypical. This indicates that the growth of individuals was restricted by high levels of competition and, therefore, that the site's capacity to support fish was near saturation.

24. The biomasses of 1+ parr at five low altitude sites - Hoy (Thurso), The Clow (Wick), Sheriff's (Wick), Bilbster (Wick) and Strathcoull (Berriedale) were anomalously low.

25. The low densities and biomasses of 1+ parr at the five anomalous sites, and particularly Hoy, merit further attention. The deficits were tentatively attributed to local relocation in response to the extreme low river flows prevalent in 2013. If this is the case, the true status of the anomalous sites will be underestimated.

26. Site classifications for parr using Godfrey's approach or based on biomass both identify the sites of lowest status for 1+ parr – Dalnagleton (Thurso), Hoy (Thurso) and Barrock Mill (Wester). Otherwise, the degree of correspondence between the two methods is low.

27. The only substantial problem raised by the survey relates to the Barrock Mill site on the River Wester. Salmon and trout, and both fry and parr, were present but extremely sparse for reasons that are not apparent. This case merits further investigation.

28. Otherwise, this report has shown that salmon belonging to the 2012 and 2013 hatch-years are in a favourable condition in all the Caithness rivers. Some sites have been shown to be at or near their maximum capacity to support fish.

1. Introduction

This report documents an electric-fishing survey of juvenile salmonids organised and undertaken by the Caithness District Salmon Fishery Board and jointly financed by the Board and The Crown Estate. The main aim of the project was to cover the funders' requirement for up-to-date information on the status of salmonid populations in advance of the development of marine renewable energy installations around the Caithness coasts. Twenty-two sites in the Board's area were surveyed in September and October, 2013, under low water conditions.

The Board previously proposed a monitoring programme for salmonids in Caithness, including electric fishing survey work on juvenile populations. These proposals were documented in the Board's representation to Marine Scotland in the context of the proposed development of a tidal turbine array in the Inner Sound of Stroma on the north Caithness coast. The Board considers that similar measures could be more generally relevant in relation to developments elsewhere around the Caithness coasts. The present report describes the juvenile survey work that forms the first part of the proposed package – a full account of the current (2013) status of juvenile salmonids in all the Caithness rivers. In time, this work can be consolidated by extending survey work to include future years or expanded by consideration of other types of data, including fishery data.

The secondary aims of this project were to train local operatives in depletion electric-fishing techniques, to promote awareness among local estate staff and to forge links with North Highland College in Thurso – all with a view to increasing future capacity within Caithness to perform survey work. To this end, the field-work was led by the authors of this report, each of whom has many years of experience in planning, conducting and interpreting electric-fishing survey work but many others participated as part of a varying team of local operatives recruited by the Board.

The particular aims of this report are to thoroughly document the survey methods and the data for future reference, to explore possible approaches to extracting information from the data, and to provide an assessment of the status of juvenile salmonids in the Caithness rivers in the year of survey.

2. Methods

2.1 Site selection

Twenty-one locations in the six major rivers of Caithness - Forss, Thurso, Wick, Dunbeath, Berriedale and Langwell - and a single location in the smaller, Wester catchment were selected for survey (Figure 1). The sites were chosen to provide uniform spatial coverage within and across catchments but with a bias towards the three SAC rivers in Caithness in recognition of their special status. Site choice was also biased towards locations for which previous survey data had been obtained by the Board. Most of these sites are characterised by good vehicle access and this was regarded as important for the present survey in view of the bulky nature of the equipment to be used.

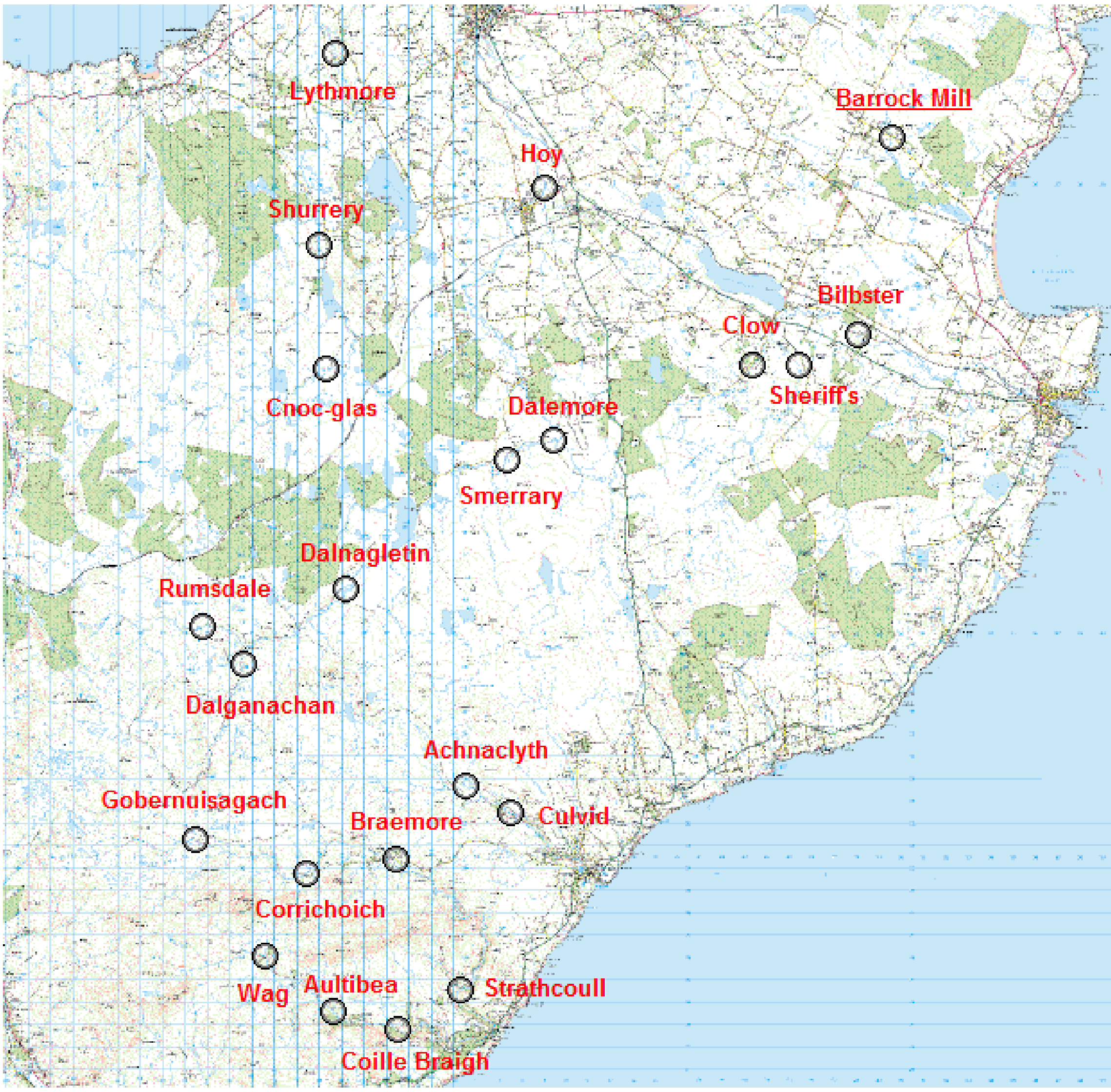

Figure 1. Map of electric-fishing sites.

A provisional list of sites was identified at the project planning stage but, on the day, some sites were substituted by others nearby according to their suitability for inclusion in the project. In particular, the main part of the survey period fell at the end of a long period of low rainfall. Provisional sites on small tributary streams in the lower Thurso catchment had become shrunken and potential main river sites had become readily accessible. The opportunity was therefore taken to substitute two proposed tributary sites in the lower catchment of the River Thurso with main-river sites that were considered more likely to be representative of the river as a whole. Additionally, when possible, provisional sites where stocking had been carried out were rejected in favour of comparable, unaffected sites. The only exceptions were the two sites on the Dunbeath Water both of which had been trickle-stocked with fry earlier in the year.

2.2 Site description

Table 1 shows the survey sites identified by name and Ordnance Survey co-ordinates. The temperature (^oC) and electrical conductivity (µS. cm) of stream water were recorded at each site. Site altitude (m) was derived from a computer-based mapping system.

River	**Site name**	**O.S.**	**Alt** (m)	**Date**	**Temp** (C)	**Conductivity** (µS. cm)
Forss	Cnoc-glas	ND 042 523	110	14th Sep	12	146
	Shurrery	ND 039 578	89	15th Sep	14	101
	Lythmore	ND 047 663	24	6th Oct	13	181
Thurso	Rumsdale	NC 988 408	159	4th Sep	14	114
	Dalganachan	ND 006 391	147	4th Sep	17	111
	Dalnagleton	ND 052 424	124	3rd Sep	15	122
	Smerrary	ND 123 482	86	2nd Sep	15	130
	Dalemore	ND 144 491	70	2nd Sep	15	123
	Hoy	ND 141 604	23	3rd Sep	15	166
Wester	Barrock Mill	ND 296 626	11	7th Sep	13	312
Wick	The Clow	ND 233 524	35	5th Sep	11	320
	Sheriff's	ND 255 525	33	6th Sep	13	312
	Bilbster	ND 281 538	9	5th Sep	17	345
Dunbeath	Achnaclyth	ND 105 337	120	9th Sep	15	165
	Culvid	ND 123 325	97	9th Sep	10	165
Berriedale	Gobernuisgach	NC 984 312	250	13th Oct	8	83
	Corrichoich	ND 034 297	200	12th Sep	15	100
	Braemore	ND 074 304	156	12th Sep	14	111
	Strathcoull	ND 103 245	38	13th Sep	14	106
Langwell	Wag	ND 016 260	188	11th Sep	12	156
	Aultibea	ND 046 236	125	10th Sep	11	158
	Coille Braigh	ND 074 228	93	11th Sep	15	165

Table 1. Identity and characteristics of electric-fishing survey sites.

Site altitude was subsequently used as a basis for linking and comparing survey sites because it is likely to be a proxy measurement for important environmental and spatial variations. Thus, for example, altitude tends to correlate with stream temperature and with water chemistry both of which affect the performance of juvenile fish. In addition, early-running adult fish typically spawn in higher altitude locations than later-running fish. The abundance, and the relative abundance, of the different run-timing groups vary with some independence between years and also over decades. Consideration of altitude is likely to capture the effect of some of the resulting spatial variation in egg deposition density and fry recruitment.

The upper and lower limits of each site were photographed to facilitate exact replication of fishing areas in future survey work. Site dimensions (length and average breadth) were determined. Breadth was assessed both as the wetted dimension, as measured on the day, and as the estimated stream-bed width at times of average stream flow. In incised channels, the two measures were often the same. The utility of the alternative measures is considered in Appendix 23 and wetted areas were used to calculate fish densities from capture numbers in what follows. However, both measures of area are given for each site in Appendices 1 – 22 to permit comparisons with future survey work when wetted areas may be different.

2.3 Electric-fishing

The electric-fishing methods used were generally those of the Scottish Fisheries Coordination Centre (SFCC) protocol[1]. In order to target the acquisition of the reference data that were the main objective of the project, three-pass depletion methods were used. Each site was fished on three occasions over a period of about three hours and the fish captured on each pass were recorded and documented separately.

Electric-fishing exploits the tendency of fish to be attracted to and temporarily incapacitated in the electrical field around a positive electrode. The field is set up by passing the minimum electrical current through stream water that is sufficient to produce an effective voltage field around the anode. The current required is affected by the electrical conductivity of the stream water. Preliminary measurements of electrical conductivity had shown relatively high values. Because of this, using a generator as a power source was considered superior to the alternative use of a battery-powered back-pack. In particular, use of a generator was considered a pre-requisite for fulfilling the quality requirements of the planned survey by targeting uniform efficiency of capture over the range of water depths and conductivities likely to be encountered. A portable Honda generator was therefore used to supply power to the electric fishing apparatus via an Electracatch WF7 control box.

In the interests of survey quality, stop-nets were used to define the limits of the survey sections. These nets are designed to prevent fish leaving the survey section ahead of any disturbance caused by the operators and they prevent fish outside the section entering it under the attracting influence of the electric-fishing probe. The stop-nets were of 5 mm mesh with a weighted ground-rope and an upper rope supported by floats. Nets were additionally supported by free-standing stakes or suspended by carabiners from ropes tensioned across the stream via bankside pegs. Where possible, the ground-rope of the stop-net was arranged to be supported in place by streambed features and rocks from outside the survey area were used as weights to ensure conformity of the ground-rope with the stream-bed, as necessary. Accumulated debris (mostly algae) was removed from the downstream stop-net between fishings.

A range of long-handled net types was available for fish capture, including 600mm D-frame and 200 x 100mm rectangular hand-nets. A small 100 x 50mm aquarium net was used in very shallow water or in closely confined positions. A banner net was used as the principal

[1] http://www.scotland.gov.uk/Resource/Doc/295194/0096725.pdf

means of capture in areas of faster flowing, deeper water and, more generally, as a back-stop for other netting methods.

Electric-fishing was conducted by working systematically across the survey area and progressively upstream. Captured fish were placed in a plastic container containing stream water and periodically transferred to perforated holding boxes outside the fishing section to await processing.

Nets were sterilised before moving between river catchments using SAM-30[2] according to the manufacturer's instructions.

2.4 Fish handling and data acquisition

Fish were lightly sedated before examination using Kusuri Masuizai Koi Sedate[3] according to the manufacturer's instructions. Fish obtained from each of the three electric-fishing passes were examined and documented in their separate groups. Salmon and trout were distinguished by visual examination and fry (hatched in 2013 and therefore less than 1 year of age) were distinguished from parr (hatched prior to 2013 and more than 1 year of age) on the same basis. Fork length (tip of snout to fork in tail) was measured for all parr. Fork length was also measured for approximately 50 salmon fry at each site or for all the fry if fewer were present. The process was replicated for trout fry at the few sites where they were sufficiently numerous to provide meaningful data. The presence of other fish species (eels, lampreys, sticklebacks or flounders) was noted.

Scale samples were obtained from parr for age determination. Scales were also obtained from presumed fry when these were sufficiently large to place visual classification in doubt. Scales were obtained from the standard sampling location on the left dorsal flank behind the caudal insertion of the dorsal fin. Samples from single individuals were stored in paper scale packets marked with site and individual numerical codes corresponding to the designations in the field notes.

After examination, fish were returned to a perforated holding box in the stream before being returned unharmed to the electric-fishing section after a period of recovery.

2.5 Scale reading

The age of individual parr was determined by scale-reading under suitable magnification. Based on observed body length distributions at specific sites, some large putative fry had been included in the group of fish from which scales were sampled but based on scale reading these fish were later assigned to the correct age group.

[2] http://www.evansvanodine.co.uk/assets/eng_fam_30.pdf
[3] http://kusuri.co.uk/kusuri-products/kusuri-masuizai-koi-sedate/

2.6 Assessment of site habitat quality

In the absence of a sufficiently explanatory model for metrics of stream habitat and salmonid density (Godfrey, 2005), habitat evaluation was by expert opinion. The characteristics of each survey site and its vicinity were visually assessed during the survey according to landscape setting, geomorphology, adjacent land-use, vegetation and streambed sediment types. Sites were graded for habitat suitability, separately for fry and parr. Grades were assigned by one of the report's authors (JW) in the absence of an awareness of the matching fish data. Particular emphasis was placed on the distribution and proportional representation of the various substrate size classes, their degree of embeddedness and the determinants of these descriptors - sediment supply, stream gradient and hydraulic response.

2.7 Data analyses

An Excel file of the primary data obtained in the survey is available from the first author of this report. Appendices 1 – 22 to the report contain all the primary data for each electric-fishing site. Numbers of both salmon fry and salmon parr captured at each of the three electric-fishing passes carried out at each survey site have been separately compiled because these data form the basis of a number of potential comparisons with studies conducted elsewhere using different (ie. non-depletion) techniques.

At each site the total number of fish captured was used to calculate a value for <u>Observed Density Per Unit Wetted Area</u> in order to facilitate comparisons within the present survey. Values for observed density were separately calculated for fry and for all the age classes of parr that were present.

Additionally, for each site, Zippin corrections were applied to the three-pass depletion counts to obtain estimates of <u>True Total Number</u> for fry and parr. Zippin estimates are based on statistical analysis and use the observed rate of decline of the catch made in successive electric-fishing passes to predict the total potential catch. Values were computed using the program *Removal Sampling II* obtained from Pisces Conservation[4]. The estimates of true total number facilitate comparisons by compensating for variation in capture efficiency among sites. Estimated numbers were used to calculate values for <u>True Density Per Unit Wetted Area</u> which further facilitate comparison.

Observed density values at each of the sites were evaluated by comparison with the analysis of Scottish electric-fishing data carried out by Godfrey (2005) using SFCC data. In particular, Table 26d of Godfrey's report provides a basis for comparison based on quintile values for observed density as calculated from capture numbers for single-pass electric-fishing (or for the first pass of 3-pass fishing). Table 5 of the current report presents an extract of these data for rivers in the North region greater than 6m in width. Godfrey also proposes a

[4] http://www.pisces-conservation.com/

classification scheme as per Table 22 of his 2005 report and this has been modified, expanded and colour-coded as per Table 5.

3. Results

3.1 Preliminary assessment of sites based on fish density

3.1.1 Densities of trout

Although large trout are known to be present in the rivers that were surveyed they were largely absent from the survey sites. Only two individuals greater than 200mm body length were captured. This was probably, in part, because the survey targeted shallow streams and riffles whereas large trout prefer different habitats and in particular the deeper streams and pools that were outside the scope of the present study.

River	Site name	Observed Density ($n.m^{-2}$)		Observed number (n)			
				Year of hatch			
		2013 0+ fry	All parr	2012 1+ parr	2011 2+ parr	2010 3+ parr	2009 4+ par
Forss	Cnoc-glas	0.51	0.06	11	-	-	-
	Shurrery	0.02	0.01	-	2	-	-
	Lythmore	0.03	-	-	-	-	-
Thurso	Rumsdale	0.24	0.05	3	6	-	-
	Dalganachan	-	0.01	-	2	-	-
	Dalnagleton	0.01	-	-	-	-	-
	Smerrary	-	0.01	1	2	-	-
	Dalemore	-	0.03	1			
	Hoy	0.01	-	-	-	-	-
Wester	Barrock Mill	0.02	0.01	1	-	-	-
Wick	The Clow	-	-	-	-	-	-
	Sheriff's	-	0.02	4	-	-	-
	Bilbster	-	0.03	7	-	-	-
Dunbeath	Achnaclyth	-	0.01	1	-	-	-
	Culvid	-	0.02	-	2	-	-
Berriedale	Gobernuisgach	0.05	0.12	11	6	1	2
	Corrichoich	-	0.02	1	2	-	-
	Braemore	-	0.02	-	1	2	1
	Strathcoull	-	-	-	-	-	-
Langwell	Wag	-	0.04	5	1	-	-
	Aultibea	0.01	0.02	-	3	1	-
	Coille Braigh	-	0.02	-	1	3	-

Table 2. Observed densities of trout for 3-pass fishing.

Table 2 shows observed densities for trout fry and trout parr at all the survey sites based on the 3-pass electric fishing totals. Data for the separate parr classes are also shown but as numbers rather than densities because of the low values observed in most cases.

Trout fry were absent at 13 of the 22 survey sites, infrequent at seven and present at substantial densities only at Rumsdale and Cnoc-glas. Trout parr were generally also infrequent but more widespread than fry, being absent at only five sites. Parr tended to be abundant only where fry were also abundant. The observed pattern of distribution suggests that, with the exception of Cnoc-glas and Rumsdale, and perhaps also Gobernuisgach, spawning by trout at or near the survey sites was at best sporadic but that fish had dispersed more widely by the parr stage.

3.1.2 Densities of salmon

Table 3 shows the observed densities of salmon fry and parr and a breakdown of the parr by age-class.

River	Site name	Observed Density ($n.m^{-2}$) and year of hatch					
		0+ fry (2013)	1+ parr (2012)	2+ parr (2011)	3+ parr (2010)	4+ parr (2009)	All parr
Forss	Cnoc-glas	0.38	0.16	-	-	-	0.16
	Shurrery	1.57	0.36	0.10	-	-	0.46
	Lythmore	1.76	0.41	0.02	-	-	0.44
Thurso	Rumsdale	1.01	0.16	0.03	-	-	0.19
	Dalganachan	1.69	0.24	0.01	-	-	0.25
	Dalnagleton	0.79	0.03	-	-	-	0.03
	Smerrary	1.26	0.28	0.02	-	-	0.30
	Dalemore	3.41	0.40	0.01	-	-	0.42
	Hoy	1.43	0.16	0.01	-	-	0.17
Wester	Barrock Mill	0.03	0.02	-	-	-	0.02
Wick	The Clow	0.18	0.36	0.07	-	-	0.43
	Sheriff’s	1.70	0.27	0.03	-	-	0.30
	Bilbster	0.60	0.26	-	-	-	0.26
Dunbeath	Achnaclyth	0.30	0.27	0.10	0.01	-	0.37
	Culvid	1.34	0.27	0.04	-	-	0.31
Berriedale	Gobernuisgach	0.24	0.06	0.06	0.04	0.01	0.16
	Corrichoich	0.22	0.17	0.03	-	-	0.21
	Braemore	1.14	0.38	0.03	0.02	-	0.42
	Strathcoull	0.17	0.35	0.08	-	-	0.43
Langwell	Wag	0.74	0.14	0.04	-	-	0.18
	Aultibea	0.91	0.43	0.11	-	-	0.28
	Coille Braigh	0.07	0.17	0.06	0.01	-	0.23

Table 3. Observed density of salmon fry and parr from 3-pass fishing.

The values observed for fry at Dalemore (3.41.m^{-2}) exceeded all other values by a substantial margin. By far the lowest values for fry were observed at Barrock Mill the only site on the River Wester. Values were less variable for parr than for fry and, overall, roughly equivalent parr values were observed at sites distributed throughout all the rivers surveyed. The only notable exception was again at Barrock Mill where, as for fry, parr densities were the lowest observed by a substantial margin.

The age structure of parr varied markedly among sites. At Bilbster, for example, only 1+ parr (hatched in 2012) were present but at Gobernuisgach the age structure was much more complex and parr that had hatched in each of the years between 2009 and 2012 were present. All the other sites showed intermediate levels of complexity but, across all sites, parr hatched in 2012 and 2011 were predominant.

River	**Site name**	**Estimated true density (n.m^{-2})**	
		Fry	**Parr**
Forss	Cnoc-glas	0.40	0.16
	Shurrery	1.60	0.46
	Lythmore	1.79	0.45
Thurso	Rumsdale	1.13	0.20
	Dalganachan	2.45	0.26
	Dalnagleton	0.94	0.03
	Smerrary	1.45	0.31
	Dalemore	4.01	0.44
	Hoy	1.72	0.18
Wester	Barrock Mill	+	+
Wick	The Clow	0.18	0.43
	Sheriff's	1.87	0.31
	Bilbster	0.67	0.26
Dunbeath	Achnaclyth	0.33	0.38
	Culvid	1.39	0.31
Berriedale	Gobernuisgach	0.25	0.16
	Corrichoich	0.24	0.21
	Braemore	1.22	0.43
	Strathcoull	0.20	0.45
Langwell	Wag	0.74	0.18
	Aultibea	0.96	0.28
	Coille Braigh	0.08	0.24

+ numbers insufficient for analysis.

Table 4. Estimated true density of salmon fry and parr.

Estimated true densities of salmon fry and salmon parr are presented in Table 4. The values given for parr are for all year-classes combined because the numbers of parr in the individual year-classes were not sufficient to support Zippin correction. The Barrock Mill site yielded too few fry or parr for Zippin correction and is therefore excluded from consideration.

In general, the values for estimated true density are not substantially greater than those for observed density given in Table 3 and the relative rankings of the sites are substantially the same. This indicates that levels of electric-fishing efficiency were similar between passes and between sites.

3.1.3 Comparison with Godfrey (2005)

Godfrey (2005) provides a basis for a comparison of fish densities with data previously obtained for northern Scottish rivers and held in the SFCC database. Godfrey's analysis considers only single-pass fishing and, in order to match this structure, comparisons were of densities observed on the first electric-fishing pass of the 3-pass fishing used in the present survey.

Six categories for density were defined using the critical quintile values identified by Godfrey for salmon and trout, and for fry and parr (Table 5). Sites were graded and colour-coded as excellent (dark blue), very good (light blue), good (green), average (yellow), low (orange) or poor (red).

		Critical percentile values for density (n.m^{-2}) and colour codings					
		< 20th	20th- 40th	40th - 60th	60th - 80th	80th -100th	> 100th
Salmon	**Fry**	0.05	0.13	0.28	0.33	0.67	
	Parr	0.04	0.07	0.13	0.19	0.28	
Trout	**Fry**	0.01	0.02	0.03	0.04	0.06	
	Parr	0.01	0.01	0.01	0.02	0.04	

Table 5. Critical percentile values for classification of observed density (n.m^{-2}) of fry or parr based on single-pass fishing (Godfrey, 2005).

Table 6 provides an evaluation of salmon fry and parr densities at all the survey sites using the colour codings given in Table 5. Trout fry and parr were evaluated at sites where numbers were sufficient to permit valid comparisons.

At most sites, observed densities of trout were low, as anticipated from Godfrey's data for previous surveys (as per Table 5). Given the very low numbers of trout often observed in the present study, it was possible to carry out formal evaluations only at Cnoc-glass, Rumsdale and Gobernuisgach. In all these cases, trout fry and parr densities were classed as "good" or "excellent".

Salmon fry and parr densities were classified at all sites. Of the 22 comparisons of fry densities, 14 were classed as "excellent/ very good", four as "good/ average" and four as "low/ poor". Parr densities were classed as "exceptional/ very good" for 12 sites, "good/ average" at seven and "low/ poor" at three. Six of the seven "low/ poor" classifications for either fry or parr were associated with an "excellent/ very good" classification for the other group. This may reflect differences in the strength of spawning year classes near the sites or the extreme characteristics of some sites and their tendency to provide suitable habitat for fish only at the smaller fry stage or as larger parr. Only at one site (Barrock Mill) were observed densities classed as "poor" for both fry and parr.

River	Site name	Salmon		Trout	
		fry	parr	fry	parr
Forss	Cnoc-glas				
	Shurrery				
	Lythmore				
Thurso	Rumsdale				
	Dalganachan				
	Dalnagleton				
	Smerrary				
	Dalemore				
	Hoy				
Wester	Barrock Mill				
Wick	The Clow				
	Sheriff's				
	Bilbster				
Dunbeath	Achnaclyth				
	Culvid				
Berriedale	Gobernuisgach				
	Corrichoich				
	Braemore				
	Strathcoull				
Langwell	Wag				
	Aultibea				
	Coille Braigh				

Table 6. Semi-quantitative evaluation of survey sites based on comparison with data presented by Godfrey (2005).

Fifteen of the 44 possible comparisons were classed as "excellent" because the values exceeded the greatest comparable values reported to the SFCC when Godfrey's report was compiled. A further 11 comparisons placed sites in the 80 -100th percentile range generated by Godfrey's analysis and these sites were therefore classed as "very good". This preponderance of high values may reflect real increases in density since Godfrey's report, as year effects or trends. However, it may also reflect methodological differences or the particular choice of sites.

Seven of the 44 comparisons were rated "low" or "poor". Whilst some sites must, by definition, be below average it is also possible that some of the low values reflect issues that require further investigation and these are addressed later in the report.

3.2. Salmon fry

So far, this report has dealt only with observed densities from single-pass fishing and all the comparisons have been with data acquired some time ago as a result of work carried out on different sites by others using slightly different procedures. For all these reasons, the comparisons in Table 6 should be regarded as preliminary evaluations that need checking using data of other kinds.

For the present survey, additional data is available for the various age classes represented among the parr at each site, the body lengths of all the age groups and the physical habitant characteristics of the sites. All the data compiled below are potentially informative for future comparisons - in line with the main objective of this study. In addition, if an appropriate approach can be developed, the preliminary assessments carried out above can be extended using more precise comparisons. Only salmon are considered in what follows due to the low numbers of trout present at most of the survey sites.

3.2.1 Distribution

Figure 2 shows fry density (estimated true density) plotted against site altitude. The site at Barrock Mill on the River Wester has been temporarily excluded from consideration due to the near-absence of both fry and parr. Among the other sites, fry densities varied substantially but there is no clear, overall relationship with altitude. The site at Dalemore on the Thurso (marked in red) was a notable anomaly, however, in showing a value for fry density that greatly exceeded all the others.

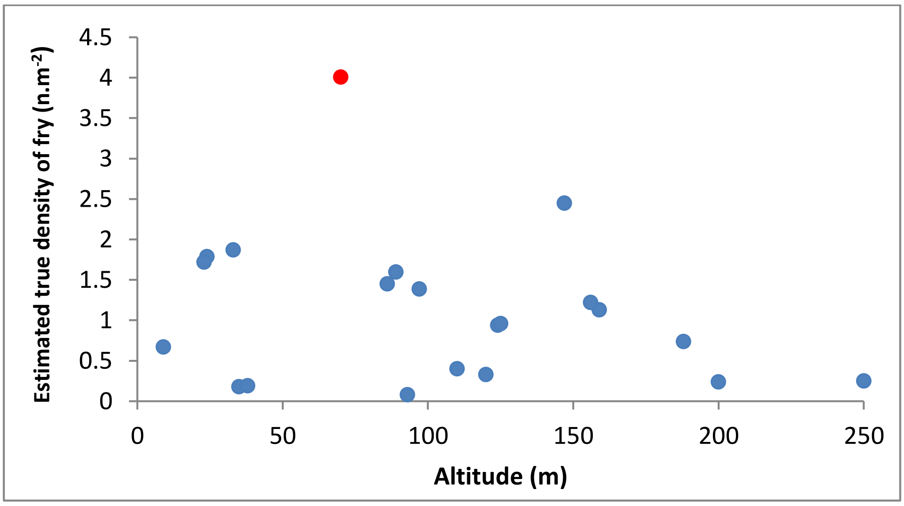

Figure 2: The relationship between estimated true density of salmon fry and site altitude.

3.2.2 Body length

Table 7 shows that the average size of salmon fry varied substantially from around 46mm at the anomalous Dalemore site to 64mm at Cnoc-glas, Barrock Mill and Wag. Otherwise, much of the variation in average length was encompassed by Dalemore and the adjacent site at Hoy where the average length of fry was around 62mm. Dalemore and Hoy are both on the mainstem of the River Thurso and only 11 km apart. The density of fry at the

Dalemore site, where the fry were very small, was the greatest value recorded in the survey ($4.01.m^{-2}$). Fry at Hoy were very large but their density ($1.72.m^{-2}$) was nearer the average for all sites.

Fry (age 0+)	
Site name	**Mean body length (mm). Standard deviation in parentheses**
Cnoc-glas	64.2 (5.15)
Shurrery	60.8 (5.41)
Lythmore	61.4 (8.08)
Rumsdale	57.6 (5.98)
Dalganachan	50.6 (4.70)
Dalnagleton	51.7 (4.45)
Smerrary	56.4 (4.82)
Dalemore	46.2 (4.46)
Hoy	61.9 (4.65)
Barrock Mill	64.4 (+)
The Clow	60.3 (3.47)
Sheriff's	55.4 (5.94)
Bilbster	59.9 (6.79)
Achnaclyth	60.4 (4.67)
Culvid	52.2 (4.51)
Gobernuisgach	51.3 (4.90)
Corrichoich	51.6 (6.48)
Braemore	47.4 (4.23)
Strathcoull	53.8 (2.80)
Wag	64.5 (3.97)
Aultibea	58.9 (5.04)
Coille Braigh	59.5 (5.07)

Table 7. Fork length of salmon fry.

The differences in size and density at the Dalemore and Hoy sites are particularly striking because their environments are likely to be rather similar. Dalemore is about 50m greater in altitude than Hoy and, since temperature tends to decrease with higher altitude, it is possible that the smaller size fry at Dalemore reflects this. The effect of temperature could be on stream productivity, or directly on fish growth. It could also reflect differences in the date at which fry emerge from the streambed to begin feeding because emergence occurs later in cooler locations and the growing period is correspondingly shorter. In addition, growth tends to be density-dependent, reflecting competition among individuals in conditions where the available food or space resource limits the performance of the group. The very high density of fry at Dalemore may therefore have restricted their growth.

Considering all the survey sites, however, it can be seen from Figure 3 that – contrary to expectation - there is no obvious relationship between altitude and the body length of fry and, from Figure 4, no obvious relationship between length and density.

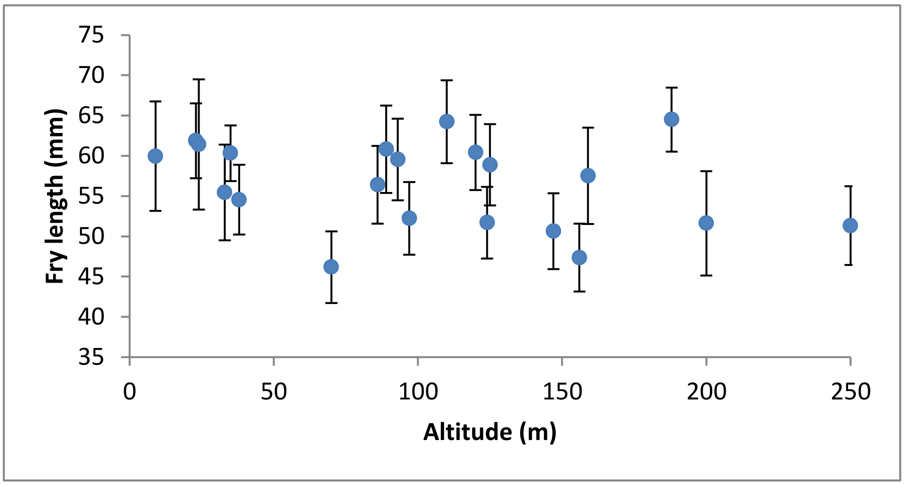

Figure 3. The relationship between altitude and body length of fry (mean +/- SD).

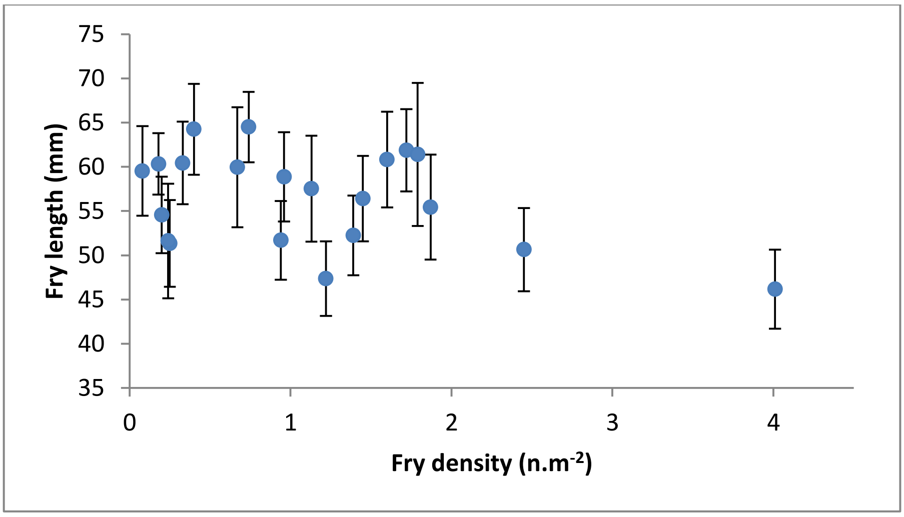

Figure 4. The relationship between fry density and body length (mean +/- SD).

The possible combined effect of altitude and density on the average size of fry was explored using multiple regression. The results of the analysis[5] indicate that the separate effects of both density and altitude are statistically significant and, taken together, they explain around 30% of the variation in length observed over the range of sites surveyed. The

[5] One-tailed Tests; P values for altitude and density are 0.011 and 0.009, respectively. Adjusted $R^2 = 0.30$.

remaining variation is likely to be attributable to a range of other factors such as differences in the chemical and physical qualities of the stream environment, size-biased mortality, rates of movement to or from sites and, perhaps, variable competition with parr or trout.

3.2.3 Biomass

In order to further examine the relationship between site altitude and fish production, biomass was considered as a single measure that combines fish size and fish number.

Body length values for individual fry were converted to estimated body mass by using the relationship derived by Shackley and cited by Godfrey -

$$\text{Body mass} = 2.8087 \times 10^{-6} \times \text{body length}^{3.3016}$$

Individual values for fry body mass were used to derive an average value for each site. Values for average body mass, estimated true number of fry and wetted site area were used to calculate the biomass density of fry at each site -

$$\text{Biomass density} = \text{estimated true fry number} \times \text{average body mass} / \text{site area}$$

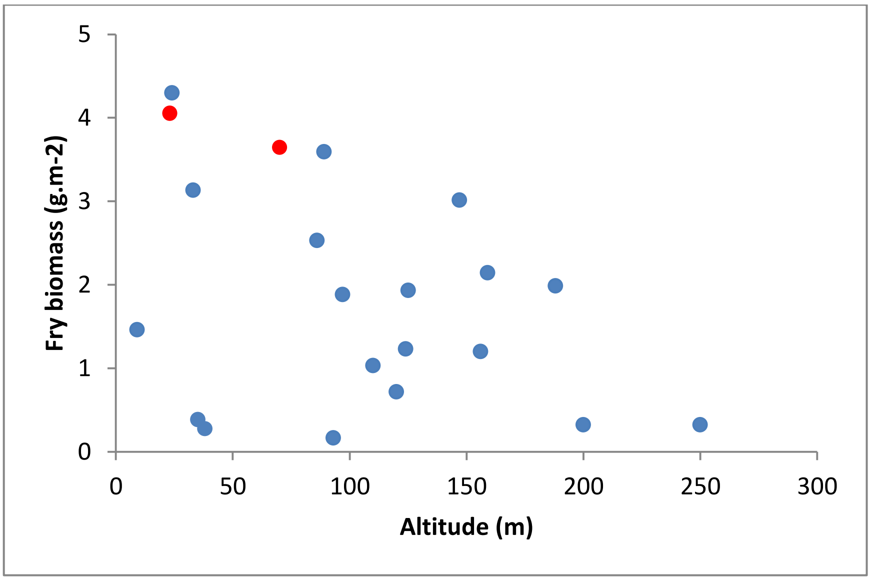

Figure 5. The relationship between site altitude and biomass of salmon fry.

Figure 5 shows the relationship between fry biomass density and site altitude. The first point to note is that the extreme differences in both length and density at the adjacent sites at Dalemore and Hoy (both marked in red) are not evident when biomass is used as a single measure of productivity. Additionally, the expected inverse relationship between biomass density and altitude (ie. lower biomass at higher altitudes) may perhaps be discerned but, if so, there are several outlying sites at lower altitudes that show biomasses of fry that are anomalously low.

However, fry biomass is not likely to be determined by altitude alone. Fry densities and individual size are both also likely to be affected by differences in the physical characteristics of sites and the quality of the habitat they provide. In order to examine such effects, sites were assigned to one of five categories (1 = poor, 5 = good) for their suitability for fry (Table 8).

The possibility of relationships between site quality and altitude was tested but no relationship could be discerned. The parr habitat gradings show less variation than those for the fry but this not surprising, given that the original choice of many of the survey sites was probably biased towards locations that were considered favourable for parr.

Site	Fry habitat quality 1-5	Parr Habitat quality 1-5
Cnoc-glas	2	1
Shurrery	3	4
Lythmore	4	4
Rumsdale	4	3
Dalganachan	4	4
Dalnagleton	3	1
Smerrary	3	3
Dalemore	5	3
Hoy	4	4
Barrock Mill	3	3
The Clow	3	3
Sheriff's	3	4
Bilbster	3	3
Achnaclyth	2	3
Culvid	3	3
Gobernuisgach	3	3
Corrichoich	1	2
Braemore	4	4
Strathcoull	1	3
Wag	4	3
Aultibea	3	3
Coille Braigh	2	2

Table 8. Assessment of site quality for fry and parr.

The possible dual effects of altitude and site quality on fry biomass were examined, again using multiple regression. In order to do this in Microsoft Excel, it was necessary to construct a "dummy" categorical variable for site quality by re-classifying the site quality values given in Table 8 in only two classes rather than five. Therefore, site quality categories 1 or 2 were re-classified as "unfavourable" and categories 3, 4 and 5 as "favourable" and re-coded 0 or 1, respectively.

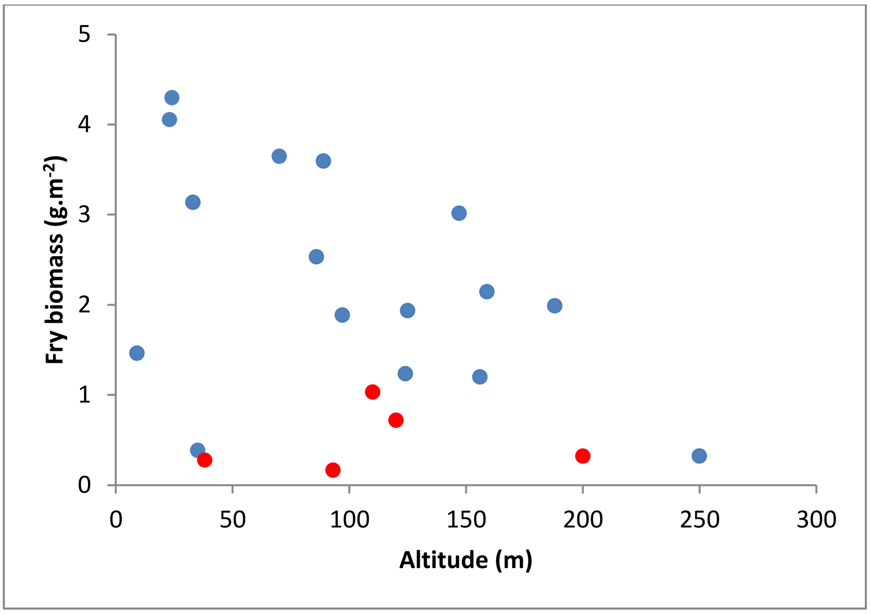

Figure 6. The distributions of "favourable" and "unfavourable" sites for fry marked in blue or red, respectively.

Figure 6 shows the distributions of "favourable" (marked in blue) and "unfavourable" sites (marked in red). As anticipated, the five "unfavourable" sites tend to be scattered in the lower part of the distribution, showing relatively lower values for biomass than other sites at around the same altitude. Multiple regression[6] then showed that the effect of altitude on fry biomass is significant, the variable for site quality is also a significant effect and, taken together, site quality and altitude explain about 40% of the variation in fry biomass observed among all the survey sites.

Fry biomass density was also tested against parr biomass density in order to check for a possible effect of the presence of parr on the growth of fry but no effect was evident.

[6] One-tailed Tests; P values for altitude and site quality are 0.011 and 0.033, respectively. Adjusted $R^2 = 0.40$.

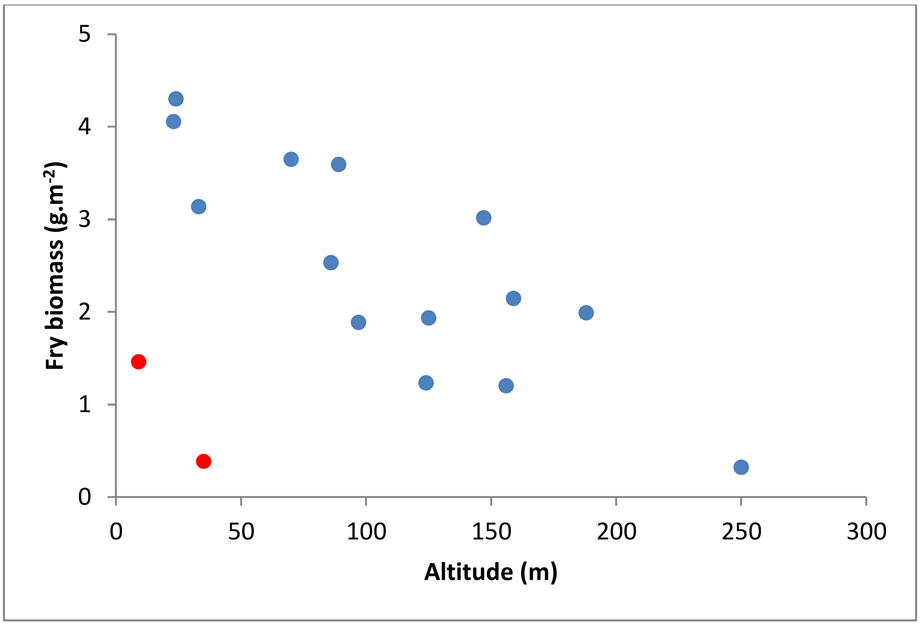

Figure 7. The relationship between observed biomass density of salmon fry and altitude, for sites classed as "favourable" habitat for fry.

Figure 7 shows the relationship between altitude and fry biomass for all the sites classed as favourable for fry. Again, the expected relationship can be discerned but it is still distorted by the presence of The Clow and Bilbster sites (both marked in red). These sites are further considered later in the report.

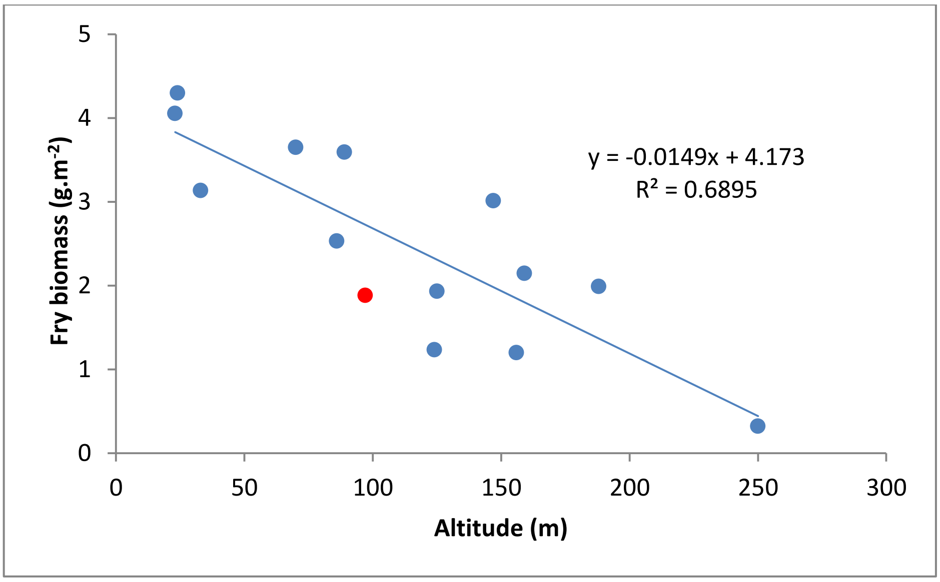

Figure 8. The relationship between observed biomass density of salmon fry and altitude, for sites classed as "favourable" for fry and excluding the anomalous sites at Bilbster and The Clow. The Culvid site is marked in red.

In Figure 8, the relationship between altitude and fry biomass is shown again but the anomalous sites at Bilbster and The Clow have been excluded. The line now shows what probably approximates the under-lying relationship between altitude and fry biomass density for favourable sites that were readily accessible for fry. One of the two sites on the Dunbeath river that had been trickle stocked with fry in 2013 (Culvid, marked in red) remains in the edited set of "favourable" sites but fry biomass there was not notably different from the distribution of values for the other sites. The relationship depicted by the line explains about 70% of all the variation observed in the edited set of sites. However, the distribution of points around the relationship is probably still affected by variation in site quality since the group of sites classed as "favourable" contains individual sites that were graded as 3, 4 or 5 for habitat quality.

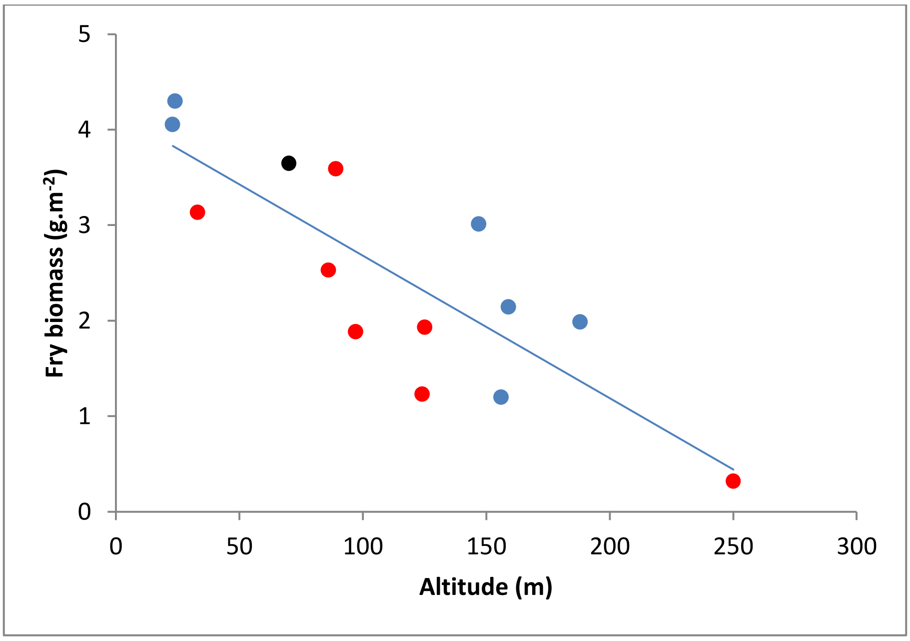

Figure 9. Distribution fry biomass against altitude for sites with fry habitat quality gradings of 3 (red), 4 (blue) or 5 (black).

Indeed, Figure 9 shows that sites graded as 3 tend to show relatively lower biomass at any given altitude than sites graded as 4 or 5. Although the number of sites is too small to explicitly test for an effect, the differences in distribution indicate that the potential explanatory power of the relationship between altitude and fry biomass for the edited set of sites may exceed the 70% value cited above.

In order to round off this section of the report, it is necessary to re-consider the relationship between altitude and fry density (previously addressed in Figure 2) having now established a reasonable basis for editing the set of survey sites.

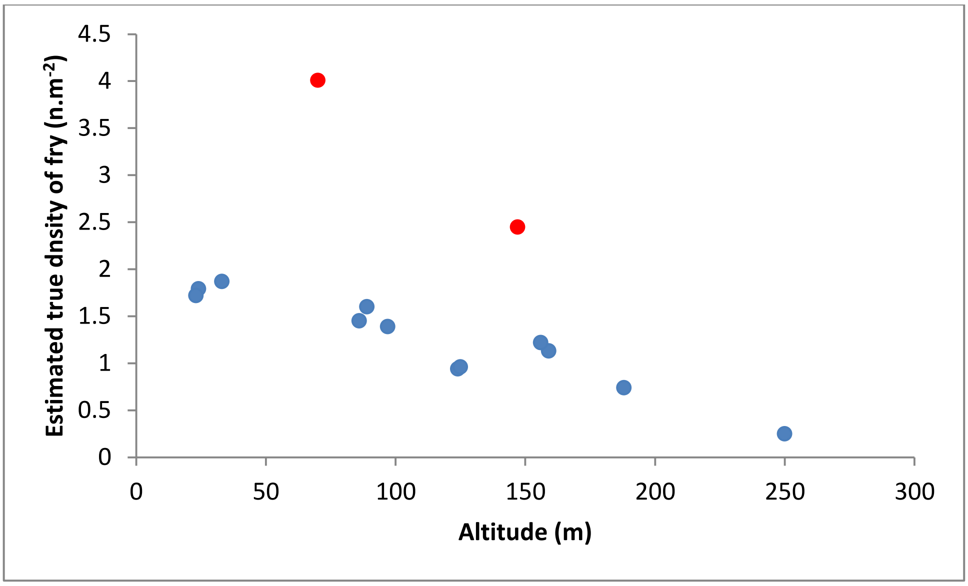

Figure 10: Re-presentation of Figure 2 for sites classed as "favourable" for fry and excluding the anomalous sites at Bilbster and The Clow. The sites at Dalemore and Dalganachan are marked in red.

Figure 10 re-presents the data shown in Figure 2 but only for the edited subset of sites that excludes those sites that do not offer "favourable" habitat for fry, and also the anomalous sites identified at Bilbster and The Clow.

An underlying inverse relationship can probably now be seen, with densities of fry at higher altitude sites tending to be lower. If this is the case, the sites at Dalemore and Dalganachan (marked in red) can be identified as outliers where fry density was anomalously high. The small size of fry at Dalemore has already been highlighted. The fry at Dalganachan were also small, as can be judged from Table 7, adding further weight to the conclusion that fry growth was depressed where their density was very high.

The relationship with biomass density depicted in Figure 9 accommodates this density-dependent growth and is therefore less variable than the relationship with numerical density shown in Figure 10. Because it is less variable, the relationship for altitude and fry biomass density shown in Figure 9 is the more useful basis for the comparisons that follow.

3.3 Assessment based on salmon fry biomass

3.3.1 Comparison with Godfrey (2005)

The central right column of Table 9 (in bold) shows all 22 survey sites ranked according to the extent by which fry biomass density differed from the value predicted by the overall relationship with altitude (ie. the value of the anomaly) as shown in Figure 9. Positive values indicate that fry biomass production was greater than predicted and negative values that production was less. The right-hand column shows the original colour-codings assigned by comparison with the data of Godfrey, as per Table 6, and the left central column repeats the habitat ratings shown in Table 8.

Site	Habitat rating	**Obs – pred biomass ($g.m^{-2}$)**	Rating cf. Godfrey (2005)
Dalganachan	4	**1.03**	
Shurrery	3	**0.75**	
Wag	4	**0.62**	
Dalemore	5	**0.52**	
Lythmore	4	**0.48**	
Rumsdale	4	**0.34**	
Hoy	4	**0.22**	
Gobernuisgach	3	**-0.13**	
Smerrary	3	**-0.36**	
Aultibea	3	**-0.38**	
Sheriff's	3	**-0.55**	
Braemore	4	**-0.65**	
Culvid	3	**-0.84**	
Corrichoich	1	**-0.87**	
Dalnagleton	3	**-1.09**	
Cnoc-glas	2	**-1.50**	
Achnaclyth	2	**-1.67**	
Bilbster	3	**-2.58**	
Coille Braigh	2	**-2.62**	
The Clow	3	**-3.26**	
Strathcoull	1	**-3.33**	
Barrock Mill	3	**-3.93**	

Table 9. Difference between observed and predicted fry biomass.

The two classification systems are somewhat independent but comparison shows that they generate site assessments that are similar in many respects. Thus, high values for biomass anomaly paired with "excellent" numerical gradings (dark blue) dominate the upper part of the table while negative biomass anomalies and "average" (yellow), "low" (orange) and "poor" (red) numerical gradings dominate the lower part.

Godfrey's classification system has the merit of requiring less field work. The particular merits of the approach based on biomass are that it (1) factors out the effect of altitude, (2) factors in density-dependent growth (3) uses more of the data that can be obtained to provide a more precise, continuously graded classification of sites, and (4) reduces reliance on comparisons with data acquired in previous years for different sites by different operators.

Accordingly, the values listed in the right central column of Table 9 are probably the more accurate basis for rating sites. If so, they identify limitations in Godfrey's approach that result in under-rating of the Wag and Gobernuisgach sites and over-rating of Dalnagleton and Bilbster.

Considering the distribution of the biomass anomalies shown in Table 9, all the sites rated as unsuitable habitat for fry are represented in the lower part of the range - as expected. However, Dalnagleton, Bilbster, The Clow and Barrock Mill are also present in this part of the range despite being rated as “favourable” habitat for fry. Assuming habitat at these sites has not been rated too highly, this suggests that the four sites in question might have been remote or partially disconnected from an adequate source of recruiting fry.

This can be checked by turning to Figure 11 which shows that the values for the numerical density of fry at Bilbster, The Clow and Barrock Mill (all marked in orange) were low outliers when compared with other “favourable” sites. This confirms that low biomass values were attributable to poor fry recruitment in these cases. However, in the case of Dalnagleton (marked in red) fry density was low relative to altitude, but not atypically so. This indicates that the low biomass density observed at the site was due to inferior growth, rather than low recruitment, although a possible cause is not apparent.

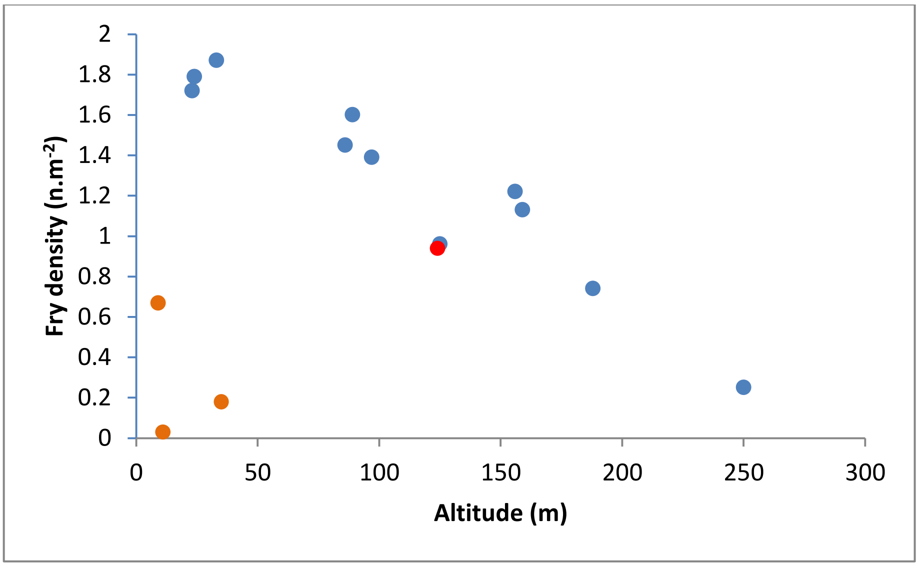

Figure 11: Re-presentation of Figure 10 for sites classed as “favourable” for fry and excluding the anomalous high-value sites at Dalemore and Dalganachan. Dalnagleton is marked in red and Bilbster, The Clow and Barrock Mill are marked in orange.

An absolute value for site status cannot be derived since both possible classification systems are comparative. However, consideration of the Dalemore site, in particular, where very high densities but only very small fry were present suggests that it was at or near saturation. Dalemore was anomalous with regard to fry numbers and fry size but not in terms of fry biomass suggesting that, with the possible exception of some of the low outliers identified above, the capacity of most sites to produce fry biomass was also somewhere near saturation.

3.3.2 Comparison with 2004 survey data

Godfrey's (2005) report contains data summaries for an electric fishing survey carried out in 2004 in relation to site condition monitoring in the Thurso and Berriedale/ Langwell SACs. Fry density values derived from 3-pass fishing with Zippin correction are available for seven sites in the Thurso catchment and six in the Berriedale/ Langwell system. The original data were accessed from the SFCC database and used to calculate biomass density. Biomass values for 2004 are presented against altitude in Figure 10 and marked in red or orange. Biomass data for the edited set of 2013 survey sites are shown in blue for comparison.

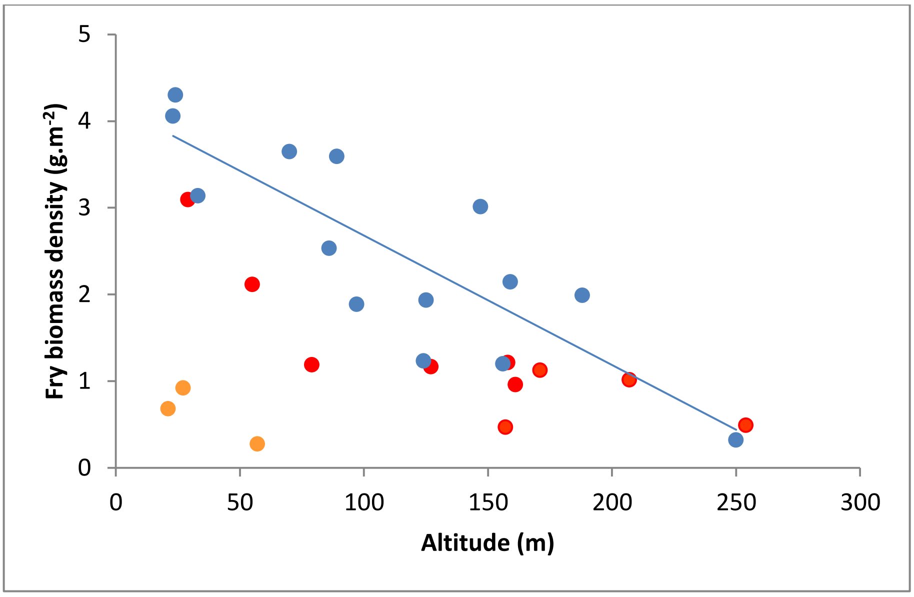

Figure 10. Relationships between altitude and biomass for the edited set of sites examined in 2013 (blue) and the set of sites for the Thurso and Berriedale/ Langwell SACs surveyed in 2004 (marked in red or orange).

The overall shape of the distributions of the 2004 and 2013 data points appear somewhat similar although, for any given altitude, the 2004 values tend to be lower than those for 2013. As for the unedited 2013 survey set, the data for 2004 show a small number of low biomass outliers. These are marked in orange. One of the outliers is the Geise Burn a small tributary stream in an agricultural setting in the lower Thurso catchment that may well be atypical of the river as a whole. The other two outliers are broadly analogous to the Coille Braigh and Strathcoull sites of 2013, both of which were removed from the edited data set for 2013 as being high-energy sites providing unfavourable habitat for fry. Indeed, it can be seen from Table 9 that the sites at Coille Braigh and Strathcoull were rated among the lowest for fry biomass in 2013.

Figure 10 raises a number of points. On its own, the 2004 data set would probably not be sufficient to identify the proposed relationship between altitude and biomass. However, the general pattern of distribution of the data points for 2004 is, at least, consistent with the

2013 pattern. Direct comparisons of 2004 and 2013 values are not appropriate because few sites were sampled in both years and, overall, the sets of sites differ qualitatively (eg. some tributary sites were sampled in 2004 while main river sites were targeted in 2013).

However, if the proposed relationship between altitude and biomass exists, and if it extends among years, it will allow valid comparison. On this basis, even when the three low altitude, low biomass outliers of 2004 are excluded from consideration, Figure 10 suggests that, biomass production of fry in 2004 was generally lower than in 2013.

For 2013, the relationship between altitude and biomass density appears to be linear (ie. a straight line) but in other years some of the factors likely to affect biomass might well result in non-linear relationships. Indeed, for 2004, the relationship for the edited set of survey sites (ie. excluding the three prominent outliers) is best represented by a curve, as shown in Figure 11.

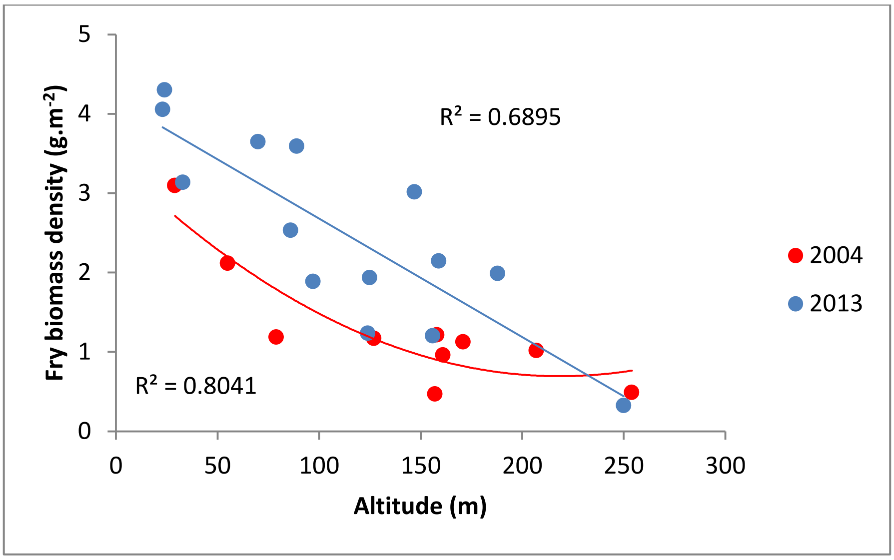

Figure 11. Relationships between altitude and fry biomass density for edited sets of survey sites in 2004 (in red) and 2013 (in blue).

Based on the relationships depicted in Figure 11, fry biomass production in 2004, averaged over the range of altitudes surveyed, was only about 60% of the 2013 value.

Again, there is a range of potential explanations for differences like these that includes year-to-year variations in spawner number, egg deposition and fry recruitment. Additionally, temperature-dependent variation in hatch date and, therefore, the length of the growing season might also affect fry biomass, as would weather-dependent variation in stream productivity during the summer.

3.4 Salmon parr

The age of salmon parr was determined by scale-reading. This procedure makes use of the compressed growth zone (or check) that scales show as a result of low growth during the winter months. Scales taken from parr in summer show a phase of renewed growth after the preceding winter check that is characterised by widely spaced growth rings (circuli) on the scale periphery. This is termed “plus growth” and supports the convention by which parr are categorised. Thus, for example, a 1+ fish captured in summer shows a single winter band on its scales followed by a period of plus growth laid down in the summer of the current year. A 2+ parr shows two winter bands. Any 1+ parr captured in 2013 hatched in 2012 and any 2+ parr hatched in 2011 – and so on.

During scale reading it was noted that the scales of some of the fish showed additional, severe summer checks in 2013. These checks may have resulted from exposure to a period of adverse, high water temperatures. It can be seen from Table 1 that water temperatures were relatively high even in September when the survey was carried out. Given the prevailing weather during the summer of 2013, temperatures had probably been much higher in June and July when the sun was near its maximum elevation although no formal records are available.

Table 10 shows that the frequency of summer checks was not uniform among survey sites. Site-to-site variation in temperature may have arisen from differences in the streams’ aspect, or to variation in their surface area to depth ratio. In addition, local variations may be due to differences in bank-side cover and shading, buffering by lochs or deep meanders, or to spatial variation in the entry of cooler side-streams or groundwater. Overall, the River Thurso sites (Rumsdale to Hoy) were most affected although Dalemore, where no scale checks were present, was a surprising discontinuity.

The data presented in Table 10 may prove to be of interest for fisheries management, particularly if the occurrence of extreme high temperatures in summer is to become more frequent.

In relation to the data analyses that follow there was no obvious indication that scale checks were associated with reduced body growth since average body size at any site was not demonstrably related to the incidence of scale checks.

Site	Frequency of 2013 checks in parr (%)
Cnoc-glas	48
Shurrery	5
Lythmore	1
Rumsdale	52
Dalganachan	97
Dalnagleton	100
Smerrary	26
Dalemore	0
Hoy	39
Barrock Mill	+
The Clow	22
Sheriff's	0
Bilbster	4
Achnaclyth	20
Culvid	13
Gobernuisgach	0
Corrichoich	42
Braemore	10
Strathcoull	4
Wag	0
Aultibea	7
Coille Braigh	0

Table 10. Frequency of 2013 summer checks on the scales of parr.

3.4.1 Distribution

Figure 12 shows the distribution of values for the density of parr of all age-classes against site altitude. The site at Barrock Mill is again excluded because it supported so few salmon of any age-class.

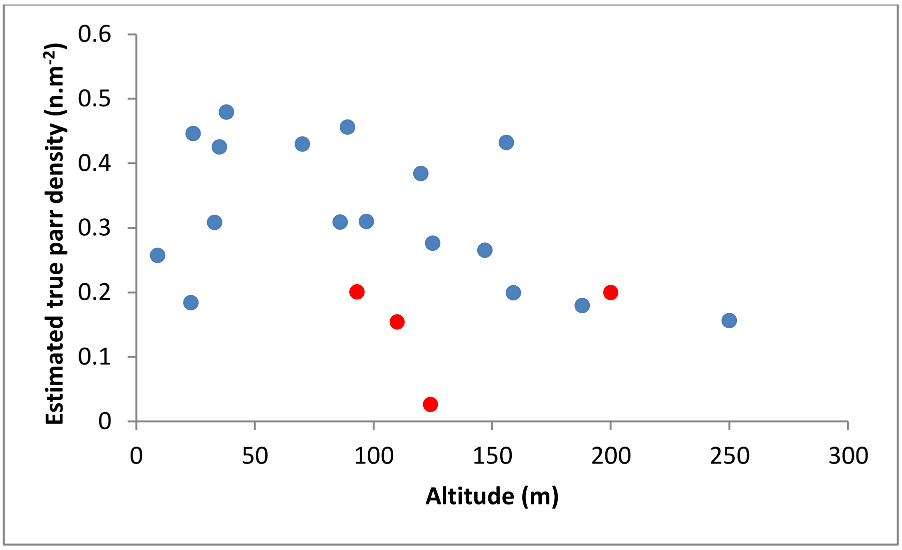

Figure 12. The relationship between parr density and altitude. Sites graded as "unfavourable" for parr are marked in red.

No particular pattern can be discerned. However, the parr group as a whole contains contributions from each of a number of separate age-classes. Because these contributions hatched in different years they are at least partially independent and a rigorous examination of the data requires that each year-class should be considered separately.

Table 11 repeats some of the data presented in Table 3. It shows the proportion of salmon parr at each site that was attributable to each of the various year-classes that were present.

		Frequency (%)			
		Parr age class (year of hatch)			
Site name	Total number	1+ (2012)	2+ (2011)	3+ (2010)	4+ (2009)
Cnoc-glas	28	100	-	-	-
Shurrery	41	78	23	-	-
Lythmore	78	95	5	-	-
Rumsdale	32	84	16	-	-
Dalganachan	36	97	3	-	-
Dalnagleton	5	100	-	-	-
Smerrary	43	93	7	-	-
Dalemore	91	97	3	-	-
Hoy	28	93	7	-	-
Barrock Mill	3	100	-	-	-
The Clow	51	84	16		
Sheriff's	48	90	10	-	-
Bilbster	54	100	-	-	-
Achnaclyth	46	72	26	2	-
Culvid	69	88	12	-	-
Gobernuisgach	27	33	37	26	4
Corrichoich	26	85	15	-	-
Braemore	73	89	7	4	-
Strathcoull	45	82	18	-	-
Wag	35	77	23	-	-
Aultibea	45	60	40	-	-
Coille Braigh	37	73	24	4	-

Table 11. Total number of parr and frequency of year-classes at each site.

The proportional representation of parr at individual sites decreased with age. This is as expected, due partly the effect of ongoing mortality and also because all surviving parr ultimately leave fresh water as smolts. However, there was substantial variation in the representation of year-classes at particular sites.

Thus, for example, all the parr at Cnoc-glas were aged 1+ (ie. hatched in 2012) indicating that previous occupants of the survey site had become smolts at two years of age. At Gobernuisgach approximately equal proportions of 1+, 2+ and 3+ parr (hatched in 2012, 2011 and 2010, respectively) were present, suggesting that many fish defer smolting until they are four years old. Indeed, a small proportion of the parr at Gobernuisgach had hatched in 2009 and these fish were therefore potential 5-year-old smolts.

3.4.2 Age and size

Table 12 shows the average body lengths of parr at each site broken down by age class.

	Mean body length (mm). Standard deviation in parentheses			
	Age class (year of hatch)			
Site name	1+ (2012)	2+ (2011)	3+ (2010)	4+ (2009)
Cnoc-glas	110.5 (5.95)	-	-	-
Shurrery	104.7 (7.36)	129.7 (9.42)	-	-
Lythmore	109.7(10.97)	142.8 (5.85)	-	-
Rumsdale	99.5 (7.37)	123.0 (7.31)	-	-
Dalganachan	95.0 (8.65)	124.0 (+)		
Dalnagleton	98.0 (+)	-	-	-
Smerrary	105.5 (9.31)	139.0 (+)	-	-
Dalemore	92.4 (8.81)	119.7 (+)		
Hoy	101.6 (9.12)	137.0 (+)	-	-
Barrock Mill	131.7 (+)	-	-	-
The Clow	95.2 (7.27)	111.9 (5.03)	-	-
Sheriff's	93.0 (8.06)	114.0 (0.71)	-	-
Bilbster	101.7(10.50)	-	-	-
Achnaclyth	102.4 (8.39)	118.0 (4.84)	124.0 (+)	
Culvid	89.1 (9.99)	105.3 (4.03)	-	-
Gobernuisgach	88.3 (5.34)	105.2 (9.17)	109.1 (7.43)	124.0 (+)
Corrichoich	94.7 (12.53)	124.5 (+)	-	-
Braemore	83.5 (8.22)	105.4 (+)	113.0 (+)	-
Strathcoull	85.6 (6.61)	113.8 (9.48)	-	-
Wag	99.1 (6.40)	121.5 (7.50)	-	-
Aultibea	91.8 (5.51)	110.7(7.11)	-	-
Coille Braigh	90.5 (8.87)	114.0 (4.39)	135.0 (+)	-

+ number insufficient to derive value.

Table 12. Length of salmon parr by age class.

Again, the average length of the older age classes is probably affected by the prior emigration of smolts. Parr that became smolts are likely to have been among the larger individuals in their age-group and the average length of the remaining fish is probably, therefore, less than it would otherwise have been. However, the values for 1+ parr are less likely to be affected by emigration since, in Caithness conditions, few fish are likely to grow fast enough to be smolts at one year of age. The average length of the 1+ group is probably, therefore, a relatively accurate reflection of their overall performance. Average values varied substantially, from 83mm at the Braemore site to 110 at Cnoc-glas. The very few 1+ parr at Barrock Mill showed by far the largest average size (132mm).

Variation in the size of parr belonging to any particular age group would be expected to depend partly on the environmental scope that sites of different altitude afford for growth.

Growth rate and body size would be expected to be lower at higher altitude. However, it can be seen from Figure 14 that no such relationship is evident for 1+ parr.

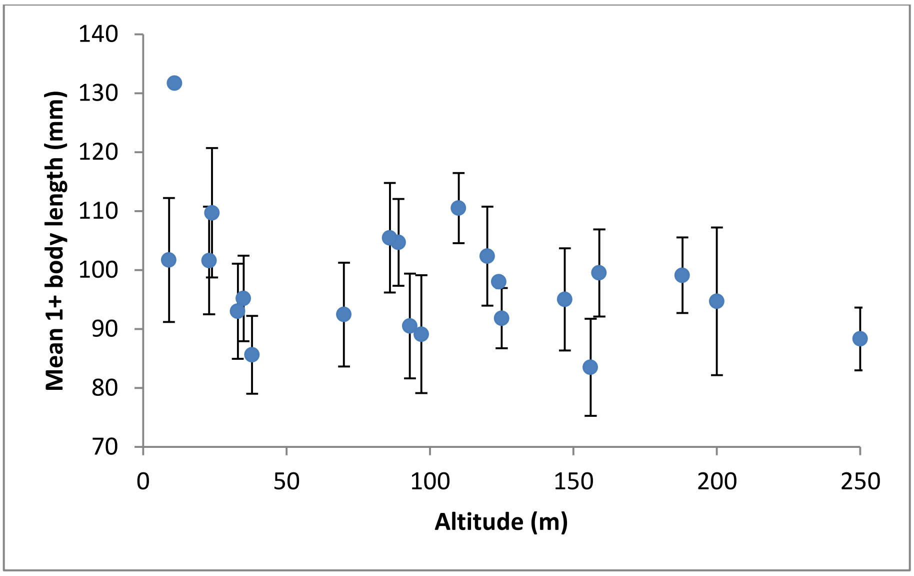

Figure 14. The relationship between site altitude and the average body length of 1+ parr. Standard deviation is indicated in appropriate cases.

Variation in the size of parr might also reflect density but Figure 15 shows that the expected inverse relationship between the body length and the density of 1+ parr is not evident.

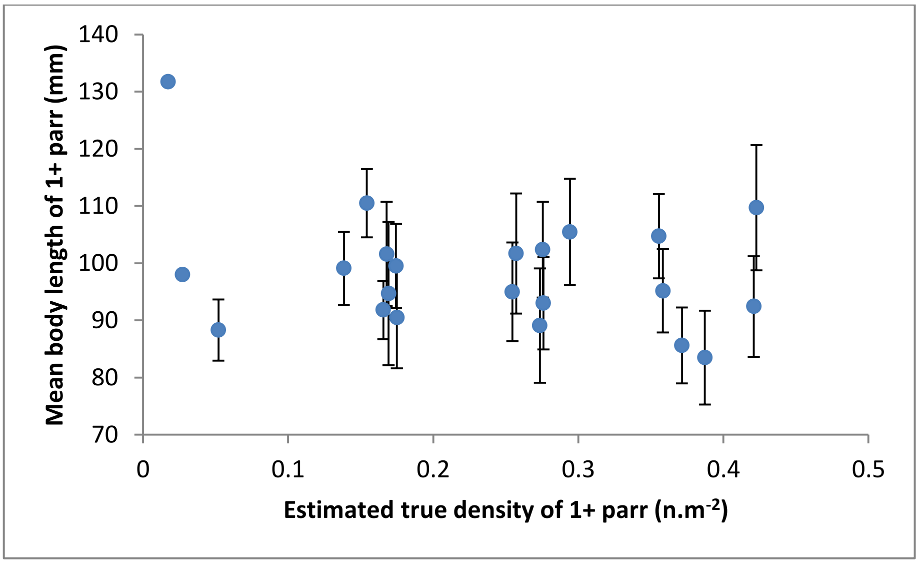

Figure 15. The relationship between the density of 1+ parr and their average body length. Standard deviation is indicated in appropriate cases.

Alternatively, it may be that levels of competition are determined among the total parr group comprising all the age-classes but, again, Figure 16 shows that there is no obvious relationship between the density of all parr and the body length of the 1+ age group..

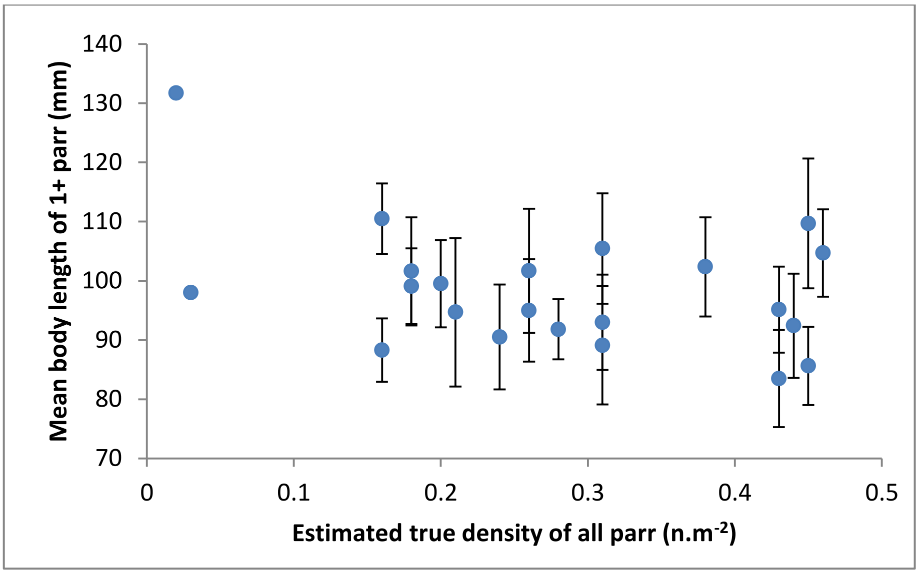

Figure 16. The relationship between the density of all parr and the average body length of 1+ parr. Standard deviation is indicated in appropriate cases.

3.5 Assessment based on salmon parr

The assessments of the status of fry presented earlier in this report refer specifically to the year-class that hatched in 2013. The survey data also contain potentially useful information on the densities of the parr year-classes that hatched earlier than 2013 and these might support additional assessments for those hatch-years. The assessments that follow use essentially the same approaches developed for the assessment of density and biomass for fry to examine the same aspects of the parr. However, in the case of the parr data, the use of multiple regression to test for joint effects of altitude and density on fish size is not appropriate for reasons that become fully apparent later – namely, altitude and density are not linked by a single relationship. To overcome this problem, sites are ranked separately by density and biomass and the results are compared.

For a rigorous examination the separate age-classes must be considered separately because they were established independently in different years. As shown above, the numbers, densities and biomasses of the 2+ and older classes of parr are mostly determined by the unknown proportion of fish that previously departed as smolts. The 1+ year-class of parr is not likely to be affected, or so much affected, in this way. The oldest year-classes of parr are therefore excluded from what follows in favour of focussing analysis and assessment on the 1+ parr (the year-class that hatched in 2012).

However, it still remains possible that some fish do become smolts and emigrate before reaching the 1+ stage. If they do so, this will hamper attempts to assess the status of the 1+ parr across sites. It is not possible to examine this directly because, if they exist, the fish in question will not be represented in the survey data. However, it is possible to approach the problem indirectly by examining patterns for 1+ parr across survey sites.

Figure 19 shows the relationship between altitude and 1+ parr density for an edited set of sites of "favourable" habitat quality (ie. graded 3-5 in Table 8). The presence of outliers showing anomalously low densities at warmer low-altitude sites where growth is likely to be fastest might indicate the prior emigration of one-year old smolts.

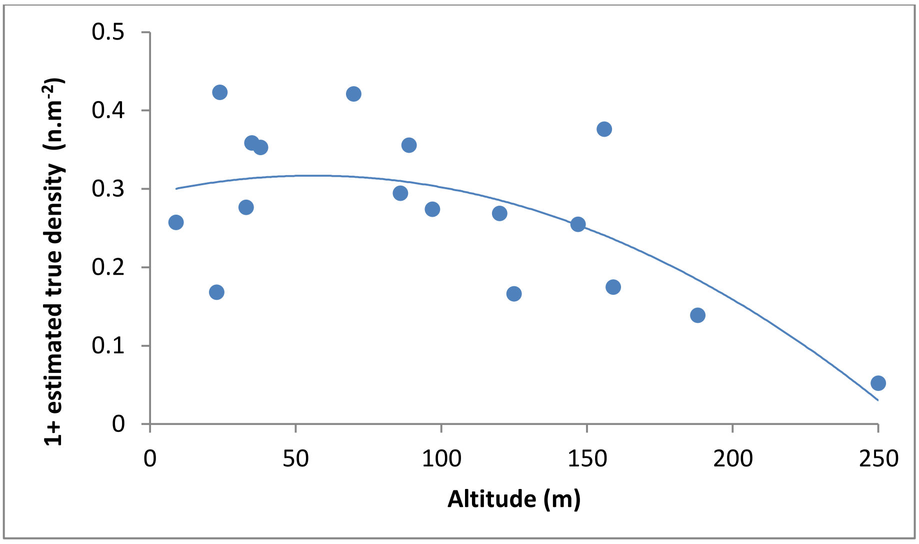

Figure 19: The relationship between site altitude and the density of 1+ salmon parr for an edited set of sites of "favourable" habitat quality, and excluding Barrock Mill.

It can be seen from Figure 19 that, overall, lower altitude sites tended to support higher, rather than lower, densities of 1+ parr. But against this background, it is also evident that densities at sites below 50 m altitude were less than expected from the progression of values for sites between 70 and 250 m, indicating that the possibility of smolting and emigration remains.

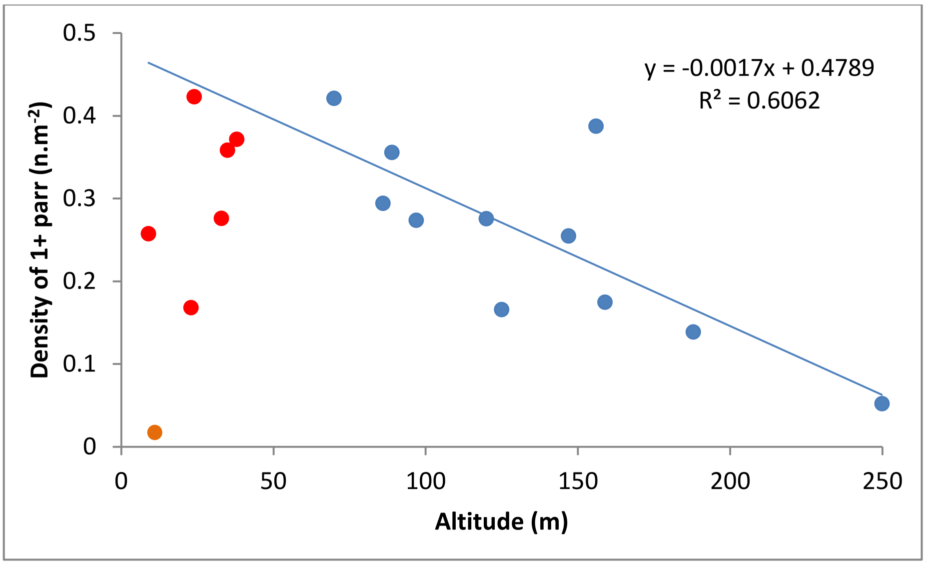

Figure 20. The relationship between altitude and 1+ density for an edited set of sites of "favourable" habitat quality at altitudes greater than 70m (marked in blue). Sites at less than 50m altitude are marked in red or orange.

Although the curve shown in Figure 19 is a reasonable fit for the whole data set, it does not adequately represent variation among the higher altitude sites. The data are therefore re-plotted in Figure 20, showing a linear relationship for sites lying between 70 and 250m. The relationship explains around 60% of the observed variation. If the same relationship is extended below 70m altitude, three of the six sites below 50m and marked in red, can now be identified as prominent outliers. They show much lower density values than expected. These sites are Hoy, Sheriff's and Bilbster. The problematic site at Barrock Mill is also now included in the figure and it is marked in orange.

It can be seen from the Appendices to this report that the very largest of the fry at Hoy and Bilbster were 70 -75 mm when surveyed in September. Fry like these would need to grow unusually rapidly over the winter in order to reach the threshold size for smolting by May - in excess of 90mm[7]. Perhaps growth rates at Hoy and Bilbster are sufficient to achieve this, bearing in mind the relatively large size of 1+ parr at these sites (Table 12) and the low numbers of remaining 2+ parr (Table 11). However, a similar case cannot be made for the site at Sheriff's because the maximum length of fry was only around 65mm, the 1+ parr were relatively small and a substantial number of 2+ fish still remained.

The possibility of smolting and emigration cannot be examined more thoroughly without any information on the numbers and size of putative smolts. On balance, it is unlikely that smolting at one year of age is a common phenomenon in Caithness and smolting is probably not the cause, and certainly not the only cause, of the low densities of 1+ parr at any of the sites in question.

[7] http://onlinelibrary.wiley.com/doi/10.1111/eff.12003/full

3.5.1 Density

The cause of the discontinuity evident in Figure 20 is so far unknown making it difficult to identify an appropriate relationship for assessing density in individual sites across the whole range of altitudes. As an expedient, the relationship for the higher altitude sites, as shown in Figure 20, was used to rank all the survey sites. The choice of this particular relationship may not be particularly appropriate for the lower altitude sites but the choice of any other plausible relationship would not materially alter the outcome of what follows.

The values for the difference between the observed density for each site and the value predicted by the relationship between altitude and density for 1+ parr were ranked, as shown in bold in the third column of Table 13. Column four contains the colour coded assessments according to Godfrey for densities for parr of all ages, repeated from Table 6. Gradings for parr habitat quality are in column two, repeated from Table 8.

Site	Habitat rating	**Obs – pred density ($n.m^{-2}$)**	Rating cf. Godfrey (2005)
Braemore	4	**0.174**	
Dalemore	3	**0.061**	
Corrichoich	2	**0.030**	
Shurrery	4	**0.028**	
Dalganachan	4	**0.026**	
Achnaclyth	3	**0.001**	
Gobernuisgach	3	**-0.002**	
Lythmore	4	**-0.015**	
Wag	3	**-0.021**	
Rumsdale	3	**-0.034**	
Smerrary	3	**-0.038**	
Culvid	3	**-0.040**	
Strathcoull	3	**-0.043**	
The Clow	3	**-0.061**	
Aultibea	3	**-0.101**	
Cnoc-glas	1	**-0.138**	
Coille Braich	2	**-0.146**	
Sheriff's	4	**-0.147**	
Bilbster	3	**-0.206**	
Dalnagleton	1	**-0.241**	
Hoy	4	**-0.272**	
Barrock Mill	3	**-0.443**	

Table 13. Difference between observed and expected density of 1+ parr.

It can be seen from the third column of Table 13 that the density of 1+ parr at the Braemore site was much greater than expected. Aultibea, Cnoc-glas, Coille Braigh, Sheriff's, Bilbster, Dalnagleton and Hoy showed markedly lower densities than expected and the site at Barrock Mill is again ranked lowest of all.

The low rankings for three of the seven lowest ranked sites are expected because they were classed as “unfavourable” habitat (ie. graded 1 or 2) but the other four sites had low rankings despite being classed as “favourable”. This group includes the sites which have already been identified as unusual - Sheriff’s, Bilbster and Hoy – and also Barrock Mill which has been identified throughout this report as an exceptional site of poor status.

Overall, the low rankings for the sites at Dalnagleton, Hoy and Barrock Mill, and perhaps Cnoc-glas, are all consistent with the classifications based on Godfrey but otherwise correspondence between the two approaches is rather low.

3.5.2 Biomass

The biomass density of 1+ parr is considered in Figure 21. As for the fry, biomass allows for the effects of any density-dependent growth by incorporating fish size into the assessments.

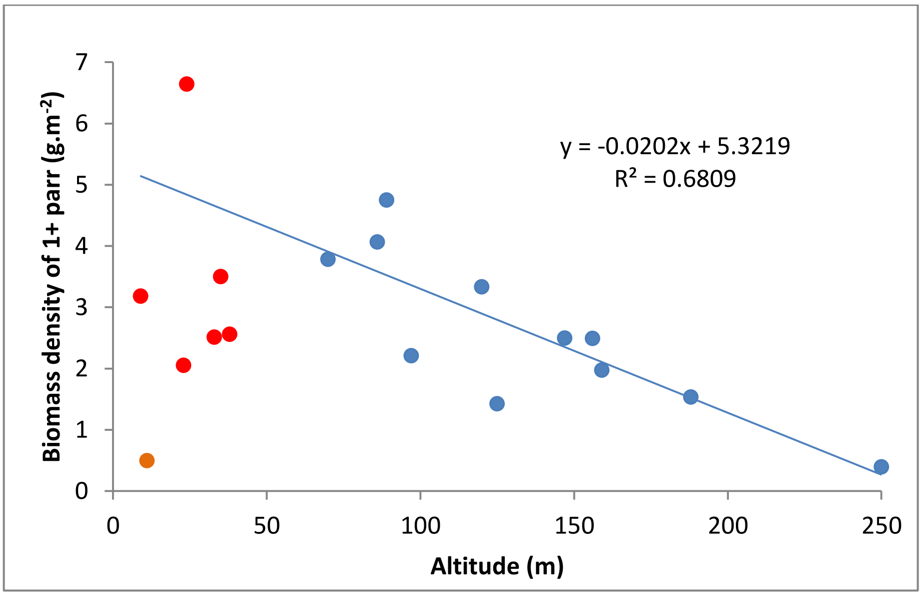

Figure 21. The relationship between altitude and 1+ biomass density for an edited set of sites of “favourable” habitat quality at altitudes greater than 70m. Sites at altitudes less than 50m are marked in red or orange.

The general pattern evident in Figure 21 is somewhat similar to the pattern evident in Figure 20 and the relationship shown explains around 70% of the variation observed in sites above 70m. However, all the low altitude sites, with the exception of Lythmore, are now clear outliers because the 1+ parr in each of the sites were of relatively small average size, as can be seen from Table 12. The parr at Lythmore were relatively large and the biomass value now exceeds the value expected from the relationship between altitude and biomass. The site at Braemore (156m) was a notable high outlier for density but it conforms to the overall biomass relationship because the 1+ parr there were relatively small.

Site	Habitat rating	**Obs – pred biomass ($g.m^{-2}$)**	Rating cf. Godfrey (2005)
Lythmore	4	**1.80**	
Shurrery	4	**1.23**	
Smerrary	3	**0.48**	
Achnaclyth	3	**0.44**	
Corrichoich	2	**0.41**	
Braemore	4	**0.32**	
Dalganachan	4	**0.14**	
Gobernuisgach	3	**0.12**	
Wag	3	**0.01**	
Dalemore	3	**-0.13**	
Rumsdale	3	**-0.13**	
Cnoc-glas	1	**-0.65**	
The Clow	3	**-1.11**	
Culvid	3	**-1.15**	
Aultibea	3	**-1.37**	
Bilbster	3	**-1.96**	
Coille Braigh	2	**-1.97**	
Strathcoull	3	**-1.99**	
Sheriff's	4	**-2.14**	
Dalnagleton	1	**-2.46**	
Hoy	4	**-2.80**	
Barrock Mill	3	**-4.60**	

Table 14. Difference between observed and expected biomass density of 1+ parr.

The biomass densities are ranked in Table 14. Comparing Tables 14 with Table 13, it can be seen that Braemore and Dalemore are downgraded in the biomass ranking compared with the density ranking and that Lythmore, Shurrery and Smerrary are upgraded. Culvid, Aultibea, Bilbster, Stathcoull, Sheriff's and Hoy are all rated low for biomass despite being rated as "favourable" habitat quality. Barrock Mill again ranks lowest of all by a substantial margin.

Site ratings derived by the approach of Godfrey do not identify the extreme biomass anomalies and low rankings at The Clow, Culvid, Aultibea, Bilbster, Coille Braigh, Strathcoull and Sheriffs although the lowest ranking sites at Dalnagleton, Hoy and Barrock Mill are common to both ranking methods.

The question remains as to why some low altitude sites classed as "favourable", notably Hoy, Sheriff's and Bilbster, contain lower than expected densities and biomasses of 1+ parr. Bilbster also showed anomalously low biomass of fry (Table 9). For the reasons given earlier, this was taken to indicate that the level of fry recruitment was locally inadequate in the year of survey (ie. 2013). It is possible that the low 1+ parr densities at Bilbster continue to reflect similarly inadequate fry recruitment in 2012. However, the same case cannot be argued for Hoy and Sheriff's where fry densities were highly ranked.

A possible explanation is that some of the parr at sites like Hoy had abandoned the habitats covered by the survey in favour of other areas. Under pressure from the unusually high temperatures and low flows prevalent before and during the survey, parr may have moved to deeper, faster-flowing water elsewhere that, under more usual river conditions, would be regarded as atypical. Habitat gradients are less pronounced in wider channels and unit survey areas are correspondingly less likely to sample all habitat types in the vicinity. In general, the scope for strategic relocation is much greater in the lower reaches of rivers where the greatest range of flow regimes and habitat types is available - often in close proximity.

If this is the case, the status of 1+ parr at the five low biomass outliers indicated in red in Figure 21 (Hoy, The Clow, Sheriff's, Bilbster and Strathcoull) will be rated too low relative to the true situation. The "missing" fish may be nearby, they will not be lost to the river and their absence from the survey sites may be flow-dependent and perhaps, therefore, temporary. In support of this the site at Lythmore was electric fished under higher flow conditions than the other sites (as can be judged from the photographs in the appendices). Neither the density nor the biomass of the 1+ parr at Lythmore (24m) was atypical, as can be judged from Figures 20 and 21, respectively.

4. Conclusions

This report has relied heavily on using site altitude as a basis for comparisons of populations of salmon across river catchments, survey sites, and years. Altitude is likely to be a reasonable proxy for many of the environmental and biological effects – related to temperature, hydrochemistry and probably spawning density and fry recruitment – that affect performance and productivity but for which direct measurements are usually not available.

The central problem with the approach lies in devising ways of identifying a useful description of the underlying relationships with altitude. The particular problem arises from the certainty that some, or many, areas of stream will fall short of their potential to produce fish because of variable levels of local recruitment to sites that also vary in their habitat quality – neither of which can be fully quantified. As an expedient, the approach adopted here has been to edit out sites judged to be of low habitat quality, to identify any major, low value outliers that remain, and to use the edited set of sites to define the relationships that serve as a basis for comparison.

From the analytical point of view, the present survey has the advantage of being based on an extensive survey covering a relatively large set of sites over the full altitudinal range. Also, relatively few outliers remained for the fry data once habitat quality had been factored out, suggesting that variable recruitment was not a widespread constraint on fish numbers. In particular, it may be that 2012 was a fortuitously good spawning year leading to rather uniform recruitment of fry in 2013. In support of this, the fry densities at some of the survey sites were exceptionally high by comparison with any of the values presented by Godfrey for past years in any of the Scottish SAC rivers.

The data for 1+ parr are likely to be inherently more complex than those for fry. The parr have experienced two variable growing periods rather than one. The parr are also both older and larger allowing more time for relocation and size-dependent mortality and more scope for size-dependent behaviours. Yet, as for the fry, the density values observed for 1+ parr were generally high and patterns of variation among sites were generally coherent. This again suggests that low or uneven recruitment, in this case in 2012, was not a constraint on production of 1+ parr in 2013 and, therefore, that 2011 was probably also a good spawning year.

All the relationships described in the report are for the Caithness rivers only and for 2013 alone and they may not have wider relevance or application. Although the Caithness sites can be ranked and compared using the approaches developed in this report, matching data are not available from surveys elsewhere. So, there is no basis for outside comparison. Scope for comparison with the Caithness rivers in previous years is also limited to the case of salmon fry in 2004. However, if the present survey is repeated or extended such comparisons will become possible and the utility of the relationships may increase as the scope of the work extends.

The relationships developed in this report should be treated with caution meantime but they are open to testing, for example, by repeat survey and analysis of the same set of sites in another year.

There are several conditions that are favourable for a test.

1. A relatively large set of sites surveyed in the same year and at around the same time.

2. Survey data of high technical quality, obtained using depletion techniques.

3. Coverage of the full altitude range.

4. Measurements of body length to characterise individual performance.

5. Age determination from scale readings because, on occasion, the length distributions of fry and parr overlap and the length distributions of the various age-classes of parr frequently do so.

6. Sound categorization of habitat quality, probably based on expert opinion in the absence of an effective, more formal approach.

Some of the clearest relationships that emerged from the analysis of the data were for biomass density rather than numerical density and the two values are not equivalent. The status of the adjacent Dalemore and Hoy sites encapsulates the resulting difficulty. Fry biomass values at the two sites were roughly the same but fish at Dalemore were very numerous and very small, while fry at Hoy were many fewer but much larger. This mismatch begs the question of which of the two sites represented the more favourable status from a fisheries management point of view.

Intuitively, it might be thought that because fry density was much higher at Dalemore its status was necessarily superior to that of Hoy. However, smolting is dependent on growth-rate and size and the opportunity to migrate occurs only once each year, around May. On average, fewer of the slower growing fish at Dalemore are likely to meet the May threshold and those fish that do not must remain in fresh water for a further year before the opportunity to leave recurs. However, fewer of those parr that delay are likely to survive to become smolts because of the extra mortality incurred during their additional time in fresh water. It is possible, therefore, that neither of the conditions observed at Hoy or Dalemore is consistently superior in terms of producing smolts. Given all the other uncertainties that fish face, and the fact that these change from year to year, the observed mix of conditions may well represent the most favourable condition for the river as a whole and the best prospect for the fishery.

In a management context, survey data can be used in two ways. Looking forwards in time, fry and parr numbers are a direct determinant of smolt numbers and these, in turn, set the initial parameters for the fisheries in following years. High production in fresh water and high smolt numbers are a pre-requisite for high fishery abundance. Looking backwards, fry and parr numbers are related to past fisheries through rates of egg deposition in previous years. However, at times of high adult abundance, density of juvenile fish is considered a somewhat insensitive measure of spawner numbers because the finite capacity of river habitat caps recruitment at a maximum value equivalent to saturation. In practical terms, this value is almost always unknown and it is impossible to predict in any meaningful way. However, if the validity of the present approach can be confirmed, comparisons of numerical density and biomass density will signal that saturation values are being approached - as appeared to be the case for some sites in 2013.

In this context, all the survey data for fry and 1+ parr are combined in the summaries contained in the figures below. In both cases, the anomaly (ie. the observed minus the expected value) for biomass is plotted against the anomaly for density. In the case of fry, it can be seen from Figure 22 that the biomass anomaly at any site was generally consistent with the density anomaly – in general, large density anomalies were associated with large biomass anomalies - as is expected.

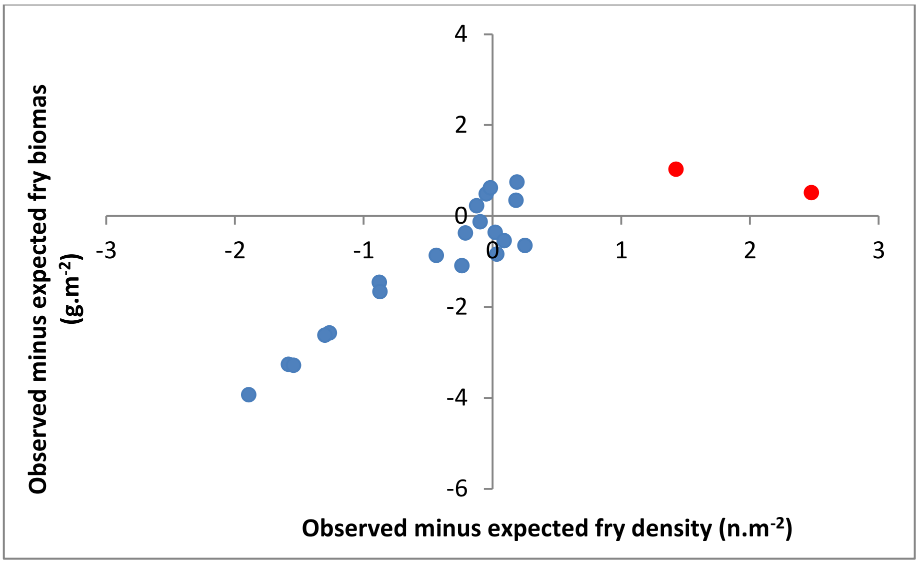

Figure 22. The relationship between the density and biomass anomalies for fry. Dalemore and Dalganachan are marked in red.

However, the unusual status of the sites at Dalemore and Dalganachan (marked in red) has already been highlighted in this report. Both sites showed large density anomalies for fry that were not matched by correspondingly large biomass anomalies, indicating that the growth of individuals was impaired. This was probably caused by intense competition among fry in sites that were saturated, or nearly saturated, with fish. Figure 22 now demonstrates that only Dalemore and Dalganachan showed clear evidence of this condition.

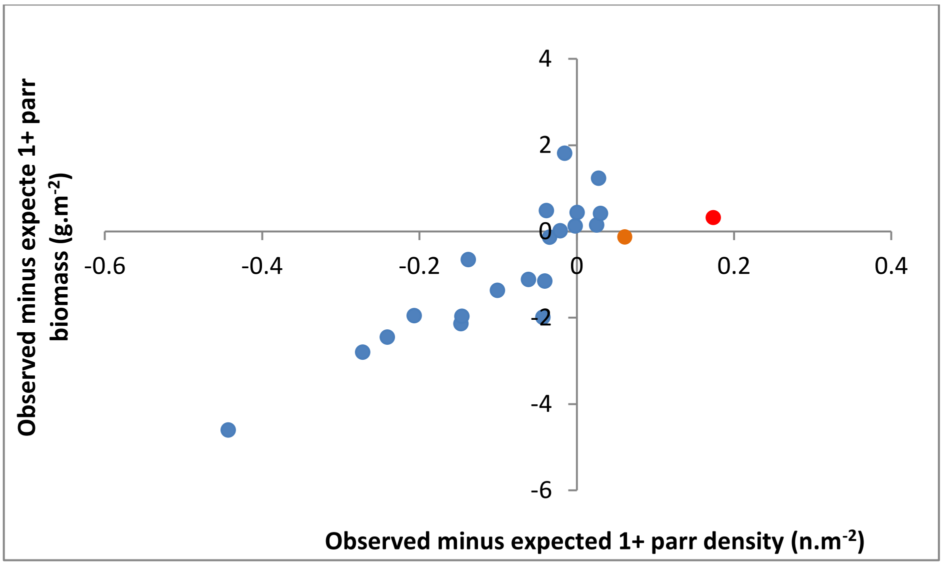

Figure 23. The relationship between the density and biomass anomalies for parr. Braemore is marked in red and Dalemore in orange.

Figure 23 shows a similar summary for the 1+ parr. As for the case of fry, it can be seen that biomass anomalies were generally consistent with density anomalies. However, Braemore (marked in red) showed an extreme high anomaly for 1+ parr density that was not matched by a high biomass anomaly, again suggesting that parr growth was impaired by intense competition in a site approaching saturation. Only Braemore was clearly affected in this way although Dalemore (marked in orange) is also a candidate.

5. Summary assessment of Caithness rivers in 2013

Trout are typically distributed in different habitat types than those habitually used by salmon. Salmon rather than trout were the main target of this survey and the survey sites were selected accordingly. Nevertheless, in a Scottish context, trout were surprisingly infrequent at most sites and they were absent from many. Trout were most abundant at Cnoc-glas on the Forss, Rumsdale on Thurso and Gobernuisgach on the Berriedale - all sites at high altitude. The generally low abundance of trout and their relative strength only around the periphery of the catchments is consistent with previous data of the same type for the northern rivers presented by Godfrey (2005). Although these findings are unusual in a broader Scottish context, they may reflect the natural condition of trout populations in these northern rivers.

For salmon, most of the preliminary comparisons with data presented by Godfrey for the northern rivers were highly favourable. This was the case both for the fry hatched in 2013 and for the 1+ parr hatched in 2012.

The data presented by Godfrey are summary data that are a useful yardstick in general comparisons at the river or catchment scales. However, they are less useful for categorising individual sites which often have characteristics that set them apart from others in relation to their intrinsic capacity to support fish. For example, habitat quality and altitude were confirmed as important determinants of the density and biomass values for both fry and 1+ parr.

Making due allowance for these differences the fish populations at the survey sites were categorized and compared. Overall, the majority of the sites appeared rather uniformly stocked and there was no evidence that they lacked either fry or parr. However, in a few cases potential shortfalls were pinpointed, as follows.

1. Fry densities at The Clow and Bilbster sites on the Wick River were lower than expected. This was probably due to inadequate local recruitment caused by lack of spawning habitat in the vicinity of the sites. In any case, judging from Table 6, the situation was as least partially resolved for 1+ parr, probably because of additional recruitment from a greater distance over the extended period between the fry and 1+ stages.

2. In some low altitude sites, 1+ parr tended to be fewer than expected. The Hoy site, in particular, deserves further attention because parr were judged few in number in all comparisons. The deficit was tentatively attributed to the movement of parr from the survey areas to atypical stream habitat nearby because of the warm, low water conditions

prevalent in 2013. This is speculation, however, and a repeat survey might permit a more definitive explanation.

3. The Barrock Mill site on the River Wester contained only very sparse populations of both trout and salmon although the site offers habitat of good quality. Indeed, the few fish there had grown well and were very large for their age, probably as a result of low levels of competition for abundant resources. The inferior status of Barrock Mill remains to be explained.

In summary, the 2013 electric-fishing survey has provided assessments of two spawning years – 2011 and 2012. This report has demonstrated that, making due allowance for altitude and habitat quality, salmon belonging to both the resulting hatch-year classes - 2012 and 2013 - are in a favourable condition at the great majority of the survey sites. Some sites are at or near their maximum capacity to support fish.

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Iain McLaren read the scales and provided ages for parr. Jason Godfrey of Marine Scotland Science provided archival data for the Caithness rivers in 2004 from the SFCC database.

Christopher Brocklebank-Fowler, James May, Norrie Russell and Tertius Threipland helped with access to some of the sites.

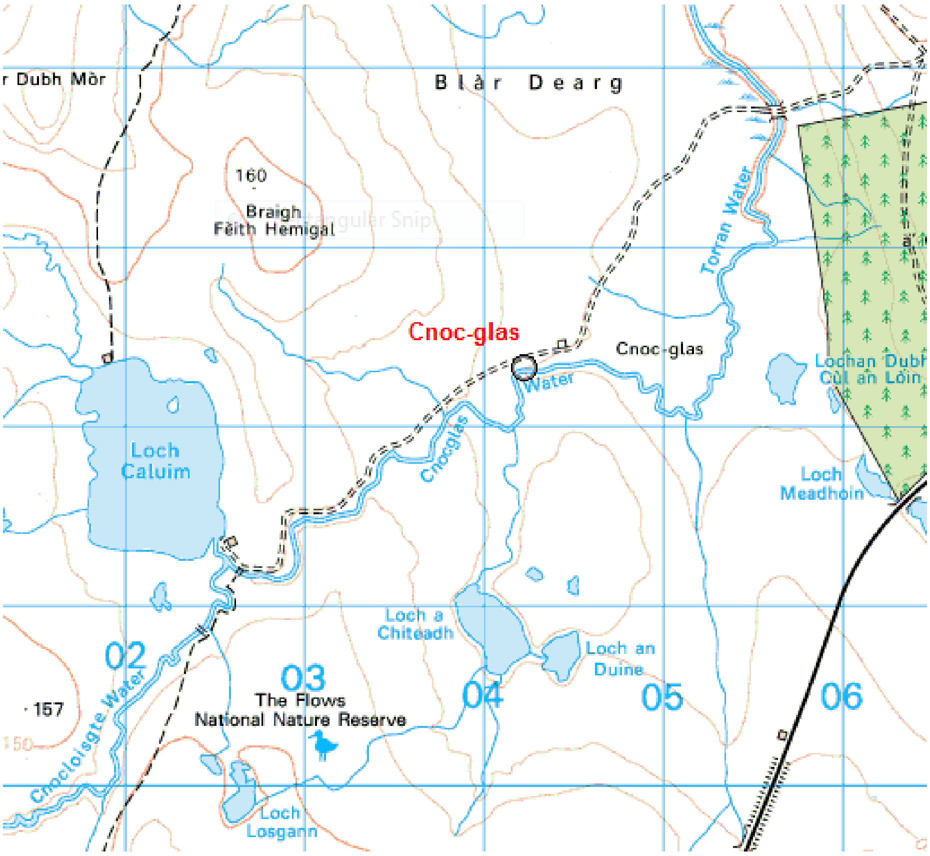
More generally, we acknowledge the help and encouragement of The Crown Estate and of the Caithness District Salmon Fishery Board. In particular, we thank Rob Hastings, Director of Energy and Infrastructure at The Crown Estate, John Thurso, the Chairman of the Board, and Eleanor Constable, the Clerk to the Board, who provided administrative support.

Reference.

J.D. Godfrey (2005). Site Condition Monitoring of Atlantic Salmon SACs. Report by the SFCC to Scottish Natural Heritage, Contract F02AC608. 274 pp.
http://www.scotland.gov.uk/Resource/Doc/295194/0096508.pdf

6. Appendices

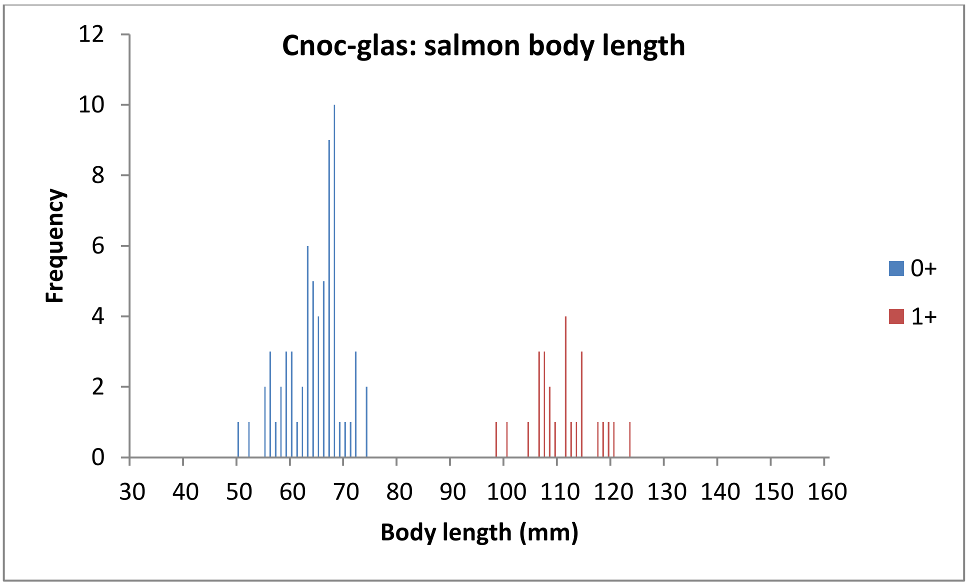
1. Cnoc-glas, Forss Water



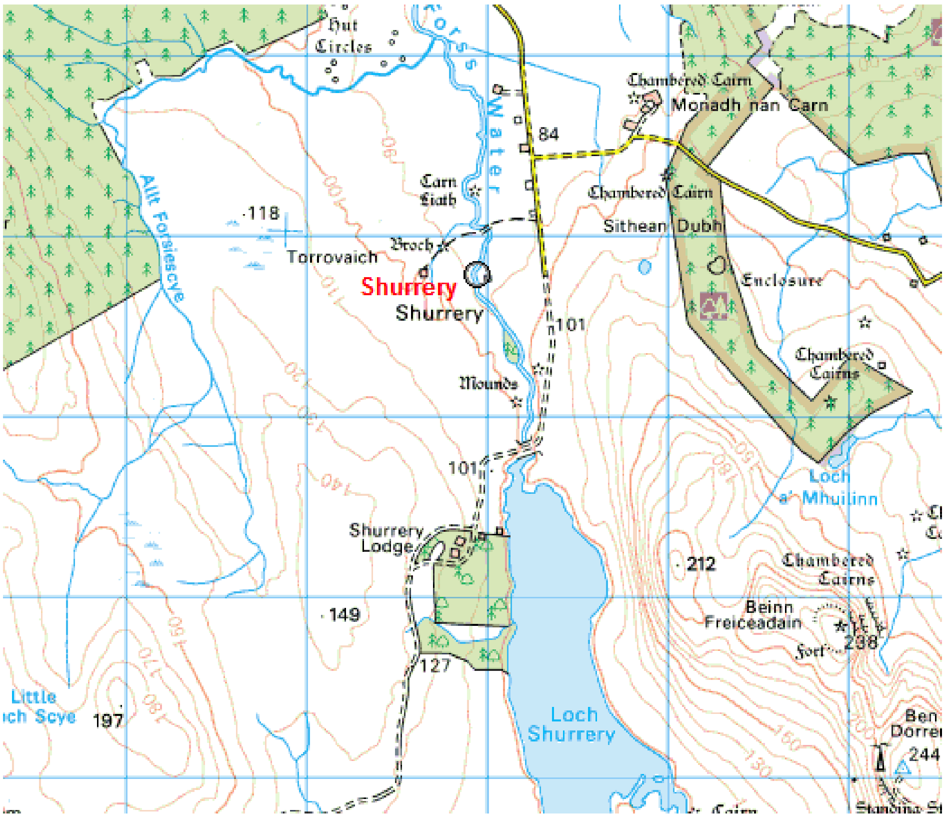
Cnoc-glas: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
28.8	6.1	175	181

Cnoc-glas: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	44	15	6	65	68	65 - 73	0.37	0.39
Salmon parr	20	7	0	27	27	27 - 29	0.15	0.15
Trout fry	56	13	5	74	76	74 - 79	0.42	0.43
Trout parr	24	2	0	26	26	26 - 26	0.15	0.15

Cnoc-glas: presence of non-salmonid species	
Eel	



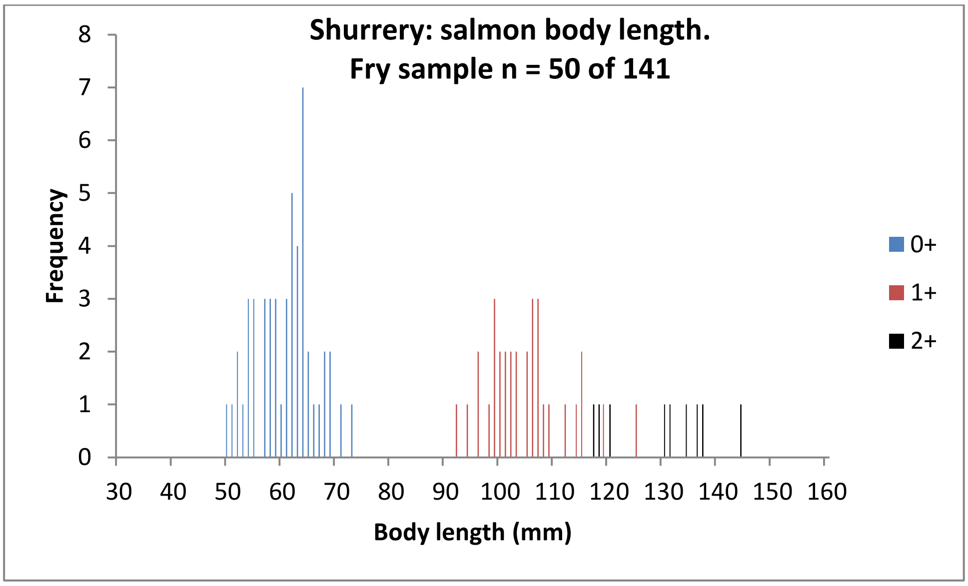
2. Shurrery, Forss Water



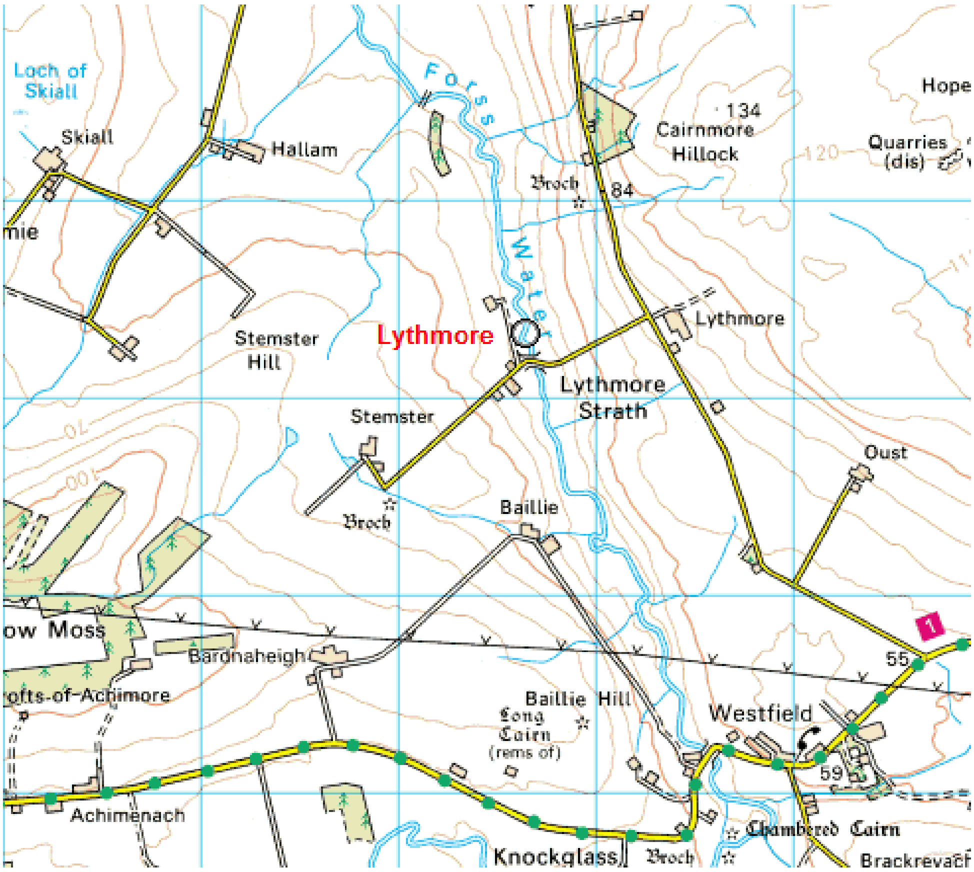
Shurrery: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
13.4	6.5	90	90

Shurrery: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	106	27	8	141	144	141 - 148	1.57	1.60
Salmon parr	33	8	0	41	41	41 - 41	0.46	0.46
Trout fry				2			0.02	
Trout parr				1			0.01	

Shurrery: presence of non-salmonid species	
Eel	



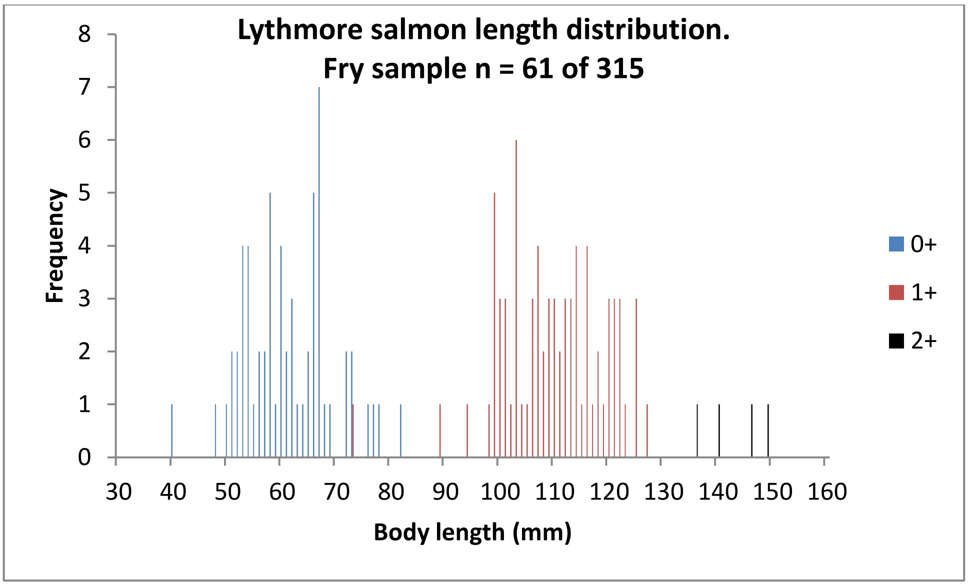
3. Lythmore, Forss Water



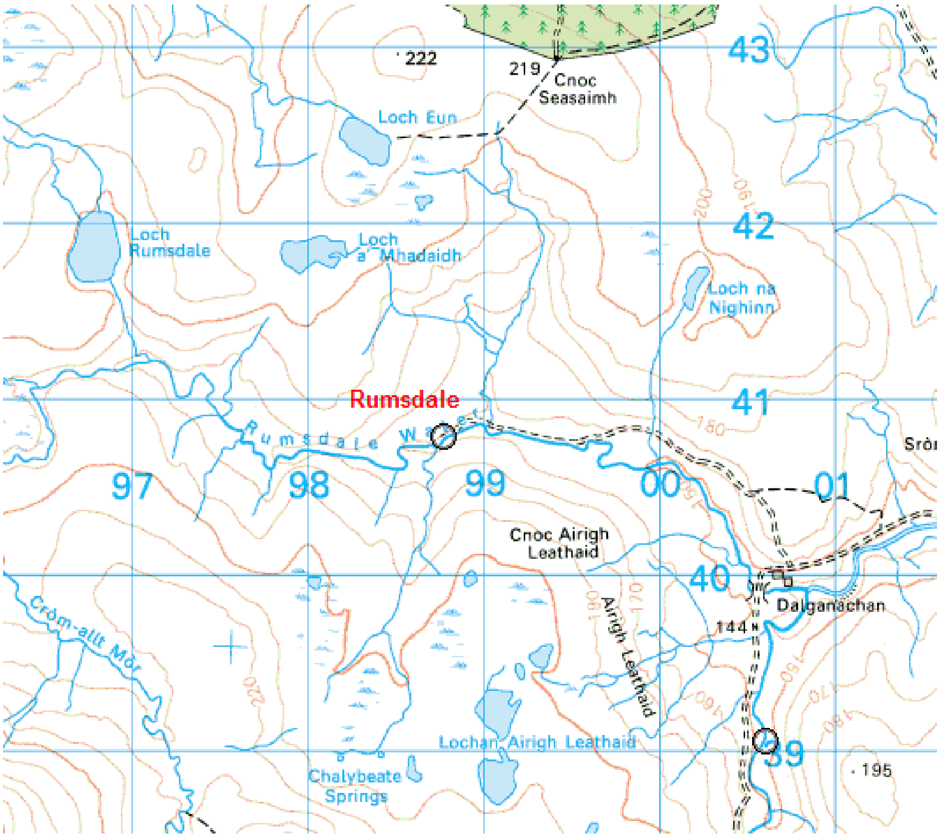
Lythmore: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
17.5	10.6	179	179

Lythmore: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. n/ m^2	Dens est. n/ m^2
Salmon fry	237	59	19	315	321	315 - 327	1.76	1.79
Salmon parr	58	15	5	78	80	78 - 83	0.44	0.45
Trout fry			6	6			0.03	
Trout parr			0	0				

Lythmore: presence of non-salmonid species		
Eel	Stickleback	



4. Rumsdale, River Thurso

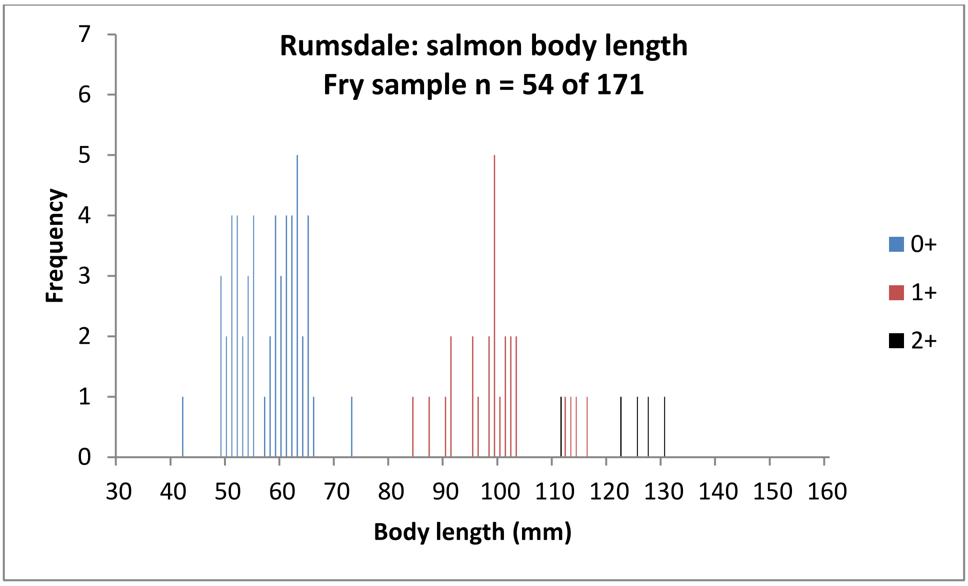


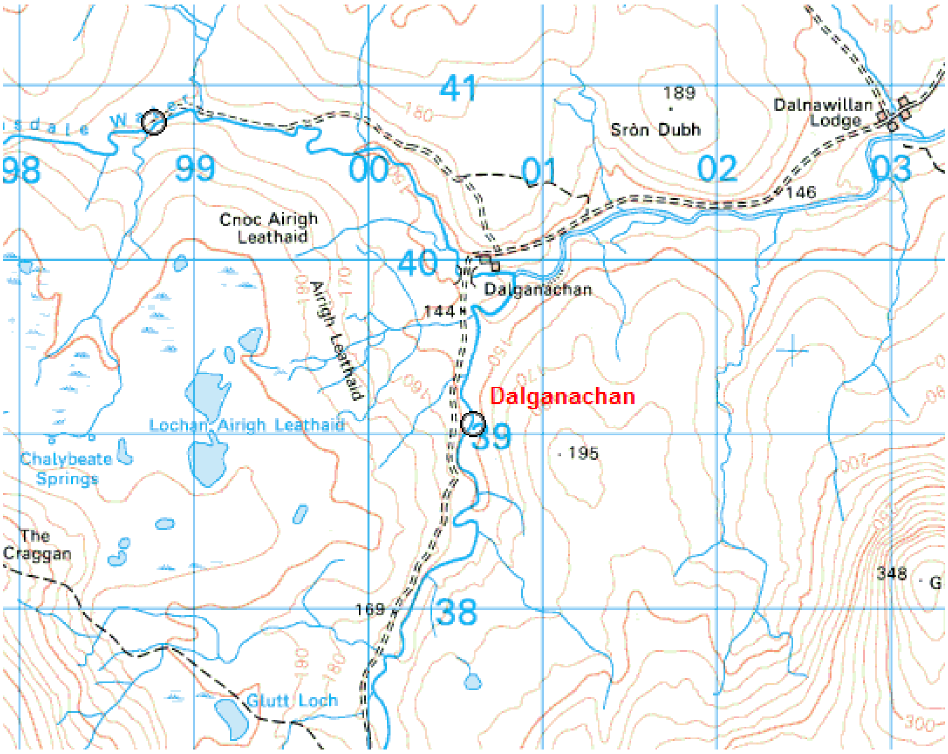
Rumsdale: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
22.7	8.1	169	169

Rumsdale: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n. m^{-2}$
Salmon fry	101	47	23	171	191	174 -209	1.01	1.13
Salmon parr	24	6	2	32	33	32 - 35	0.19	0.20
Trout fry			40	40			0.24	
Trout parr			9	9			0.05	

Rumsdale: presence of non-salmonid species	
Eel	



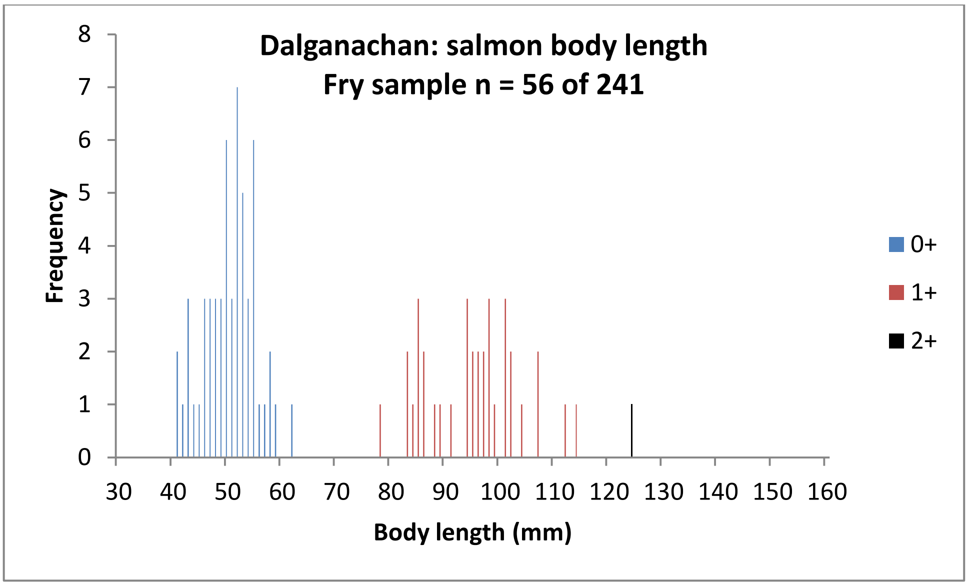
5. Dalganachan, River Thurso



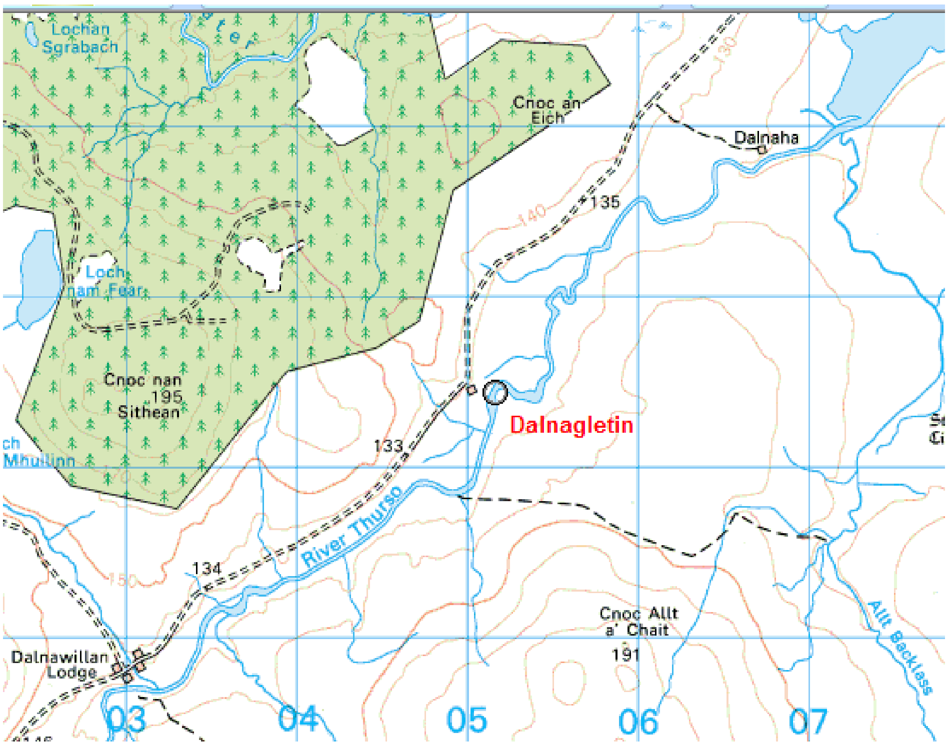
Dalganachan: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
29.2	4.9	143	159

Dalganachan: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	115	72	54	241	350	270 - 430	1.69	2.45
Salmon parr	27	8	1	36	37	36 - 38	0.25	0.26
Trout fry			0	0			0	
Trout parr			2	2			0.01	

Dalganachan: presence of non-salmonid species		
Eel	Stickleback	



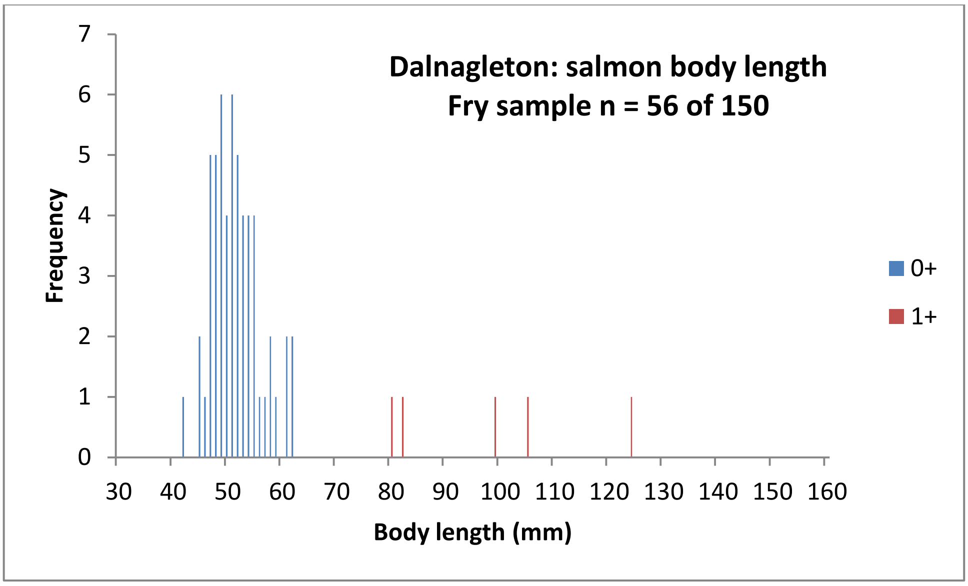
6. Dalnagleton, River Thurso



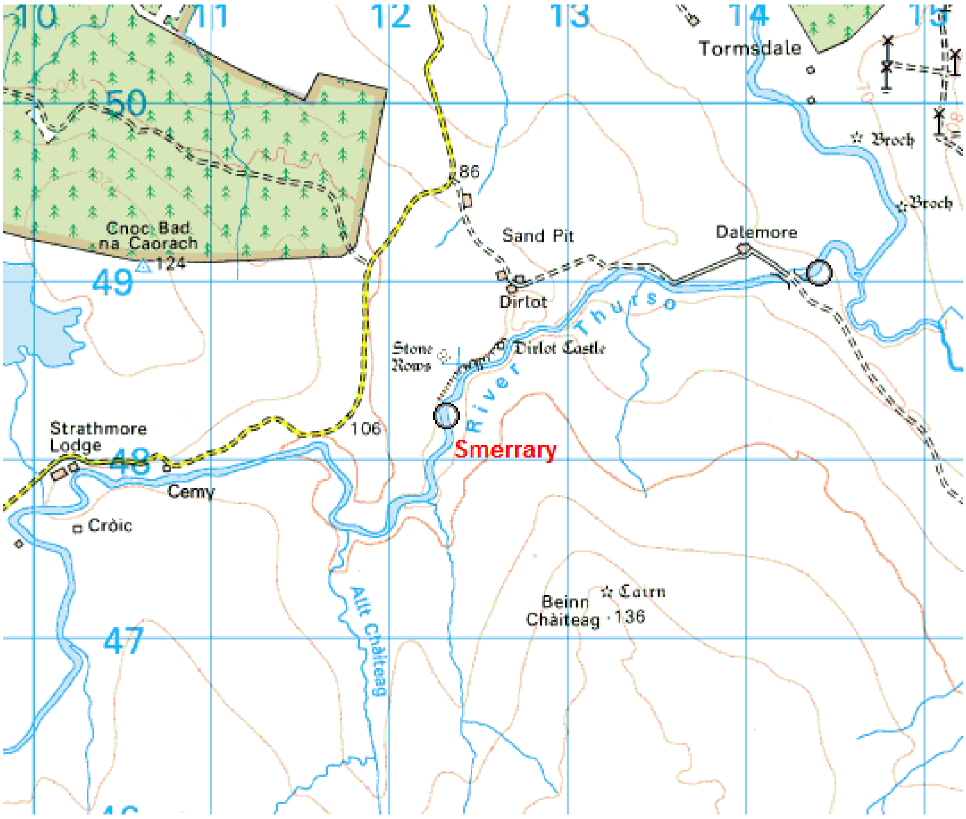
Dalnagleton: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
34	5.6	190	264

Dalnagleton: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. n/m^2**	**Dens est. n/m^2**
Salmon fry	89	30	31	150	178	154 -202	0.79	0.94
Salmon parr	3	2	0	5	5	5 - 7	0.03	0.03
Trout fry			2	2			0.01	
Trout parr			0	0			0	

Dalnagleton: presence of non-salmonid species	
Eel	



7. Smerrary, River Thurso

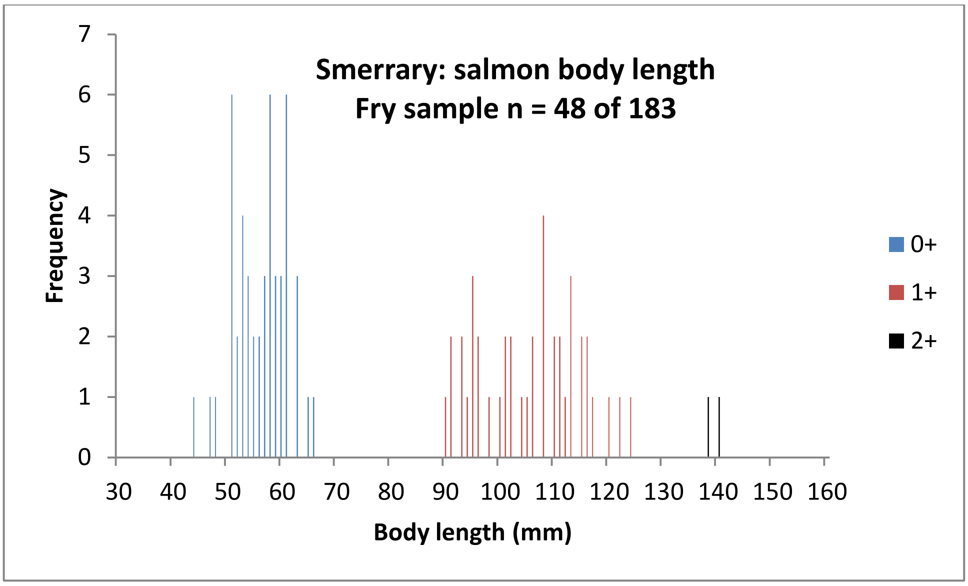


Smerrary: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
16.4	9.6 *	144	144

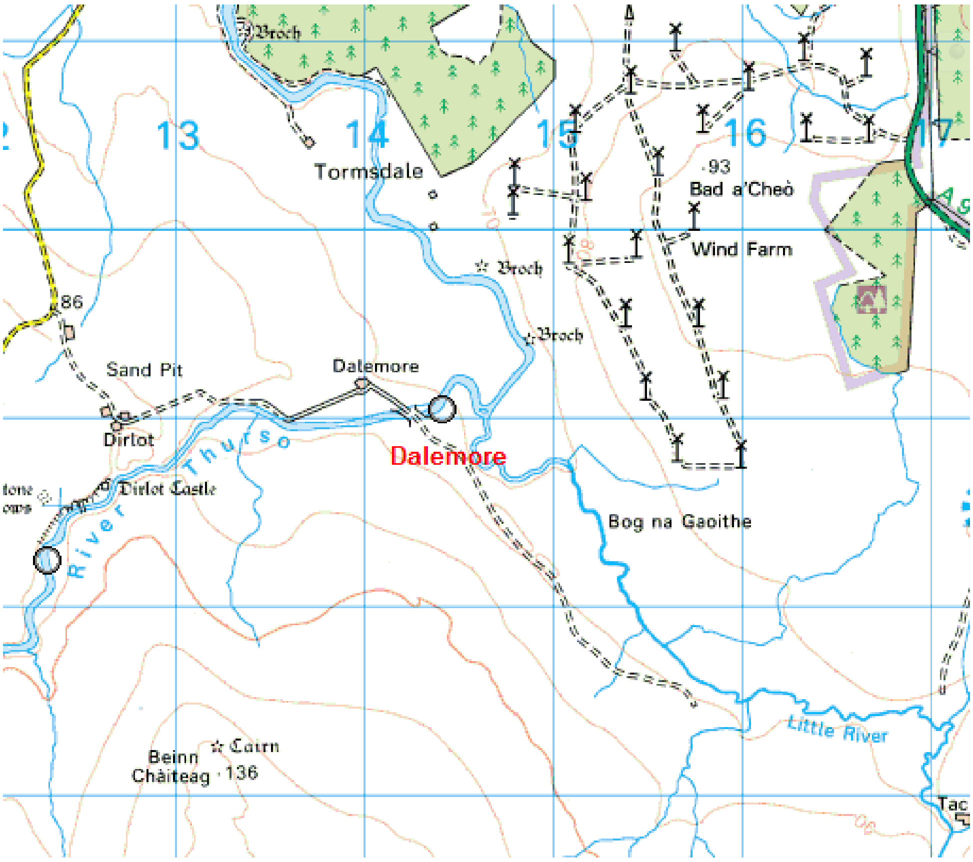
*Section not rectangular

Smerrary: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. n/m^2**	**Dens est. n/m^2**
Salmon fry	107	45	30	182	209	188 - 230	1.26	1.45
Salmon parr	34	7	2	43	44	43 - 45	0.30	0.31
Trout fry			0	0			0	
Trout parr			2	2			0.01	

Smerrary: presence of non-salmonid species	
Eel	



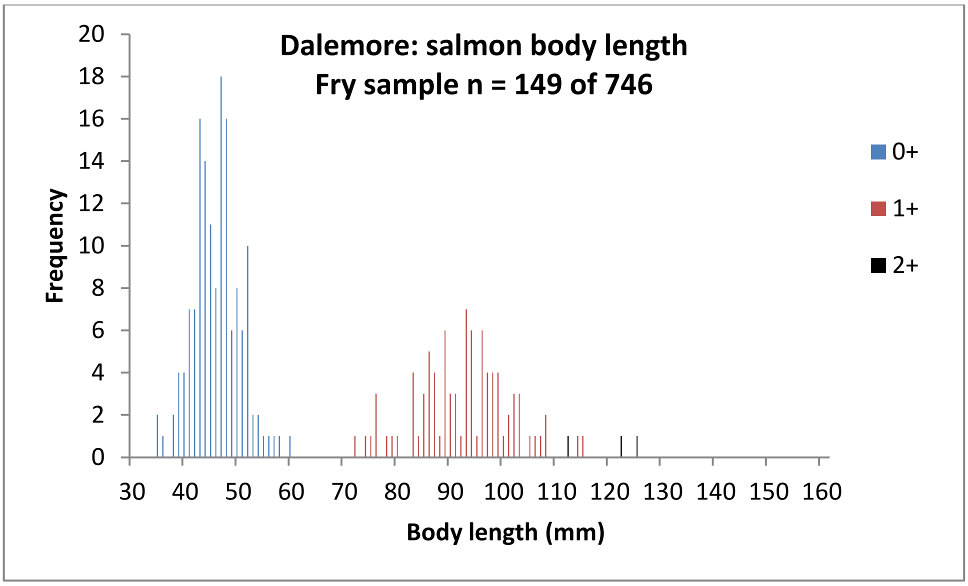
8. Dalemore, River Thurso



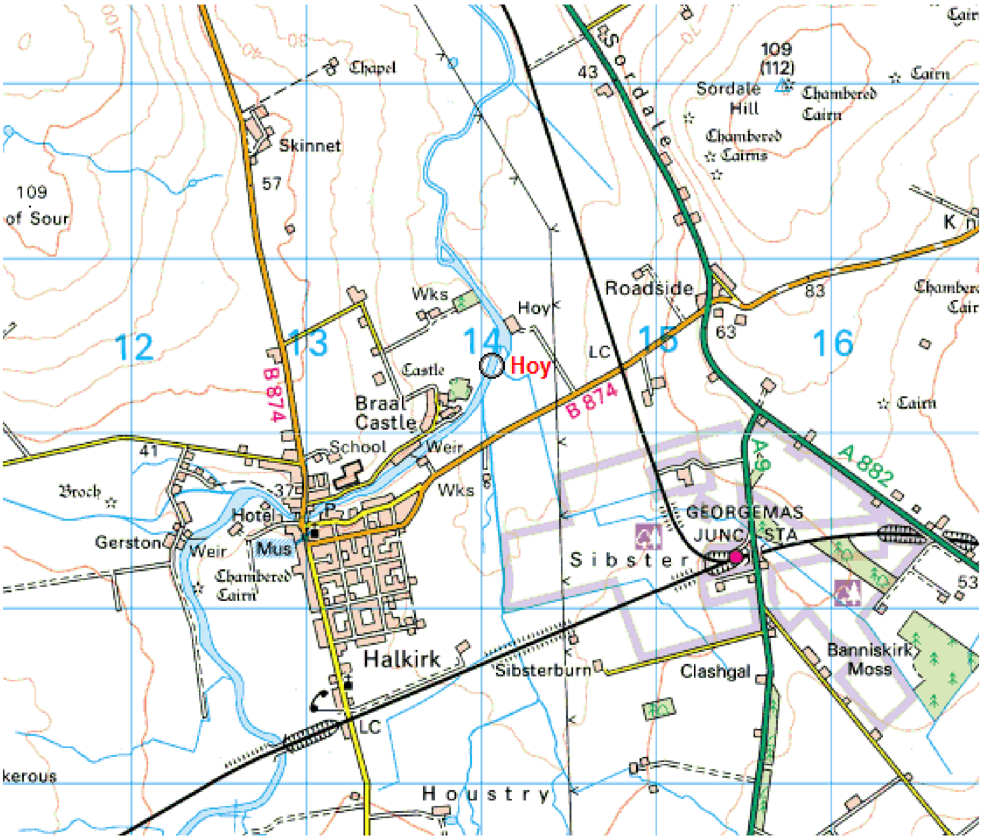
Dalemore: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
50	4.4	219	263

Dalemore: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens. est. $n.m^{-2}$
Salmon fry	407	227	112	746	878	827 - 929	3.41	4.01
Salmon parr	60	20	11	91	97	91 - 105	0.42	0.44
Trout fry	0			0			0	
Trout parr	6			6			0.03	

Dalemore: presence of non-salmonid species			
Eel			



9. Hoy, River Thurso

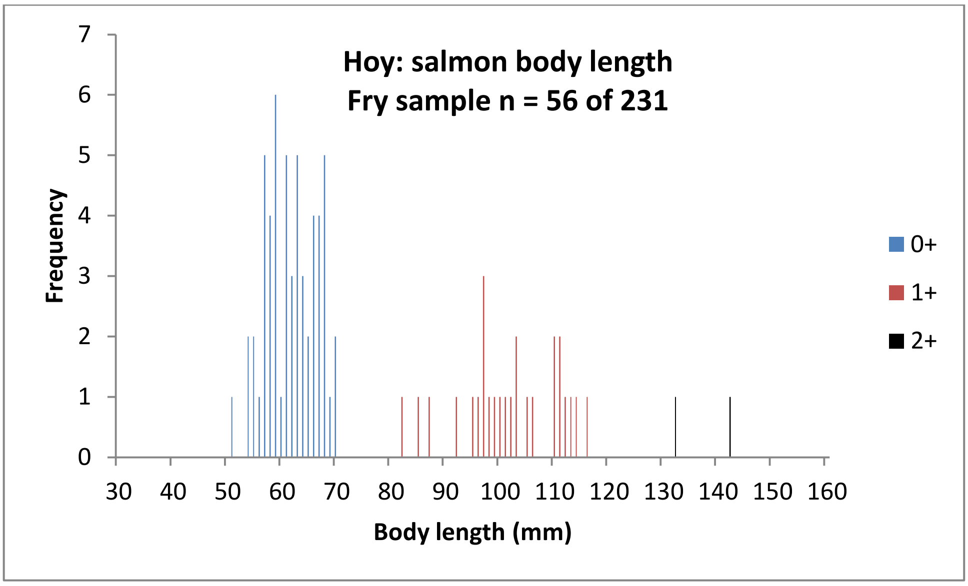


Hoy: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
21.4	7.9 *	161	231

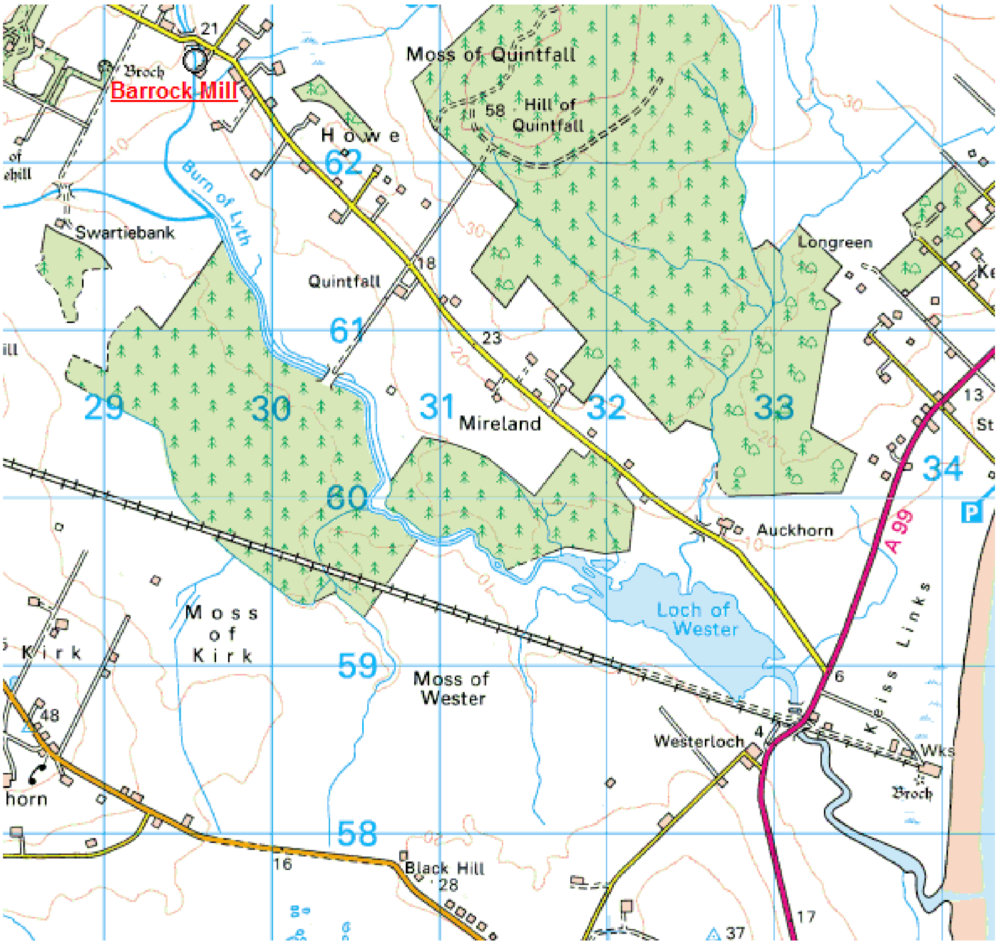
*Section not rectangular

Hoy: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	125	68	38	231	277	245 - 309	1.43	1.72
Salmon parr	20	6	2	28	29	28 - 31	0.17	0.18
Trout fry			1	1			0.01	
Trout parr			0	0			0	

Hoy: presence of non-salmonid species		
Eel	Stickleback	



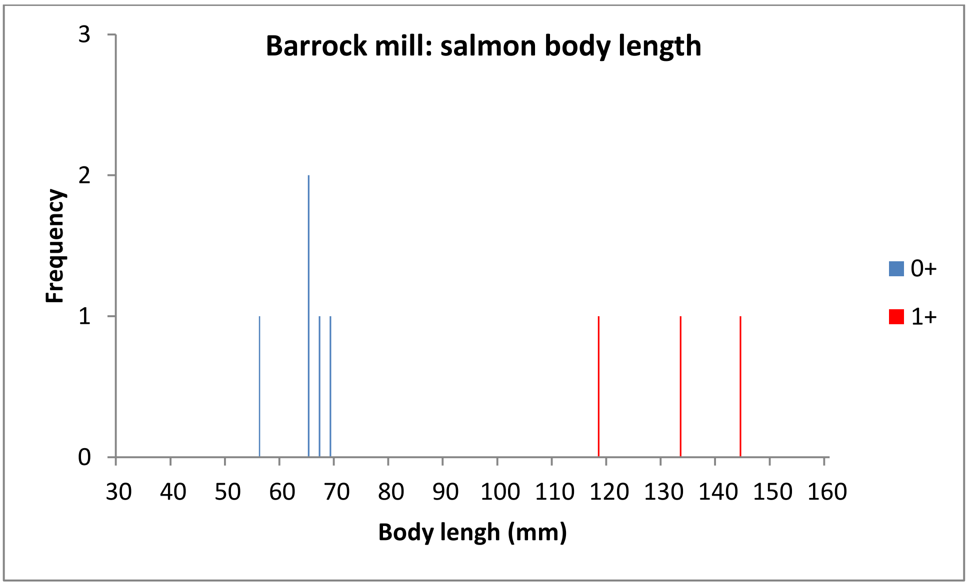
10. Barrock Mill, Wester/ Burn of Lyth



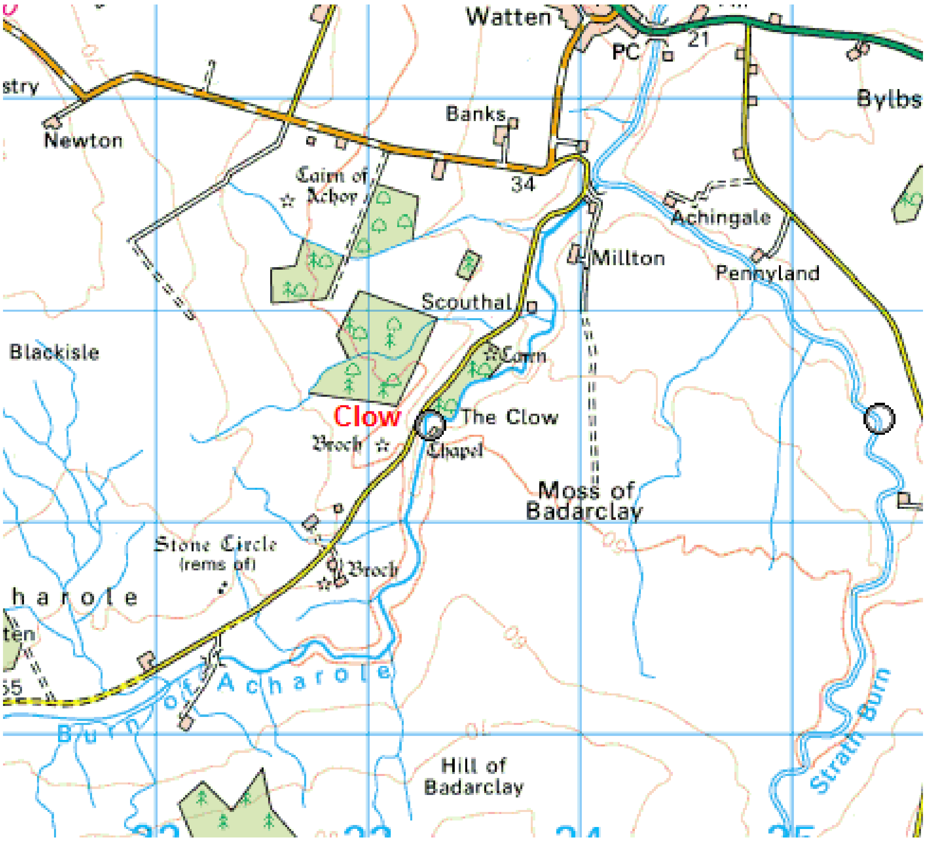
Barrock Mill: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
22.4	7.9	173	173

Barrock Mill: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. n/ m^2**	**Dens est. n/ m^2**
Salmon fry	4	1	0	5			0.03	
Salmon parr	2	1	0	3			0.02	
Trout fry	2	1	0	3			0.02	
Trout parr	1	1	0	2			0.01	

Barrock Mill: presence of non-salmonid species		
Eel	Stickleback	



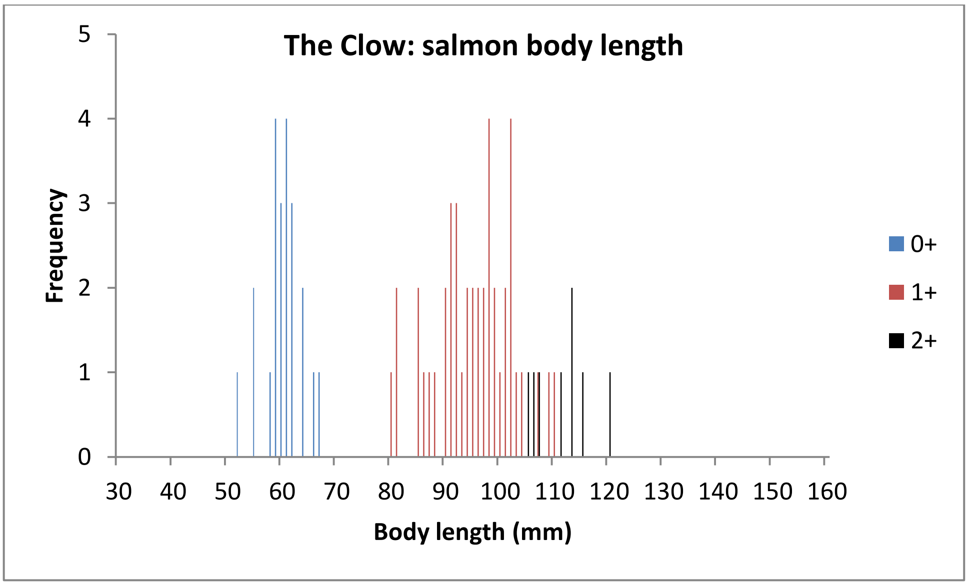
11. The Clow, Wick River



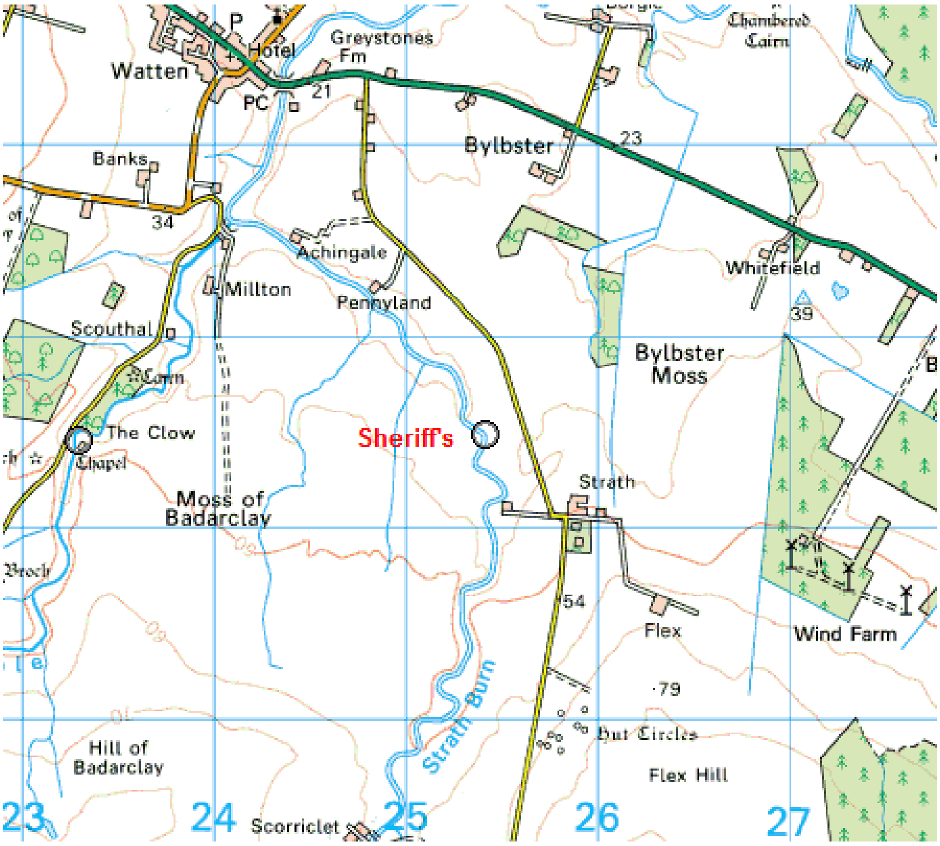
The Clow: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
28.0	4.3	120	167

The Clow: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. $n.m^{-2}$**	**Dens est. $n.m^{-2}$**
Salmon fry	16	4	1	21	21	21 - 23	0.18	0.18
Salmon parr	41	6	4	51	52	51 - 54	0.43	0.43
Trout fry			0	0			0	
Trout parr			0	0			0	

The Clow: presence of non-salmonid species	
Eel	



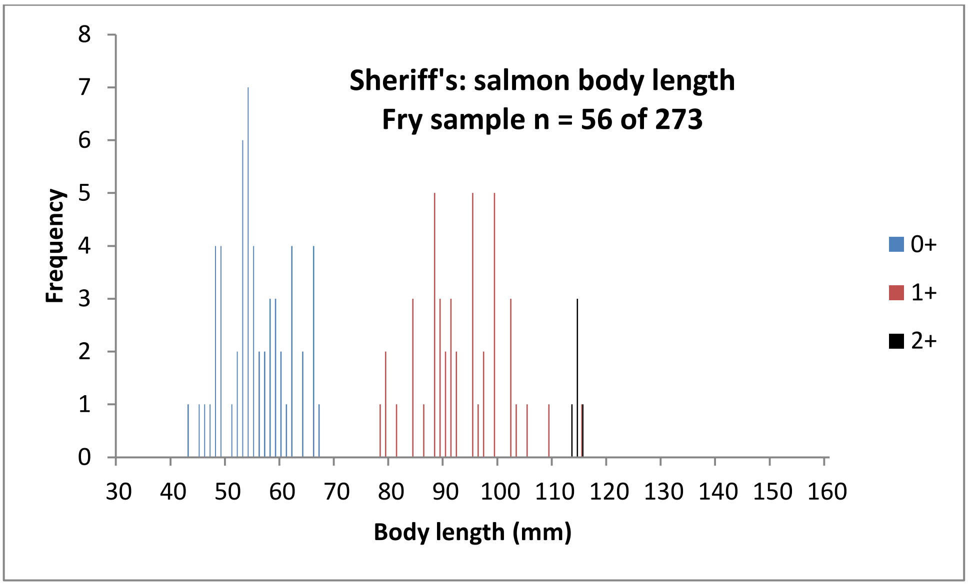
12. Sheriff’s, Wick River



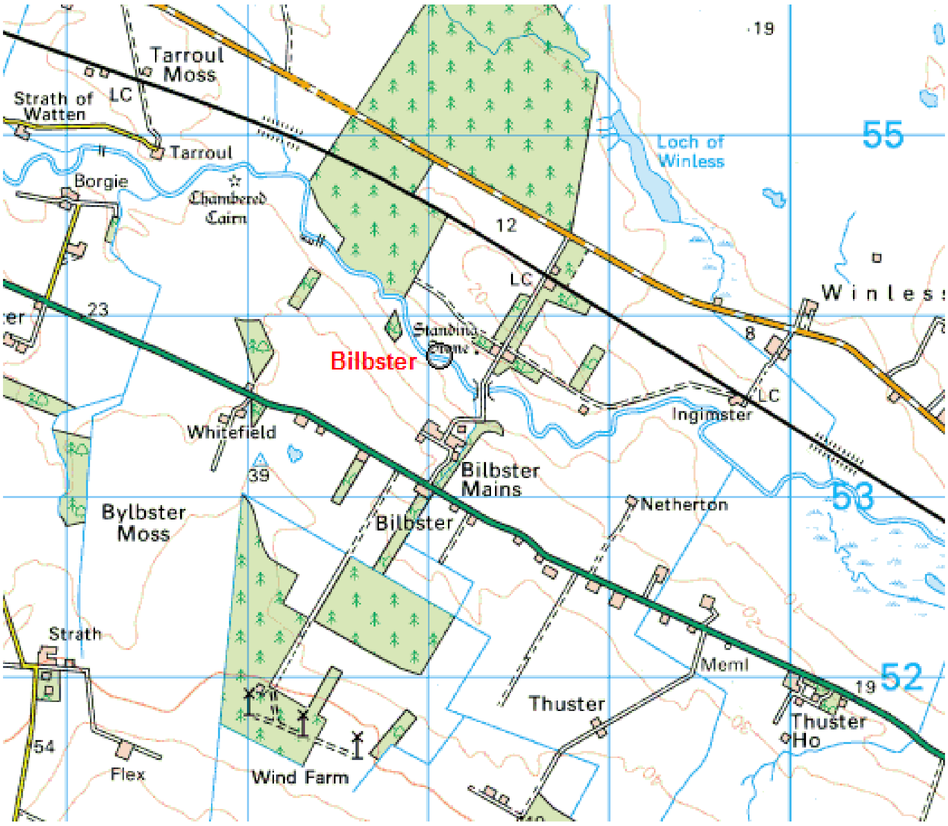
Sheriff's: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
22.1	7.3	161	169

Sheriff's: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. $n.m^{-2}$**	**Dens est. $n.m^{-2}$**
Salmon fry	161	82	30	273	301	282 - 320	1.70	1.87
Salmon parr	32	13	3	48	50	48 - 54	0.30	0.31
Trout fry			0	0			0	
Trout parr			4	4			0.02	

Sheriff's: presence of non-salmonid species		
Eel	Stickleback	



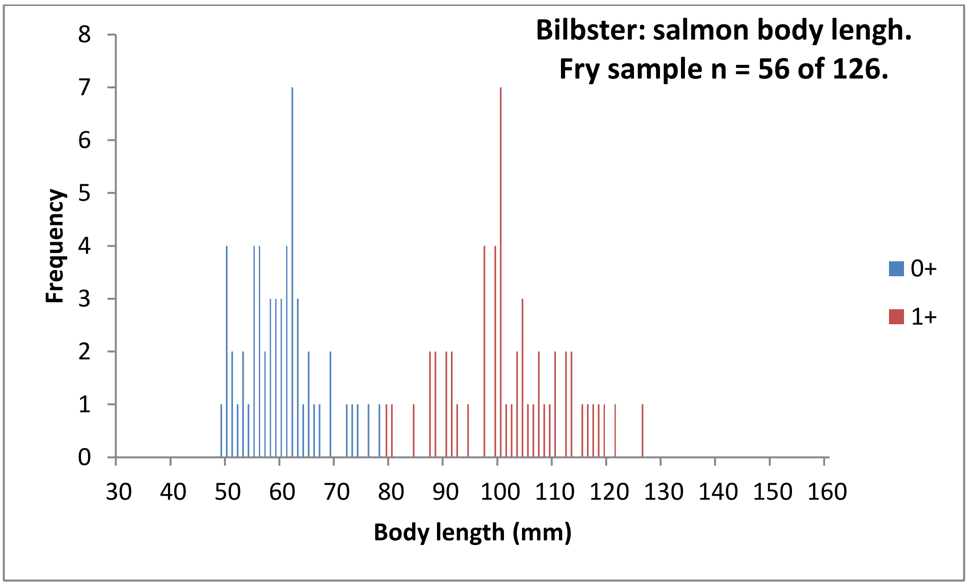
13. Bilbster, Wick River



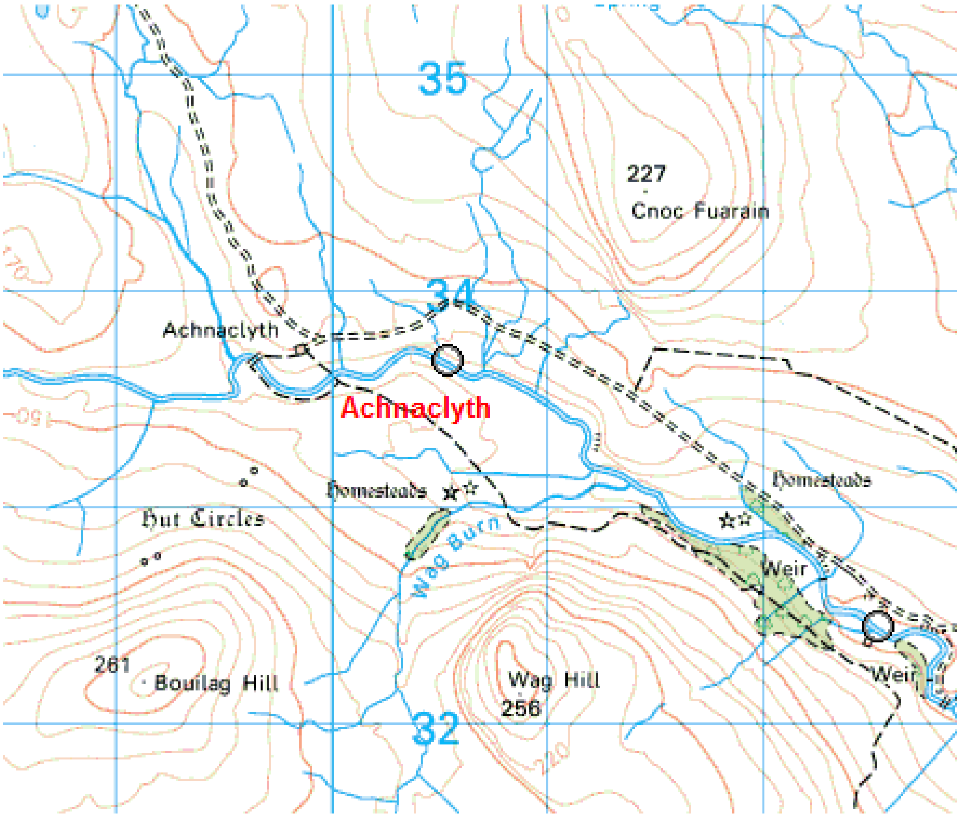
Bilbster: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
26.0	8.0	210	380

Bilbster: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	79	26	21	126	141	126 - 155	0.60	0.67
Salmon parr	47	6	1	54	54	54 - 55	0.26	0.26
Trout fry	0							
Trout parr	7			7			0.03	

Bilbster: presence of non-salmonid species			
Eel	Stickleback	Flounder	Lamprey (*Lampetra* sp.)



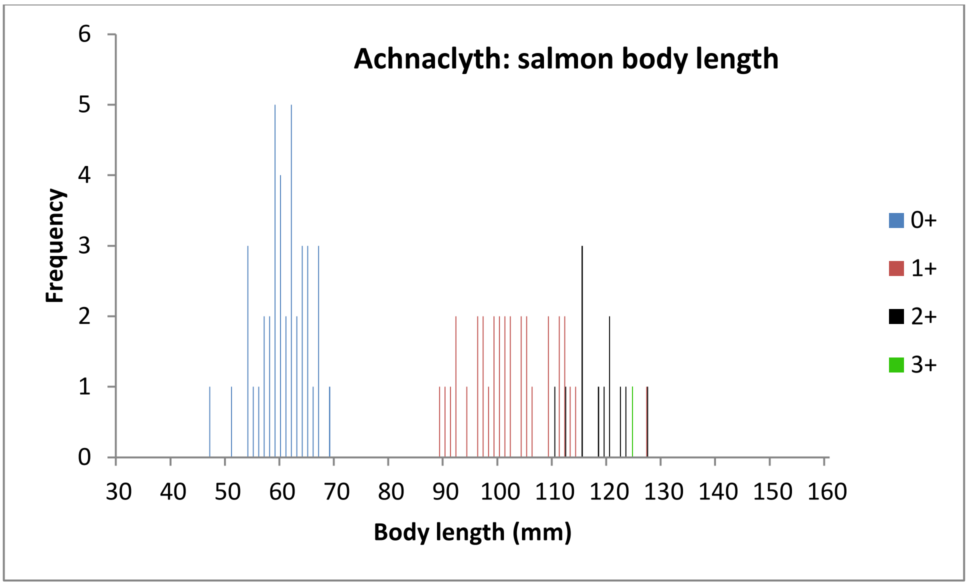
14. Achnaclyth, Dunbeath Water



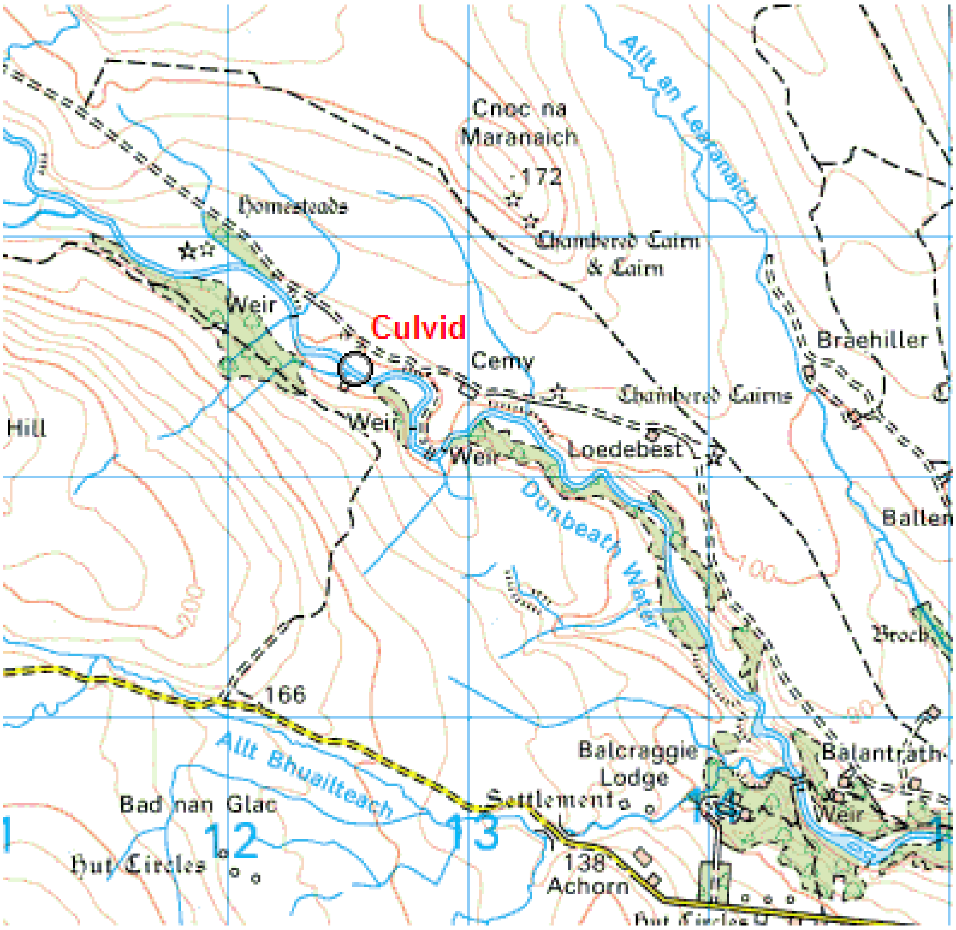
Achaclyth: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
12.3	10.0	123	135

Achnaclyth: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	33	4	3	40	40	40 - 42	0.33	0.33
Salmon parr	33	11	2	46	47	46 50	0.37	0.38
Trout fry			0	0			0	
Trout parr			1	1			0.01	

Achnaclyth: presence of non-salmonid species
None



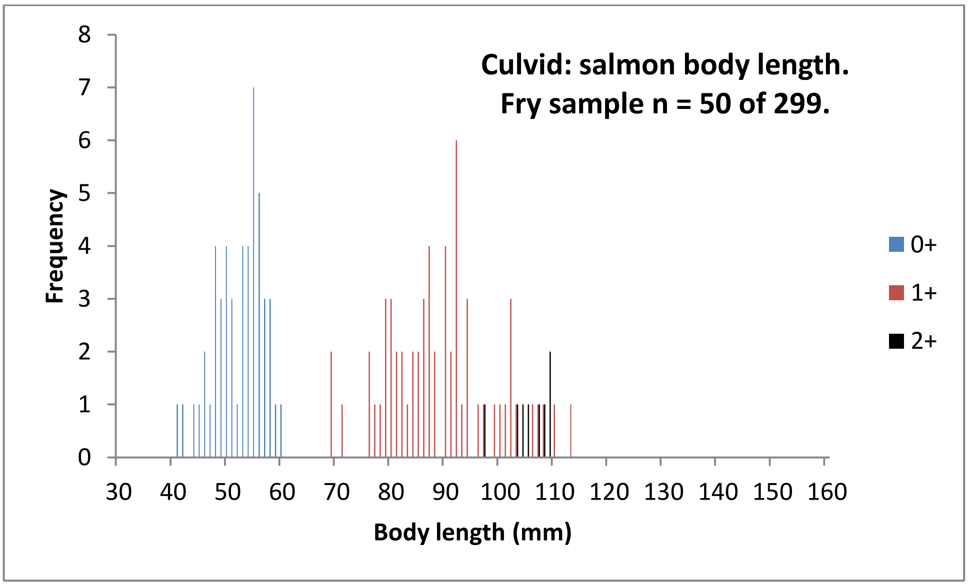
15. Culvid, Dunbeath Water



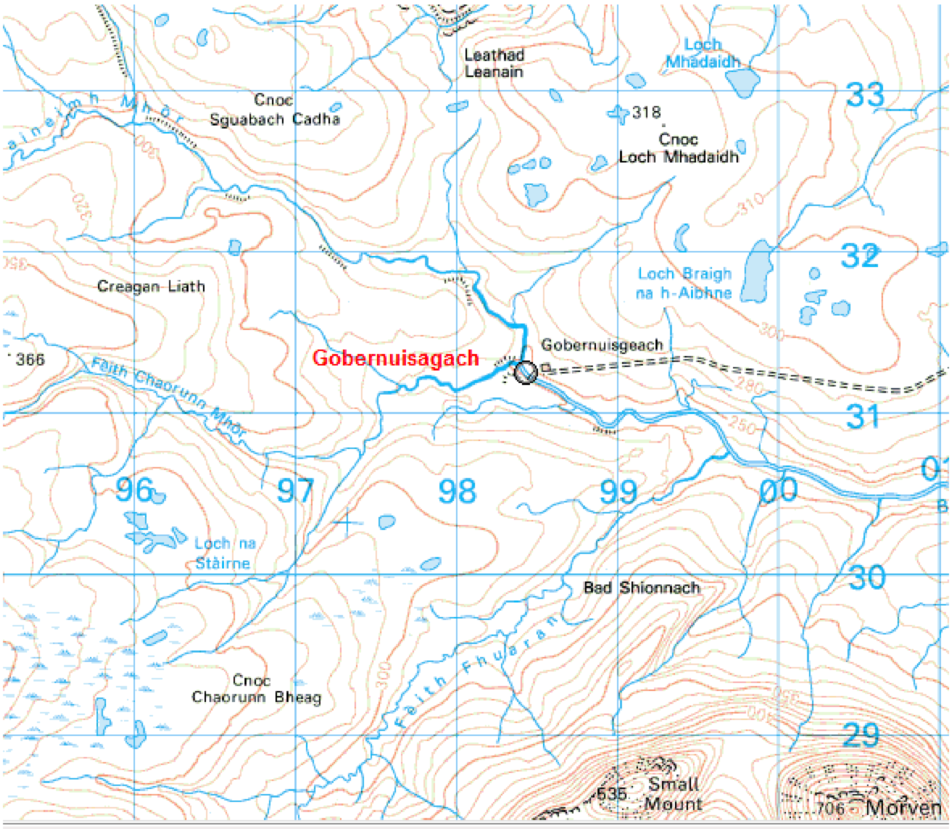
Culvid: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
16.7	13.3	223	270

Culvid: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. n/ m^2	Dens est. n/ m^2
Salmon fry	205	70	24	299	311	302 -321	1.34	1.39
Salmon parr	61	6	2	69	69	69 - 70	0.31	0.31
Trout fry			0	0			0	
Trout parr			4	4			0.02	

Culvid: presence of non-salmonid species	
Eel	



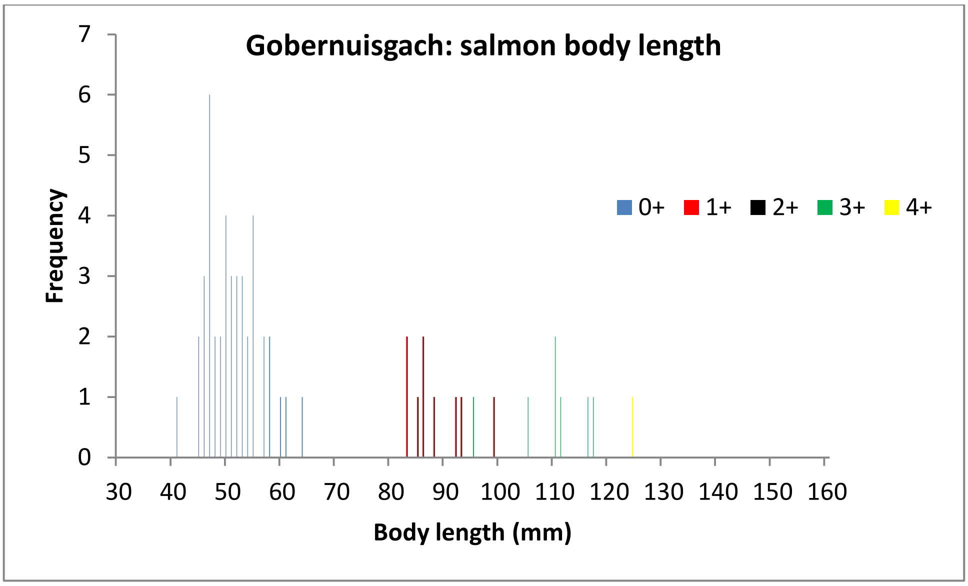
16. Gobernuisgach, Berriedale Water



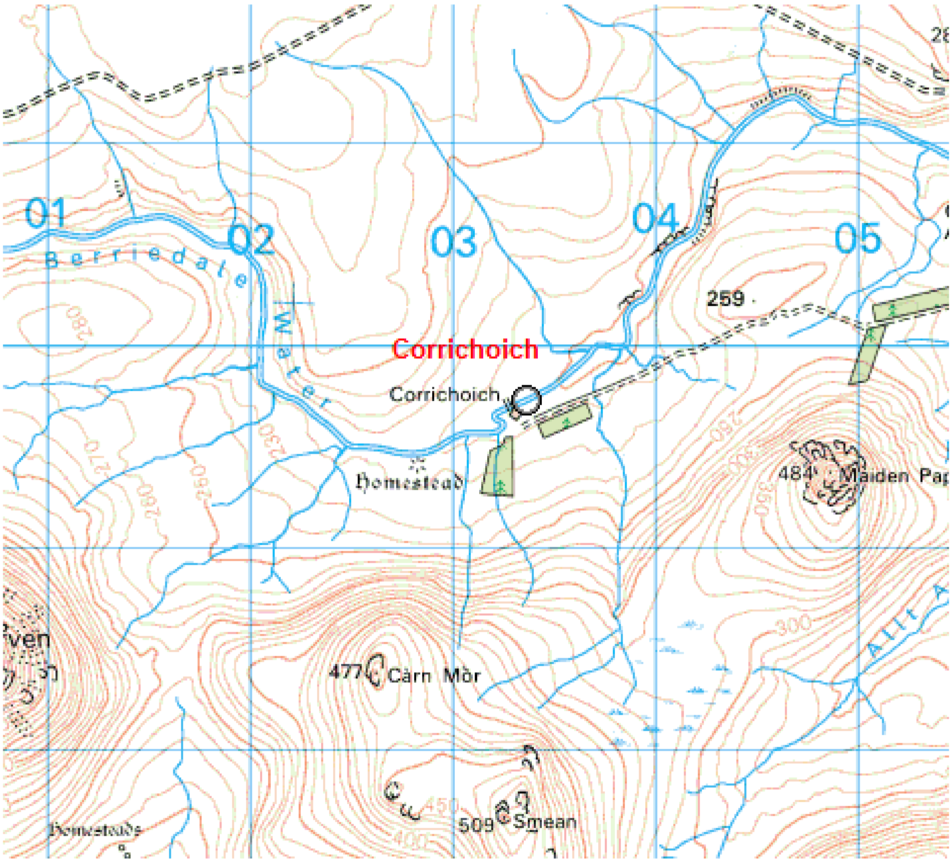
Gobernuisgach: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
13.8	12.5	173	173

Gobernuisgach: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	31	9	2	42	43	42 - 45	0.24	0.25
Salmon parr	22	4	1	27	27	27 - 28	0.16	0.16
Trout fry	7	1	0	8	8	8 - 8	0.05	0.05
Trout parr	15	5	0	20	20	20 - 21	0.12	0.12

Gobernuisgach: presence of non-salmonid species	
none	



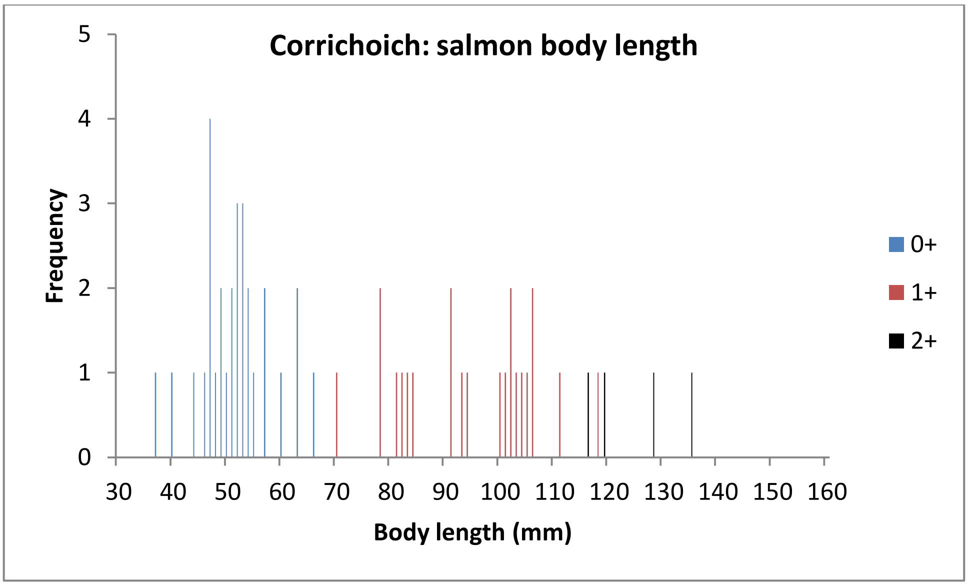
17. Corrichoich, Berriedale Water



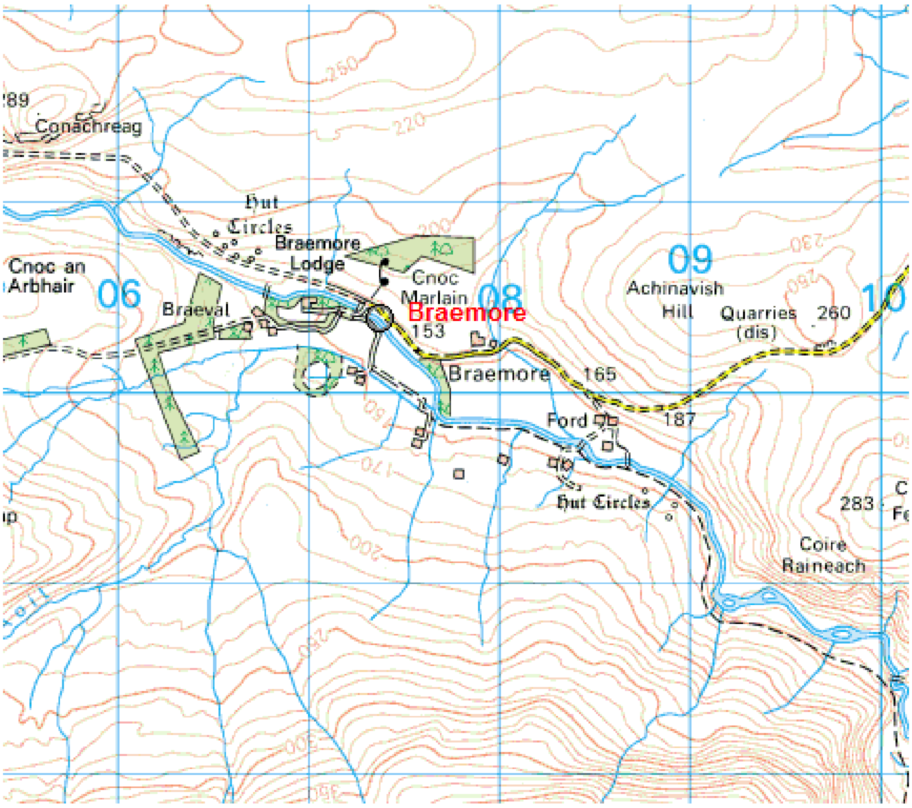
Corrichoich: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
12.5	10.6	130	130

Corrichoich: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. n/ m^2**	**Dens est. n/ m^2**
Salmon fry	19	6	4	29	31	29 - 36	0.22	0.24
Salmon parr	24	2	1	27	27	27 - 28	0.21	0.21
Trout fry			0	0			0	
Trout parr			3	3			0.02	

Corrichoich: presence of non-salmonid species	
Eel	



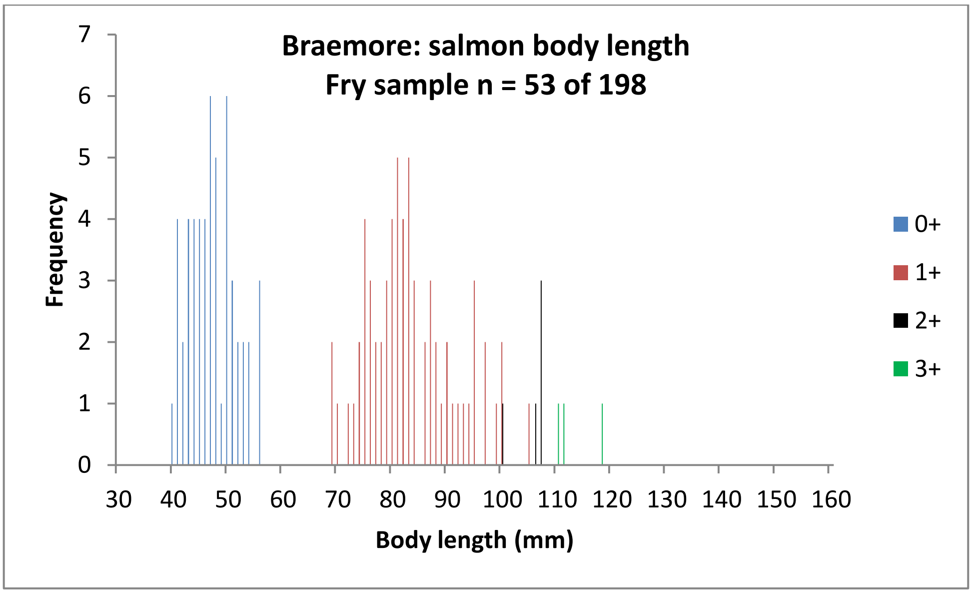
18. Braemore, Berriedale Water



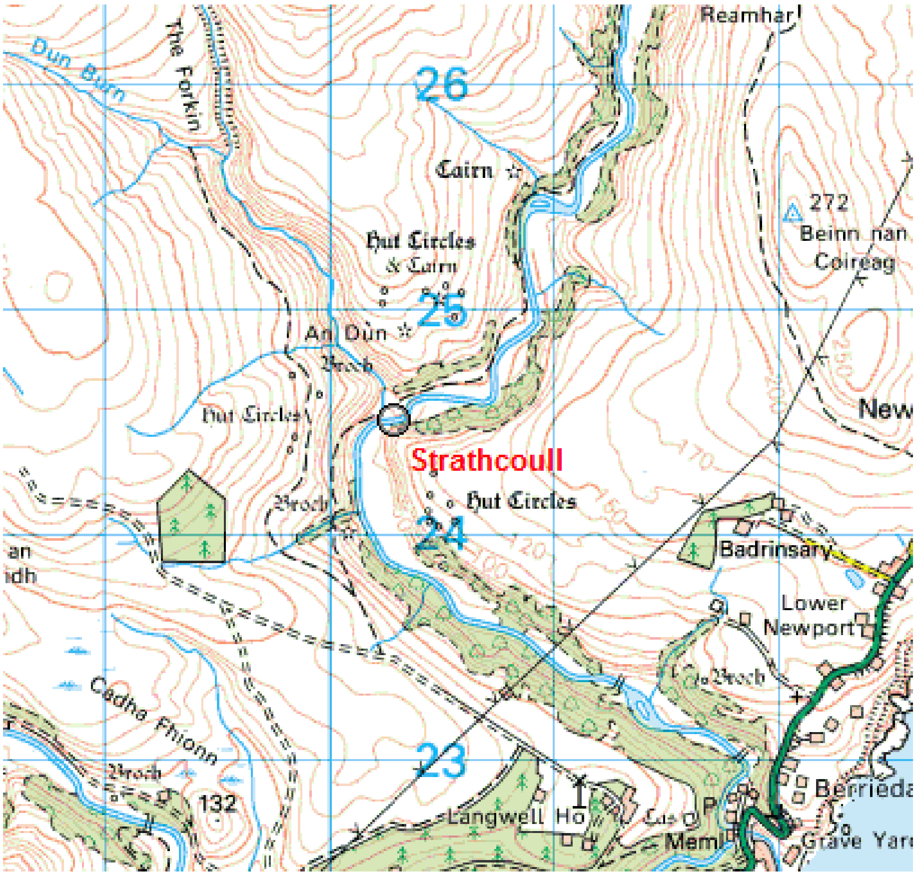
Braemore: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
13.8	12.5	173	173

Braemore: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	133	40	25	198	211	200 - 222	1.14	1.22
Salmon parr	54	13	6	73	75	73 - 79	0.42	0.43
Trout fry			0	0			0	
Trout parr			4	4			0.02	

Braemore: presence of non-salmonid species	
Eel	



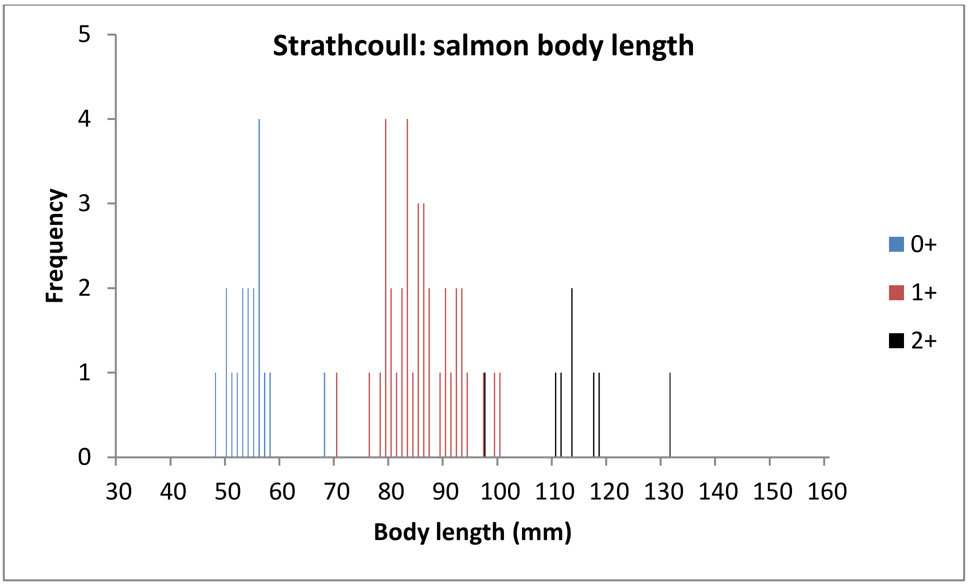
19. Strathcoull, Berriedale Water



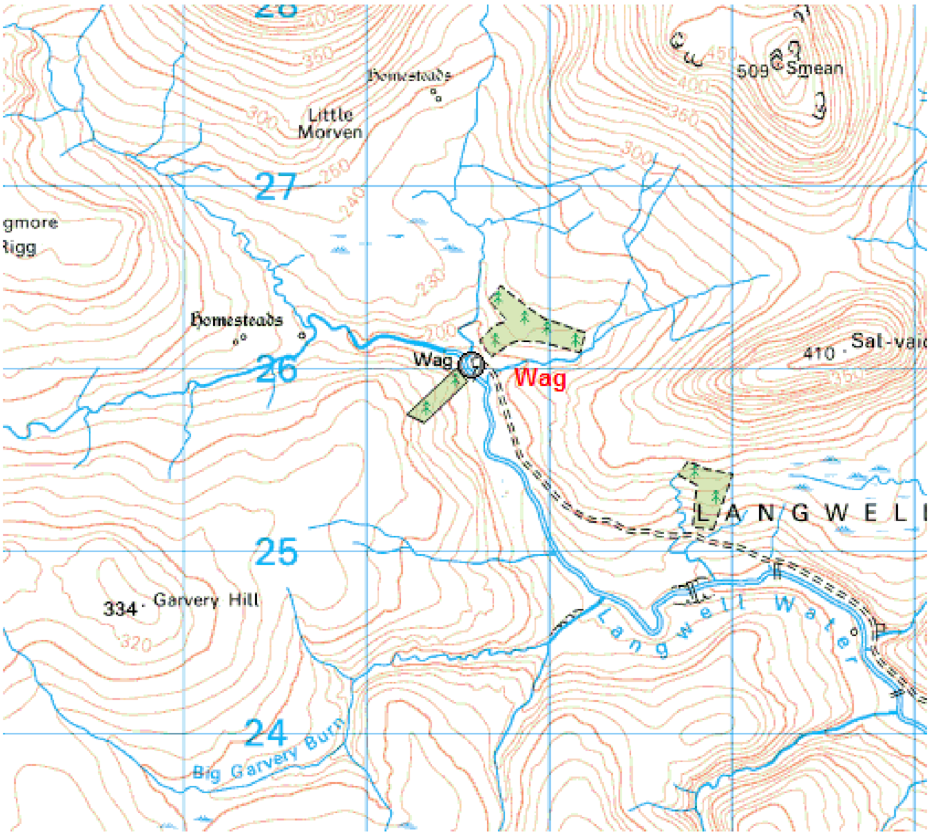

Strathcoull: site dimensions			
Section left bank (m)	Mean channel wet width (m)	Wetted area (m^2)	Streambed area (m^2)
11.8	8.9	105	137

Strathcoull: fish census values								
	E/F Pass							
	1 n	2 n	3 n	Total obs. n	Total est. n	95% conf interval	Dens obs. $n.m^{-2}$	Dens est. $n.m^{-2}$
Salmon fry	9	7	2	18	21	18 - 30	0.17	0.20
Salmon parr	30	11	4	45	47	45 - 52	0.43	0.45
Trout fry			0	0			0	
Trout parr			0	0			0	

Strathcoull: presence of non-salmonid species	
Eel	



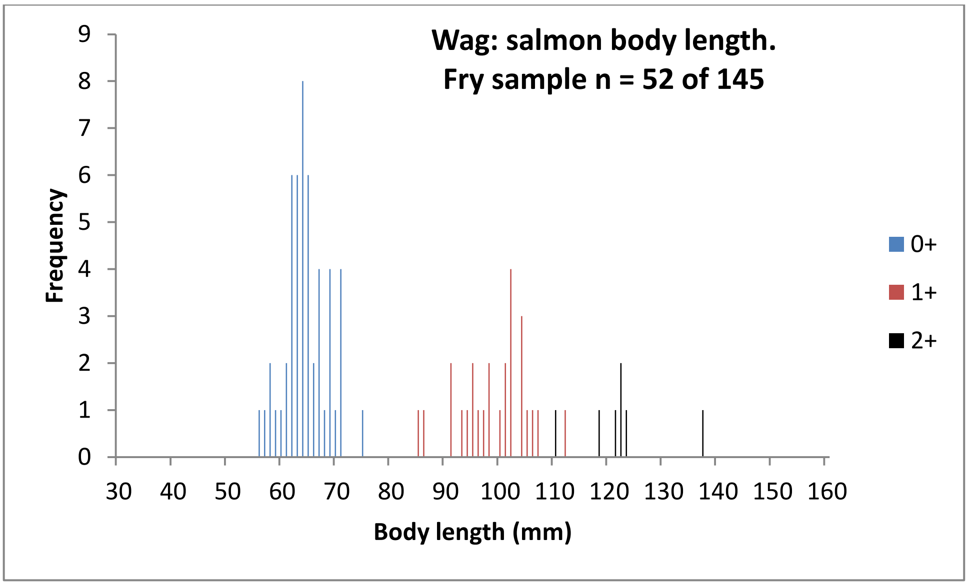
20. Wag, Langwell Water



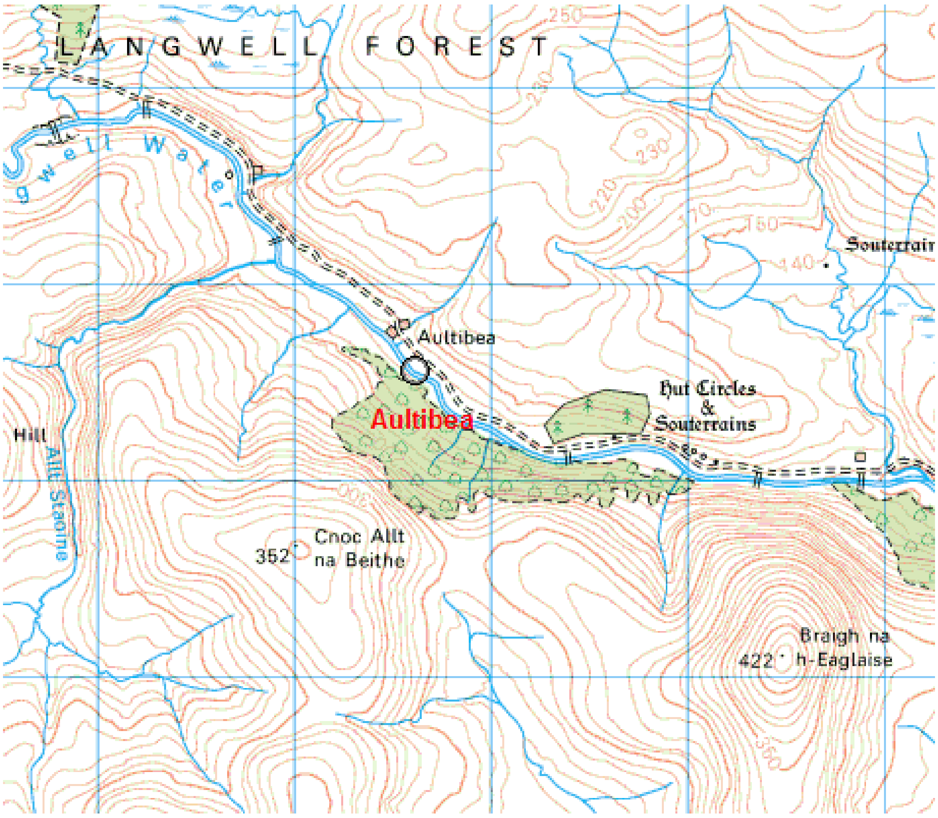
Wag: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
23.3	8.4	195	209

Wag: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. n/ m^2**	**Dens est. n/ m^2**
Salmon fry	108	28	9	145	148	145 - 153	0.74	0.76
Salmon parr	28	7	0	35	35	35 - 36	0.18	0.18
Trout fry			0	0			0	
Trout parr			7	7			0.04	

Wag: presence of non-salmonid species	
Eel	



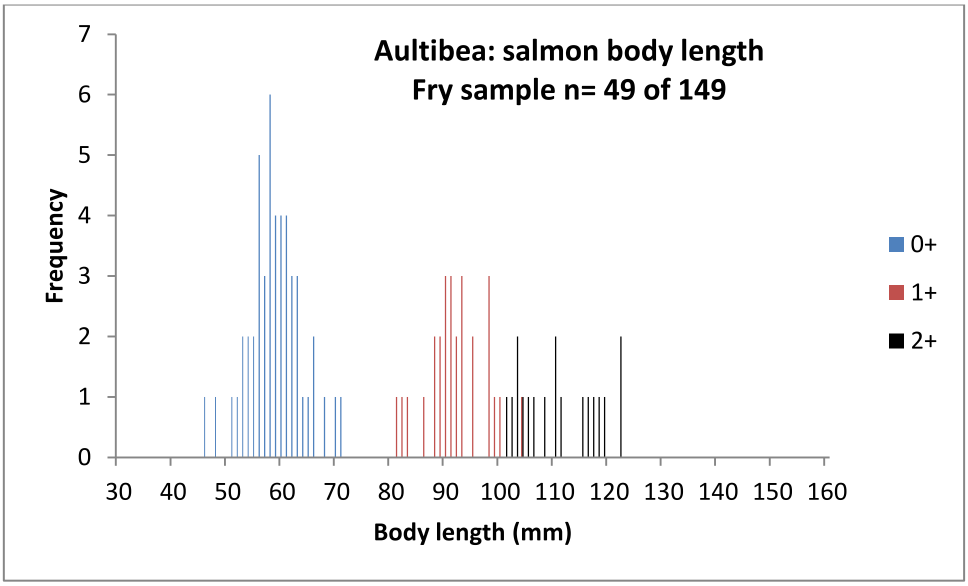
21. Aultibea, Langwell Water



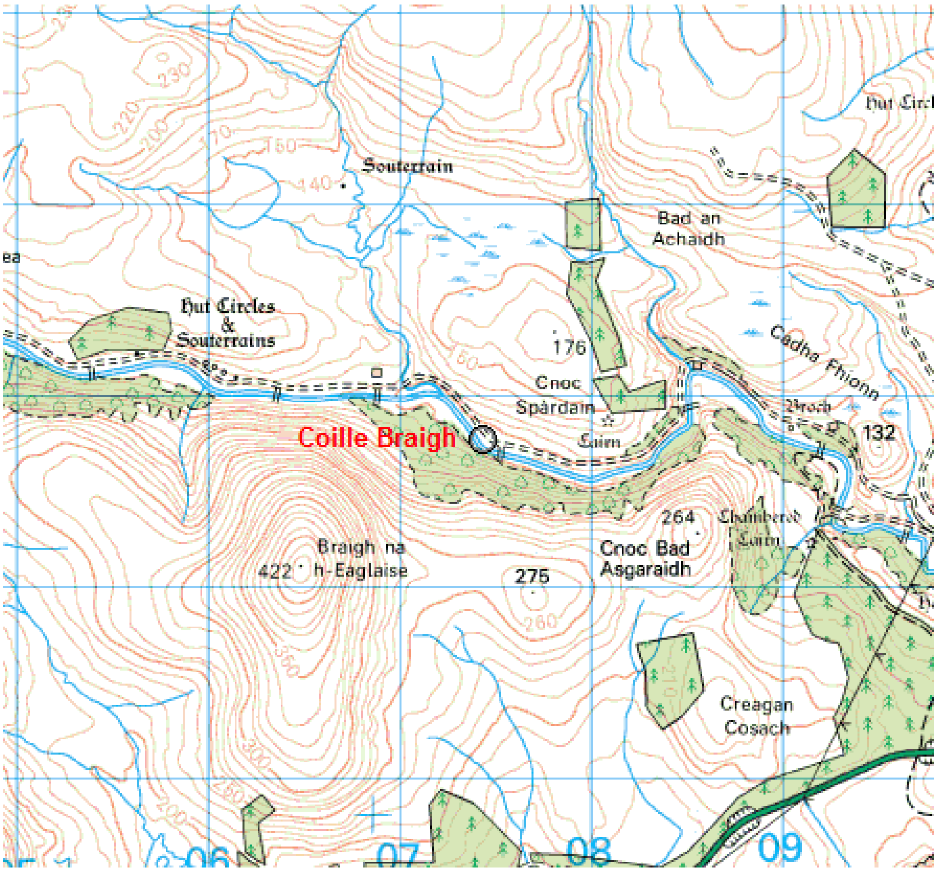
Aultibea: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
16.0	9.3	163	187

Aultibea: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. $n.m^{-2}$**	**Dens est. $n.m^{-2}$**
Salmon fry	101	35	13	149	156	149 - 164	0.91	0.96
Salmon parr	38	6	1	45	45	45 - 46	0.28	0.28
Trout fry			1	1			0.01	
Trout parr			4	4			0.02	

Aultibea: presence of non-salmonid species	
Eel	



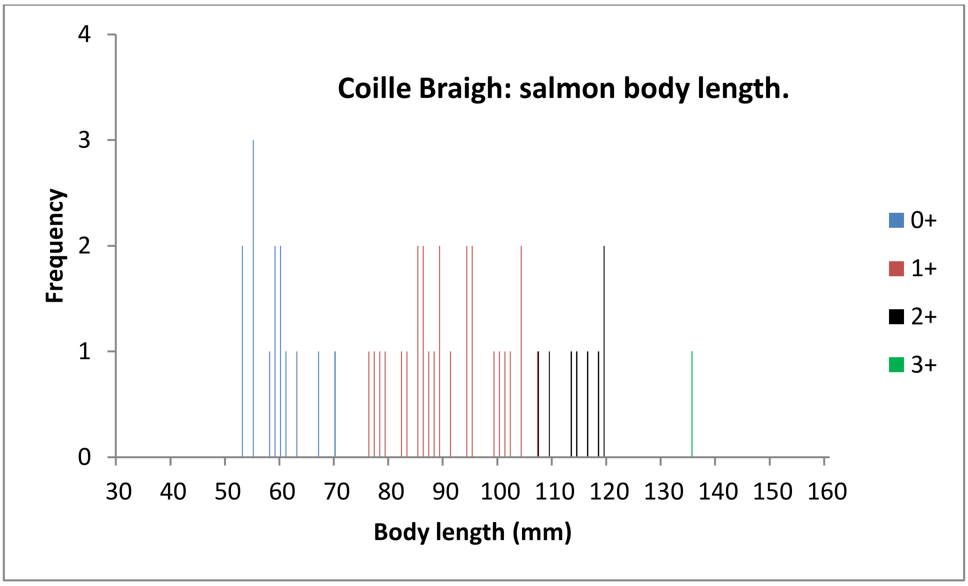
22. Coille Braich, Langwell Water



Coille Braigh: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
12.0	13.4	161	168

Coille Braigh: fish census values								
	E/F Pass							
	1 n	**2 n**	**3 n**	**Total obs. n**	**Total est. n**	**95% conf interval**	**Dens obs. $n.m^{-2}$**	**Dens est. $n.m^{-2}$**
Salmon fry	8	3	1	12	13	12 - 15	0.07	0.08
Salmon parr	23	11	3	37	39	37 - 44	0.23	0.24
Trout fry			0	0			0	
Trout parr			4	4			0.02	

Coille Braigh: presence of non-salmonid species	
Eel	



23. Consideration of fish density in relation to wetted streambed area and estimated total streambed area.

Throughout this report fish density values have been expressed relative to the wetted stream area as measured on the day. The total area of the stream bed was not fully wetted in some sites because the survey was conducted under low water conditions. Total streambed area was therefore also estimated according to the likely position of the edges of the stream under average flow conditions, as judged by eye.

Obtaining accurate estimates of total stream width was particularly problematic where the stream was bounded by gravel. Lateral bars accumulate in times of high rather than average flow and, therefore, their limits cannot be taken to define the normal stream edge. The sites at Dalnagleton, Bilbster, Culvid, Strathcoull and Aultibea posed particular difficulties, as can be judged from the photographs in the relevant appendices. The difficulties could be resolved by re-measuring the sites when stream discharge conditions are considered to be normal and, if necessary, re-calculating the values shown below.

		Estimated true density ($n.m^{-2}$)				
River	**Site name**	**Measured wetted area**		**Estimated total streambed area**		**Wetted area/ total area**
		Fry	**Parr**	**Fry**	**Parr**	
Forss	Cnoc-glas	0.40	0.16	0.39	0.15	0.98
	Shurrery	1.60	0.46	1.60	0.46	1.00
	Lythmore	1.79	0.45	1.79	0.45	1.00
Thurso	Rumsdale	1.13	0.20	1.13	0.20	1.00
	Dalganachan	2.45	0.26	2.20	0.23	0.88
	Dalnagleton	0.94	0.03	0.67	0.02	0.71
	Smerrary	1.45	0.31	1.45	0.31	1.00
	Dalemore	4.01	0.44	3.34	0.37	0.83
	Hoy	1.72	0.18	1.20	0.13	0.70
Wester	Barrock Mill	+	+	+	+	1.00
Wick	The Clow	0.18	0.43	0.15	0.31	0.72
	Sheriff's	1.87	0.31	1.78	0.30	0.95
	Bilbster	0.67	0.26	0.37	0.14	0.55
Dunbeath	Achnaclyth	0.33	0.38	0.30	0.35	0.91
	Culvid	1.39	0.31	1.15	0.26	0.83
Berriedale	Gobernuisgach	0.25	0.16	O.25	0.16	1.00
	Corrichoich	0.24	0.21	0.24	0.21	1.00
	Braemore	1.22	0.43	1.22	0.43	1.00
	Strathcoull	0.20	0.45	0.15	0.34	0.76
Langwell	Wag	0.74	0.18	0.69	0.17	0.93
	Aultibea	0.96	0.28	0.84	0.24	0.87
	Coille Braigh	0.08	0.24	0.08	0.23	0.96

+ numbers insufficient to derive value

Table A. Comparison of density values expressed by wetted area or total streambed area.

Table A shows numerical densities for fry and parr expressed relative to the alternative measures of the survey area. For many sites where the stream channel was incised the alternative measures of density have the same value. Where this was not the case, density expressed relative to total streambed area is necessarily less than the value expressed for wetted area.

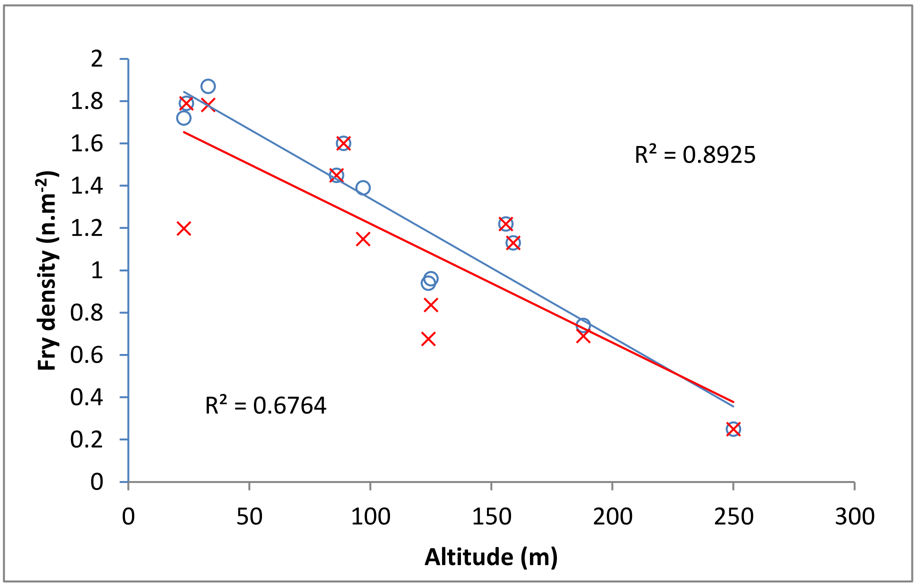


Figure A. The relationships between altitude and fry density for an edited set of sites of "favourable" quality, expressed relative to wetted area (in blue) and total streambed area (in red).

Figure A is in part a re-presentation of Figure 11 of the main text. As per Fig. 11, Fig. A shows the relationship (marked in blue) between altitude and fry density expressed per wetted area. The relationship is for the edited set of "favourable" sites. The corresponding relationship between fry density expressed per total streambed area is also depicted (marked in red). It can be seen that the overall relationships differ only slightly but that the distribution of points is more coherent for wetted area than for total streambed area, suggesting that wetted area is the more informative measure.

In this context, it must be remembered that juvenile salmonids are territorial and, in a well-stocked stream, it is highly unlikely that they passively contract their territories to accommodate displaced competitors when falling water levels make marginal habitat untenable. It is much more likely that they continue to regulate their density. In the main part of this report it was suggested that when marginal habitat contracts at times of low flow, fish temporarily disperse to newly suitable habitat that arises reciprocally elsewhere. If this is the case, measures of wetted area will be more biologically appropriate than measures of total streambed area and, as for Figure A, density values based on wetted area will be the more coherent.