Survey of Juvenile Salmonids in the Rivers of Caithness, 2014.

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Electric-fishing at Aultibea, Langwell Photograph by Tom Milne

Caithness District Salmon Fishery Board

The Crown Estate

Contents

Summary

1. 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 surveyed by electric fishing in September and October, 2014. The site fished at Hoy (Thurso) in 2013 could not be fished in 2014 due to adverse water conditions. A new site at The Fanks (Thurso) was added to the set of sites. Otherwise, repeat sites exactly replicated those of the 2013 survey.

2. The electric fishing methods were the same as those used in 2013. In order to target high quality reference data, three-pass depletion fishing was carried out using a portable Honda generator to supply power to an Electracatch WF7 control box.

3. Trout fry were present only at three sites and then only at low density. Trout parr were more widespread, being present at 16 of the 22 sites but also infrequent where they occurred. Eels were present at 16 sites. Otherwise only stickleback (five sites) and flounder (one site) were identified.

4. Salmon fry and parr were present at all the survey sites.

5. Densities of fry or parr were classified by comparing the density observed on the first pass of the 3-pass fishing with reference values proposed by Godfrey (2005). Fry densities were classed as "excellent/ very good" at 17 sites, "good/ average" at four sites and "low/ poor" at one. Parr densities were classed as "exceptional/ very good" for 10 sites, "good/ average" at nine and "low/ poor" at three. As for 2013, only at Barrock Mill were densities classed as "low/ poor" for both fry and parr.

6. Comparisons of site ratings for 2013 and 2014 showed that most sites were rather similar in both years. Fourteen of 21 sites were within a single category of difference. The most notable exceptions were that fry had been only poorly represented at The Clow, Strathcoull and Coille Braigh in 2013 but were present in "excellent" or "very good" densities in 2014.

7. Only a single 3+ parr (hatched 2011) was identified among all the parr captured. Otherwise, only 1+ and 2+ parr (hatched in 2013 and 2012, respectively) were present with 1+ parr predominant overall. In contrast to 2013, summer checks for the current year were essentially absent from parr scales.

8. For both fry and 1+ parr, there was a high measure of agreement between site ratings based on estimated true density derived from 3-pass fishing compared with those based only on 1st pass values. A notable exception was for 1+ parr at Bilbster which was under-rated on 1st pass fishing.

9. Estimated true density values for fry in 2014 exceeded those for 2013 at 14 sites and were less at four sites indicating a greater general abundance of fry. For 1+ parr the

respective figures were at 10 and seven, indicating that, overall, parr density values were similar in 2013 and 2014.

10. For fry, the median value for density across all survey sites was 0.95/ m^{-2} in 2013 and 1.34/ m^{-2} in 2014 – making the 2014 median value the greater by about 40%. For 1+ parr the median values across all survey sites were similar at 0.28/ m^{-2} in 2013 and 0.30/ m^{-2} in 2014.

11. Fry were more evenly spread among sites in 2014 than in 2013 with fewer low density values. For 1+ parr, the range of density values was greater in 2014 than for 2013. In particular, three sites (Shurrery, Lythmore and The Clow) showed particularly high values (> 0.50/ m^{-2}) for parr in 2014.

12. Salmon populations in the Caithness rivers were in a favourable condition overall. The age-structure of the parr population was rather simple because the majority of the parr were aged only 1+. However, the smaller size of the 2014 fry is likely to result in more balanced parr populations in future years, spreading both risk and advantage over a greater number of years

13. As in 2013, Barrock Mill was grossly deficient in both fry and parr.

14. The approach developed in 2013 for incorporating body size into density measurements (ie. biomass density) for fry or 1+ parr was repeated.

15. Fry were smaller in 2014 than in 2013 at most sites.

16. As for 2013, there was a strong relationship between altitude and the density of fry. The Clow was a notable high density outlier. The relationship between altitude and biomass density was also strong. The Clow conformed better to the relationship for biomass density, rather than numerical density, because the fry were extremely small. These findings suggest that fry were at, or near, saturation density at The Clow.

17. Information from the 2013 and 2014 surveys was combined. For each site the higher value for biomass density of fry was selected as being closer to the potential maximum productive capacity of the site. This approach reduces the effect of the randomness that affects the presence of fry at particular sites in particular years because of patchiness in spawning patterns.

18. For fry, the relationship between altitude and the greater site values for biomass density was good and it explained around 70% of the observed variation.

19. The altitude v biomass density relationship was used to generate an expected value for fry biomass density for each site given its altitude. On this basis, observed minus expected values for both survey years showed that Lythmore was the most productive site, capable of generating around 1g/ m^{-2} (ca. 25%) greater biomass of fry than expected in 2013. Barrock

Mill was rated lowest, generating only about 25% of the expected biomass value with a shortfall of 3.2 $g.m^{-2}$, even in its better year (2014).

20. Mean values for 1+ parr length were variable among sites but there was no relationship between length and altitude and no consistent patterns were evident in comparisons of length values for 2013 and 2014.

21. No relationship was evident between altitude and the densities of 1+ parr or between altitude and the biomass densities of 1+ parr. The Clow, which showed an extreme value for 1+ density, conformed closely to the average biomass density value for all sites because the 1+ parr were relatively small, indicating that 1+ parr at The Clow were at, or near, saturation densities.

22. For 1+ parr, the relationship between altitude and the greater value for biomass density for 2013 or 2014 was moderate.

23. Based on this relationship, Lythmore was rated highest among sites, producing around 4 $g.m^{-2}$ greater biomass of 1+ parr than expected in its better year (2014). Barrock Mill was ranked lowest, under-producing by around 5 $g.m^{-2}$ in its better year (2014).

24. In a fisheries management context, ranking sites by observed minus expected biomass density offers a new way of investigating sites by comparing their potential production of fry or 1+ parr biomass with the values that the sites actually achieve.

1. Introduction

This report documents an electric-fishing survey of juvenile salmonids carried out in September and October, 2014. The survey was organised and undertaken by the Caithness District Salmon Fishery Board and jointly financed by the Board and The Crown Estate. The survey of 2014 was a repeat of work undertaken in 2013, as documented in a previous report[1]. The aim of the 2014 work was to consolidate and build on the findings of the previous survey in order to provide the funders with contemporary information on the status of salmonid populations in Caithness. Twenty-one of the 22 sites surveyed in 2013 were again surveyed in 2014 and a new site (The Fanks, River Thurso) was added to the set.

The particular aims of this report are to document the 2014 survey data for future reference, to build on previous work by continuing to examine ways of extracting information from survey data, and to provide an assessment of the status of juvenile salmonids in the Caithness rivers for 2014.

2. Methods

2.1. Site details

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 surveyed (Figure 1).

The previous site at Hoy on the River Thurso could not be electrofished due to adverse water conditions. A site at The Fanks (Figure 1 and Appendix) on the River Thurso was added to the survey set. The Fanks is only 500m above the site at Smerrary which was also surveyed. However, Smerrary, like Hoy, is a mainstem site that is susceptible to being unfishable at relatively modest river heights. The Fanks site differs from Smerrary in being located on a branch in a braided section of the main river and it is therefore likely to be more consistently accessible for any future survey work.

Photographic records and bank measurements obtained in 2013 were used to position the upper and lower stop-nets that defined each survey site and the sites repeated in 2014 therefore exactly replicated those of 2013.

All the fish captured were the result only of natural spawning, with the exceptions of the two sites on the Dunbeath Water (Culvid and Achnaclyth) which, as in 2013, had been trickle-stocked with fry earlier in the year.

[1] http://caithness.dsfb.org.uk/files/2014/05/2013-Survey-of-Juvenile-Salmonids-in-Caithness-Rivers-FINAL.pdf

Figure 1. Map of electric-fishing survey sites.

2.2. Site description

Table 1 shows the survey sites identified by name and Ordnance Survey co-ordinates. Wetted areas derived from site dimensions (length and average breadth) determined on the day were used to calculate fish densities from capture numbers in what follows. Site altitude at each site was derived from a computer-based mapping system.

River	Site name	O.S.	Alt (m)	Date	Temp (C)	Conductivity (µS. cm)	Wetted area (m^2)
Forss	Cnoc-glas	ND 042 523	110	4 Sep	16	68	185
	Shurrery	ND 039 578	89	19 Sep	16	71	94
	Lythmore	ND 047 663	24	19 Sep	16	162	176
Thurso	Rumsdale	NC 988 408	159	1 Sep	12	56	174
	Dalganachan	ND 006 391	147	1 Sep	13	61	156
	Dalnagleton	ND 052 424	124	2 Sep	15	66	254
	The Fanks	ND 120 478	91	20 Sep	16	71	140
	Smerrary	ND 123 482	86	3 Oct	11	85	164
	Dalemore	ND 144 491	70	2 Sep	14	62	243
Wester	Barrock Mill	ND 296 626	11	4 Sep	17	333	173
Wick	The Clow	ND 233 524	35	3 Sep	14	231	165
	Sheriff's	ND 255 525	33	3 Sep	16	166	176
	Bilbster	ND 281 538	9	6 Sep	15	296	351
Dunbeath	Achnaclyth	ND 105 337	120	5 Sep	17	90	130
	Culvid	ND 123 325	97	5 Sep	16	96	218
Berriedale	Gobernuisgach	NC 984 312	250	12 Sep	14	78	157
	Corrichoich	ND 034 297	200	12 Sep	18	86	130
	Braemore	ND 074 304	156	11 Sep	17	84	175
	Strathcoull	ND 103 245	38	13 Sep	14	99	110
Langwell	Wag	ND 016 260	188	10 Sep	14	93	202
	Aultibea	ND 046 236	125	10 Sep	-	-	170
	Coille Braigh	ND 074 228	93	11 Sep	16	102	163

Table 1. Electric-fishing survey sites.

2.3. Electric-fishing

The electric-fishing methods used were generally those of the Scottish Fisheries Coordination Centre (SFCC) protocol[2] and were identical to those used in 2013. In short, in order to target the acquisition of high quality reference data, three-pass depletion fishing was carried out using a portable Honda generator to supply power to an Electracatch WF7 control box. The three fishings were carried out over a period of about three hours and the fish captured on each electric fishing pass were recorded and documented separately.

The site at Dalganachan was fished four times to compensate for an equipment malfunction on the first fishing pass which resulted in reduced capture efficiency. The 4-pass data were

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

used to reconstruct the likely values for 3-pass fishing at constant efficiency knowing the total number of fish captured and the capture efficiency on runs two to four.

Fork length 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. On completion of the site survey all the fish were returned to the stream where they had been obtained.

Scale samples were obtained from parr for age determination. Scales were also obtained from some fry when these were sufficiently large to place visual classification in doubt. Based on scale reading, the few fry included among the fish from which scales were sampled were subsequently re-assigned to their correct age group.

The presence of trout and non-salmonid species was recorded.

2.4. Data analyses

At each site the total number of fish captured was used to calculate observed density per unit wetted area of stream. 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 the true total number for fry, parr and 1+ parr only. Values were computed using the program *Removal Sampling II* [3]. Estimates of true total number support comparisons among sites by compensating for variation in capture efficiency. Estimated total number was used to calculate true density per unit wetted area of stream in order to compare sites.

Biomass and biomass density were derived by transforming body length measurements to estimates of body mass using the relationship derived by Shackley and cited by Godfrey (2005).

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

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 as in the present case. Table 4 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 classification scheme as per Table 22 of the 2005 report and this has been modified, expanded and colour-coded as per Table 4.

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

3. Results

3.1. Trout and other species

River	Site name	Density of trout ($n.m^{-2}$)		
		Fry	Parr	Other species
Forss	Cnoc-glas	0.03	-	stickleback
	Shurrery	-	-	eel
	Lythmore	0.01	0.02	eel
Thurso	Rumsdale	-	0.05	-
	Dalganachan	-	-	eel
	Dalnagleton	-	-	stickleback
	The Fanks	-	+	eel
	Smerrary	-	0.02	eel
	Dalemore	-	-	eel, stickleback
Wester	Barrock Mill	0.05	0.01	eel
Wick	The Clow	-	-	eel, stickleback
	Sheriff's	-	0.06	eel
	Bilbster	-	0.02	eel, stickleback, flounder
Dunbeath	Achnaclyth	-	0.04	eel
	Culvid	-	0.04	eel
Berriedale	Gobernuisgach	-	0.07	-
	Corrichoich	-	0.05	-
	Braemore	-	+	-
	Strathcoull	-	0.02	eel
Langwell	Wag	-	0.08	eel
	Aultibea	-	0.07	eel
	Coille Braigh	-	0.04	eel

Table 2. Presence of trout and non-salmonid species.

Trout fry were present at only at three sites and then only at low density. Trout parr were more widespread, being present at 16 of the 22 sites but also infrequent where they occurred. Eels were present at most of the survey sites. Otherwise only stickleback (five sites) and flounder (one site) were identified.

3.2. Numbers of salmon

3.2.1. Assessment of sites based on 1st pass of 3-pass fishing

Table 2 shows the primary electric fishing data for salmon fry and parr, being the total number of each class captured on each of the three electric fishing passes.

River	Site name	Fry			Parr		
		1st pass	2nd pass	3rd pass	1st pass	2nd pass	3rd pass
Forss	Cnoc-glas	137	45	21	16	6	4
	Shurrery	98	32	15	38	12	3
	Lythmore	434	99	32	87	47	14
Thurso	Rumsdale	111	49	34	36	15	3
	Dalganachan	56	29	13	30	8	3
	Dalnagleton	53	42	28	2	1	2
	The Fanks	162	61	19	14	7	2
	Smerrary	178	66	23	30	4	1
	Dalemore	214	73	23	29	9	3
Wester	Barrock Mill	14	4	3	2	0	0
Wick	The Clow	272	128	63	43	22	15
	Sheriff's	167	65	35	26	9	3
	Bilbster	221	98	47	18	14	11
Dunbeath	Achnaclyth	122	28	12	30	4	1
	Culvid	136	60	29	55	15	7
Berriedale	Gobernuisgach	30	12	4	14	1	0
	Corrichoich	36	18	2	34	6	2
	Braemore	127	50	21	38	13	5
	Strathcoull	58	24	6	20	4	1
Langwell	Wag	40	25	8	42	11	2
	Aultibea	164	42	20	42	12	3
	Coille Braigh	142	36	13	25	9	5

Table 3. Numbers of salmon fry and parr captured at each site for each pass of 3-pass electric-fishing.

Godfrey's procedure considers only single-pass fishing and, in order to match this structure, comparisons were made 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 fry or parr (Table 4). 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
Fry	0.05	0.13	0.28	0.33	0.67	
Parr	0.04	0.07	0.13	0.19	0.28	

Table 4. Critical percentile values for classification of observed density (n.m^{-2}) of salmon fry or parr based on single-pass fishing (Godfrey, 2005).

Table 5 provides an evaluation of salmon fry and parr densities at all the survey sites using the colour codings given in Table 5.

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

Table 5. Semi-quantitative evaluation of survey sites based on comparison with data presented by Godfrey (2005).

Of the 22 comparisons of fry densities, 17 were classed as "excellent/ very good", four as "good/ average" and one as "low/ poor". Parr densities were classed as "exceptional/ very good" for 10 sites, "good/ average" at nine and "low/ poor" at three. Only at one site (Barrock Mill) were observed densities classed as "low/ poor" for both fry and parr. The preponderance of high values, especially for fry, may reflect real increases in density since Godfrey's report, as year effects or trends. Alternatively, the high values reported here may

be due to differences in the methodology used to obtain the data sourced for Godfrey's report.

Four of the 44 comparisons were rated "low" or "poor" – fry at Barrock Mill and parr at Dalnagleton, Barrock Mill and Bilbster. 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 further considered later in the report.

3.2.2. Comparisons of sites replicated in 2013 and 2014.

River	Site	Salmon			
		Fry		Parr	
		2013	2014	2013	2014
Forss	Cnoc-glas				
	Shurrery				
	Lythmore				
Thurso	Rumsdale				
	Dalganachan				
	Dalnagleton				
	The Fanks				
	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. Comparisons of fry and parr densities at survey sites replicated in 2013 and 2014, Colour codings as per Table 5.

Table 6 is again based on the classifications proposed by Godfrey (2005). Comparisons of 2013 and 2014 values show that 14 of the 22 sites are within a single quintile category indicating a substantial level of overall coherence between years. The main exceptions were that fry had been only poorly represented at The Clow, Strathcoull and Coille Braigh in 2013 but were present in "excellent" or "very good" densities in 2014. In addition, parr were

represented at distinctly lower densities at Dalemore and Bilbster in 2014 than in 2013. Both fry and parr were poorly represented at Barrock Mill in both survey years.

3.2.3. Observed densities for 3-pass fishing and estimated true densities

Table 7 shows the observed densities of salmon fry and parr derived from 3-pass fishing and a breakdown of the captured parr by age-class.

River	Site name	Observed Density (n.m^{-2}) and year of hatch				
		0+ fry (2014)	1+ parr (2013)	2+ parr (2012)	3+ parr (2011)	All parr
Forss	Cnoc-glas	1.10	0.14	-	-	0.14
	Shurrery	1.54	0.54	0.02	-	0.56
	Lythmore	3.21	0.83	0.01	-	0.84
Thurso	Rumsdale	1.11	0.31	-	-	0.31
	Dalganachan	0.63	0.24	0.02	-	0.26
	Dalnagleton	0.48	0.02	-	-	0.02
	The Fanks	1.74	0.16	-	-	0.16
	Smerrary	1.63	0.21	-	-	0.21
	Dalemore	1.28	0.14	0.02	-	0.17
Wester	Barrock Mill	0.12	0.01	-	-	0.01
Wick	The Clow	2.81	0.48	0.01	-	0.48
	Sheriff's	1.51	0.22	-	-	0.22
	Bilbster	1.04	0.12	0.00	-	0.12
Dunbeath	Achnaclyth	1.25	0.26	0.01	-	0.27
	Culvid	1.03	0.31	0.05	-	0.35
Berriedale	Gobernuisgach	0.29	0.06	0.03	-	0.10
	Corrichoich	0.43	0.26	0.05	0.01	0.32
	Braemore	1.13	0.25	0.07	-	0.32
	Strathcoull	0.80	0.12	0.11	-	0.23
Langwell	Wag	0.36	0.25	0.02	-	0.27
	Aultibea	1.33	0.28	0.05	-	0.34
	Coille Braigh	1.17	0.17	0.07	-	0.24

Table 7. Observed density of salmon fry and parr from 3-pass fishing.

The age structure of parr varied among sites. A single 3+ parr (hatched 2011) was identified at Corrichoich. Otherwise, only 1+ and 2+ parr (hatched in 2013 and 2012, respectively) were present with 1+ predominant overall. Again, the lowest values for both fry and parr were observed at Barrock Mill, the only survey site on the River Wester.

In contrast to 2013, summer checks in the current year were essentially absent on the scales of the parr.

River	Site name	Estimated true density ($n.m^{-2}$)	
		Fry	Parr
Forss	Cnoc-glas	1.15	0.16
	Shurrery	1.63	0.57
	Lythmore	3.26	0.91
Thurso	Rumsdale	1.31	0.32
	Dalganachan	0.71	0.27
	Dalnagleton	0.80	0.02
	The Fanks	1.80	0.19
	Smerrary	1.71	0.21
	Dalemore	1.33	0.15
Wester	Barrock Mill	0.13	0.01
Wick	The Clow	3.15	0.60
	Sheriff's	1.66	0.23
	Bilbster	1.15	0.23
Dunbeath	Achnaclyth	1.26	0.28
	Culvid	1.14	0.37
Berriedale	Gobernuisgach	0.31	0.10
	Corrichoich	0.45	0.32
	Braemore	1.21	0.34
	Strathcoull	0.83	0.24
Langwell	Wag	0.41	0.28
	Aultibea	1.37	0.34
	Coille Braigh	1.45	0.26

Table 8. Estimated true density of salmon fry and parr.

Observed density values for fry and parr were transformed by Zippin correction to values for estimated true density - the most accurate values than can be derived from the primary data set. The values are shown in Table 8.

All the colour-coded comparisons made so far have used the density of fish observed only on the first pass of the 3-pass electric fishing protocol deployed – as is required by Godfrey's procedure for classifying sites. Tables 9 and 10 compare values from 1-pass and 3-pass fishing.

In Table 9, all the survey sites are ranked according to values for the estimated true density of fry, repeating the values given in Table 8. The colour-coded site ratings derived from Godfrey's procedure are repeated from Table 5. Physical habitat quality ratings (1 = low, 5 = high) are repeated from the report on the 2013 survey of Caithness rivers and are based on expert opinion.

Site name	Estimated true density of fry (n.m^{-2})	Colour code	Habitat quality
Lythmore	3.26		4
The Clow	3.15		3
The Fanks	1.80		4
Smerrary	1.71		3
Sheriff's	1.66		3
Shurrery	1.63		3
Coille Braigh	1.45		2
Aultibea	1.37		3
Dalemore	1.33		5
Rumsdale	1.31		4
Achnaclyth	1.26		2
Braemore	1.21		4
Bilbster	1.15		3
Cnoc-glas	1.15		2
Culvid	1.14		3
Strathcoull	0.83		1
Dalnagleton	0.80		3
Dalganachan	0.71		4
Corrichoich	0.45		1
Wag	0.41		4
Gobernuisgach	0.31		3
Barrock Mill	0.13		3

Table 9. Survey sites ranked according to estimated true density of fry. Site ratings for fry based only on 1st pass fishing (as per Godfrey's procedure) and physical habitat quality ratings for fry are also indicated.

A high measure of overall coherence is evident between ratings based on the two measures of fry abundance. There is some correspondence also between these measures and physical habitat ratings although Coille Braigh and Achnaclyth are ranked relatively high according to fry abundance despite being accorded poor habitat quality ratings.

Table 10 repeats these comparisons for parr. Again, there is a high level of overall coherence between ratings based on 1st pass or 3-pass electric fishing. Bilbster, however, is notably anomalous and is under-rated based on 1st-pass fishing only. There is some correspondence between parr density and habitat quality ratings although Corrichoich and Coille Braigh are ranked relatively high by parr density despite being accorded poor habitat quality ratings.

Site name	Estimated true density of parr (n.m^{-2})	Colour code	Habitat quality
Lythmore	0.91		4
The Clow	0.60		3
Shurrery	0.57		4
Culvid	0.37		3
Braemore	0.34		4
Aultibea	0.34		3
Corrichoich	0.32		2
Rumsdale	0.32		3
Achnaclyth	0.28		3
Wag	0.28		3
Dalganachan	0.27		4
Coille Braigh	0.26		2
Strathcoull	0.24		3
Sheriff's	0.23		4
Bilbster	0.23		3
Smerrary	0.21		3
The Fanks	0.19		2
Cnoc-glas	0.16		1
Dalemore	0.15		3
Gobernuisgach	0.10		3
Dalnagleton	0.02		1
Barrock Mill	0.01		3

Table 10. Survey sites ranked according to estimated true density of parr. Site ratings for parr based only on 1st pass fishing (as per Godfrey's procedure) and physical habitat quality ratings for parr are also indicated.

3.2.4. Comparisons of sites replicated in 2013 and 2014.

In order to compare estimated true densities for 2013 and 2014, the values for 2014 have been recalculated in Table 11 based on the wetted area of stream measured at each site in 2013. This adjustment is necessary because the wetted area, measured in the standard length of stream surveyed at each site in both years, was commonly greater in 2014 (although by an average of only 4% based on median values). This difference resulted from the generally higher river levels pertaining during the 2014 survey. The 2014 values for Dalnagleton (wetted area +34% on 2013) and Bilbster (wetted area +67%) were particularly affected by conditions. Standardisation of site area between sampling years discounts the effects of minor or short-term changes in the stream's width on the presence of fish. It is important to note that between-years comparison of densities, based on a standard value

for stream area, is exactly equivalent to comparing the numbers of fish that are present in the length of stream defined for each site by the position of the stop nets.

River	Site name	Estimated true density (n.m^{-2}) standardised to 2013 site area			
		Fry		Parr	
		2013	2014	2013	2014
Forss	Cnoc-glas	0.40	**1.22**	0.16	0.17
	Shurrery	**1.60**	**1.70**	0.46	**0.59**
	Lythmore	1.79	**3.21**	0.45	**0.89**
Thurso	Rumsdale	1.13	**1.35**	0.20	**0.33**
	Dalganachan	**2.45**	0.76	0.26	**0.29**
	Dalnagleton	0.94	**1.07**	0.03	0.03
	The Fanks				
	Smerrary	1.45	**1.95**	**0.31**	0.24
	Dalemore	**4.01**	1.48	**0.44**	0.17
	Hoy				
Wester	Barrock Mill	0.03	**0.13**	0.02	0.01
Wick	The Clow	0.18	**4.33**	0.43	**0.83**
	Sheriff's	1.87	1.81	**0.31**	0.25
	Bilbster	0.67	**1.92**	0.26	**0.38**
Dunbeath	Achnaclyth	0.33	**1.33**	**0.38**	0.30
	Culvid	**1.39**	1.11	0.31	**0.36**
Berriedale	Gobernuisgach	0.25	**0.29**	**0.16**	0.10
	Corrichoich	0.24	**0.45**	0.21	**0.32**
	Braemore	1.22	1.22	**0.43**	0.34
	Strathcoull	0.20	**0.87**	**0.45**	0.25
Langwell	Wag	**0.74**	0.42	0.18	**0.29**
	Aultibea	0.96	**1.43**	0.28	**0.35**
	Coille Braigh	0.08	**1.47**	0.24	0.26

Table 11. Values for estimated true densities of fry and parr standardised to 2013 values for wetted stream area.

In Table 11 the greater value for density at each site, either 2013 or 2014, is indicated in bold where the difference was greater than 10%. On this basis, Table 11 shows that fry values for 2014 exceeded those for 2013 at 14 sites and were less at four suggesting a greater general abundance of fry considered over all the Caithness rivers. In the case of parr the corresponding figures were nearer equality at 10 and seven, respectively, suggesting that overall parr values were generally similar in 2013 and 2014.

The distribution of adjusted density values for fry and parr are shown Figures 2 and 3, respectively. For fry, the median value across all survey sites was 0.95/ m^{-2} in 2013 and 1.34/

m^{-2} in 2014 – making the 2014 median value the greater by about 40%. For parr the median values across all survey sites were rather similar at 0.28/ m^{-2} in 2013 and 0.30/ m^{-2} in 2014.

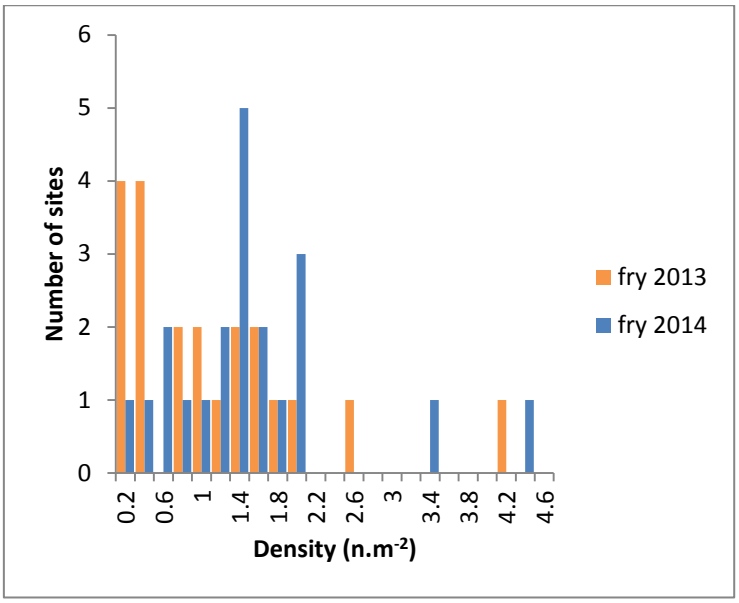

Figure 2. Frequency distribution of sites by density of fry.

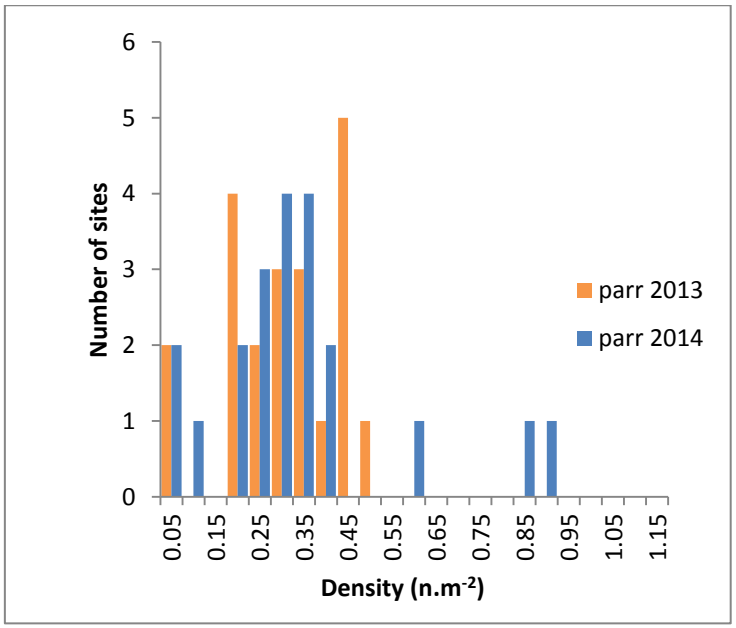

Figure 3. Frequency distribution of sites by density of 1+ parr.

Figures 2 and 3 also show that the distribution of site values differed between years. Fry were more evenly spread in 2014 than in 2013 with fewer low value sites. For parr, the

range of site values was greater in 2014 than for 2013. In particular, three sites (Shurrery, Lythmore and The Clow) showed particularly high values (> 0.50/ m^{-2}) for parr in 2014.

3.3. Performance of salmon

All the assessments given in the sections above are based on density and they are all based on somewhat arbitrary comparisons. Thus, Godfrey's approach compares contemporary fish densities with values previously obtained for sites in similar locations. The comparisons made in Table 11, above, are for single sites for consecutive years and the comparisons made in Tables 9 and 10 compare values between sites in the same year. However, none of these comparisons can measure how any site has performed relative to its potential.

The report on the 2013 survey indicated that it might be possible to provide more informative assessments by considering the density of fish coupled with their growth as reflected in body size. This combined value is expressed as biomass (the product of fish numbers and fish weight) or biomass density (the weight of fish per unit area) – the latter being more useful in practice. Biomass density may be a more accurate measure of the productivity of survey sites than numerical density because reductions in growth (and fish size) occur where the number of fish begins to exceed the stream's capacity to provide sufficient shelter and food. Using measures of biomass density it may be possible to identify at least an approximate value for each site's maximum productive capacity - its carrying capacity. If so, this value would constitute an absolute, rather than a relative, reference point for the assessment of populations. The biomass density approach developed using data obtained in 2013 is extended in what follows using data for 2014.

3.3.1. Body length

Table 12 shows the average length of fry at each survey site. The standard deviation is shown in parentheses as a measure of the spread of the individual values around the average. Average body length varied among sites over the range between 49 and 89mm. By far the highest mean value was for the site at Barrock Mill where fry were present only at low density. The lowest mean value was shared by the high-density site at The Clow and the high-altitude site at Gobernuisgach. Otherwise, no particular pattern was evident.

River	Site name	Mean body length of fry (mm). Standard deviation in parentheses
Forss	Cnoc-glas	49.7 (4.88)
	Shurrery	54.5 (5.94)
	Lythmore	54.6 (6.29)
Thurso	Rumsdale	52.6 (5.29)
	Dalganachan	50.9 (4.41)
	Dalnagleton	50.6 (6.31)
	The Fanks	56.0 (5.62)
	Smerrary	54.0 (6.42)
	Dalemore	54.4 (5.28)
Wester	Barrock Mill	89.3 (10.9)
Wick	The Clow	49.0 (5.01)
	Sheriff's	52.3 (5.04)
	Bilbster	56.3 (7.27)
Dunbeath	Achnaclyth	54.5 (4.56)
	Culvid	50.1 (5.54)
Berriedale	Gobernuisgach	49.0 (5.21)
	Corrichoich	51.9 (4.40)
	Braemore	53.0 (4.20)
	Strathcoull	53.7 (6.56)
Langwell	Wag	63.0 (3.33)
	Aultibea	57.4 (5.21)
	Coille Braigh	53.2 (5.00)

Table 12. The mean body length of fry at each site. The standard deviation is given in parentheses.

Figure 4 ranks the survey sites by altitude and repeats the values given in Table 12 in graphical form (in blue). The corresponding values for fry length in 2013 are also shown (in orange). For most sites it can be seen that fry were commonly smaller in 2014 than in 2013. Both surveys were carried out around the same time of year and the fry were therefore of comparable age. Excepting Barrock Mill where the fish were too few in number for valid comparison, only Dalemore and Braemore showed marked increases in fry size for 2014.

In 2013, Dalemore had been one of two sites picked out as being saturated with relatively small fry and the increase in fry size in 2014 may reflect return to non-saturation levels. Counter to this, Dalganachan was also picked out as being saturated in 2013 but fry sizes were not larger in 2014

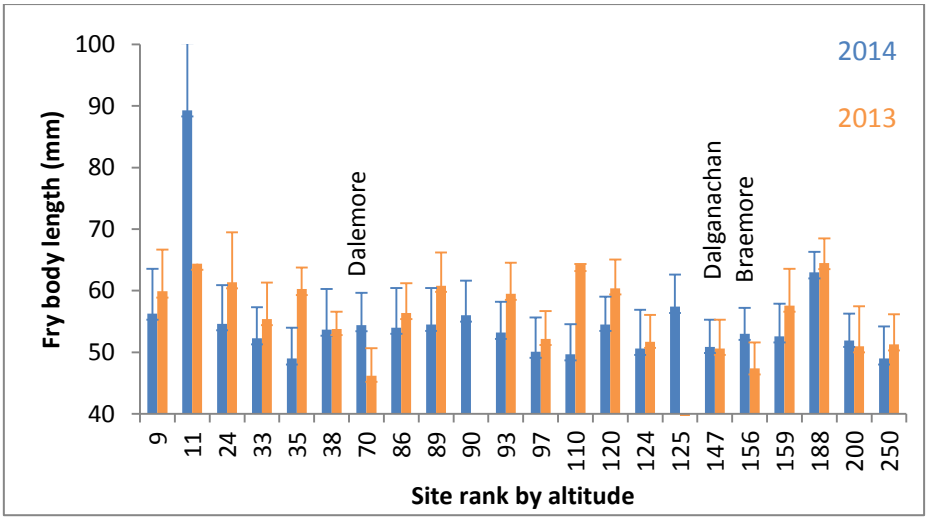

Figure 4. Graphical representation of mean body length of fry in 2014 (blue) and 2013 (orange) for sites ranked by altitude). The standard deviation for each value is indicated by the bar.

despite their now being present at reduced densities. Braemore was the only site picked out in 2013 as being saturated with large numbers of small 1+ parr. The small size of fry at Braemore in 2013 coupled with the rebound raises another type of possibility, namely that fry growth was inhibited in 2013 by the presence of saturation densities of small, 1+ parr. The rebound in fry size in 2014 may reflect a lower level of competition due to the lower density of 1+ parr (see Table 11).

3.3.2. Density v altitude

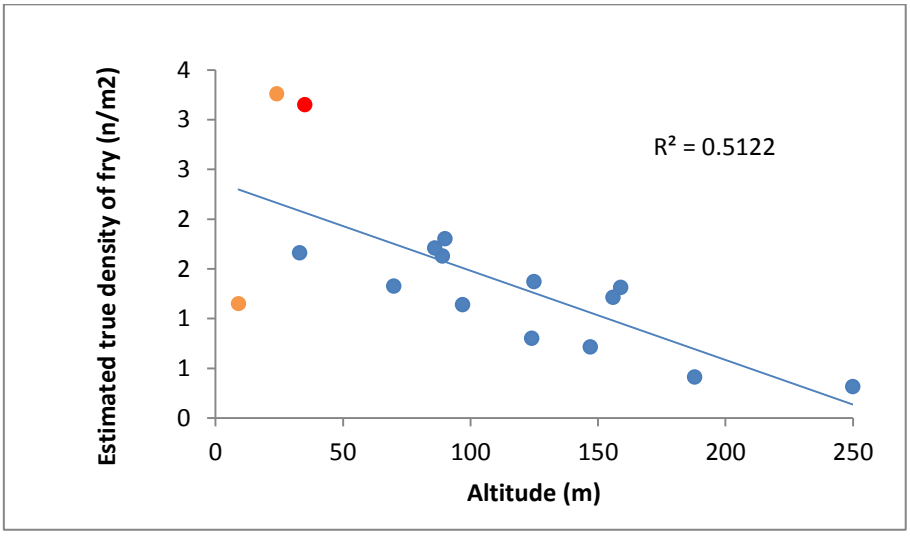

Figure 5. The relationship between site altitude and estimated true density of salmon fry for sites classed as "favourable" habitat for fry. The anomalous site at Barrock Mill has been excluded.

Figure 5 shows fry density plotted against altitude for sites classed as being of favourable habitat quality. The site at Barrock Mill is excluded because of its consistently low-density status. Prominent outlying values for the sites at The Clow (red) and Lythmore and Bilbster (both in orange) are indicated. The distribution of individual site values around the overall relationship depicted by the line is relatively compact and the relationship is robust.

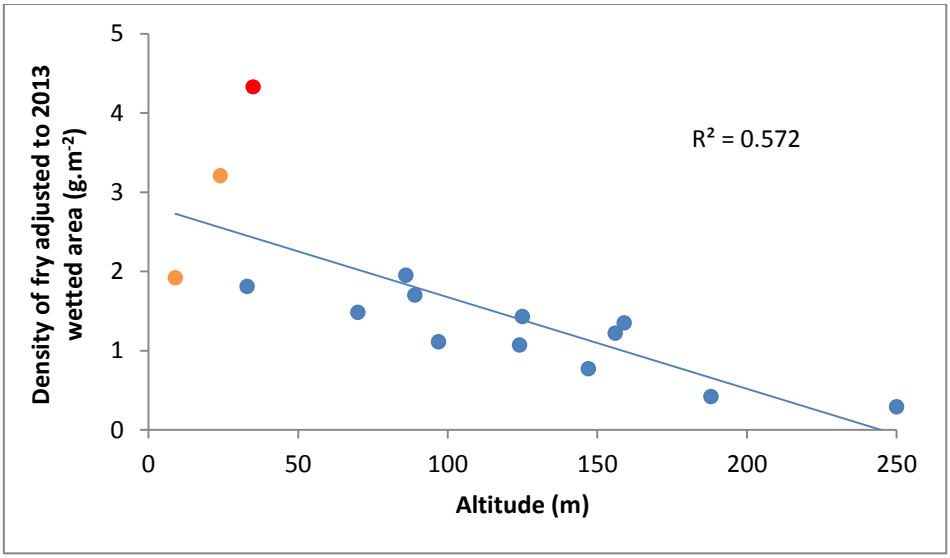

Figure 6. The relationship between altitude and density of salmon fry for sites classed as "favourable" habitat for fry. The values have been expressed according to the wetted areas of sites as measured in 2013 to permit subsequent comparison between years. The Clow is marked in red and Bilbster and Lythmore in orange.

In Figure 6 the density values for 2014 have been standardised by expressing them relative to the wetted stream areas as measured in 2013. As discussed above, this facilitates comparison between surveys by making due allowance for differences in site width between years. Standardisation of wetted area has improved the overall relationship between altitude and fry biomass density because the sites, for example, at Bilbster and Lythmore (in orange) now conform better to the overall relationship than before. The Clow (in red) remains an outlier.

3.3.3. Biomass density v altitude

In Figure 7 body size has been taken into account by showing biomass densities against altitude. The Clow (the high density outlier shown in red in Figure 6) now conforms better to the overall relationship because the fry were extremely small (see Table 12). The Clow

therefore fulfils the criteria for being at saturation or near-saturation levels for fry - a high positive anomaly for density coupled with a biomass density value that conforms more closely to the expected value.

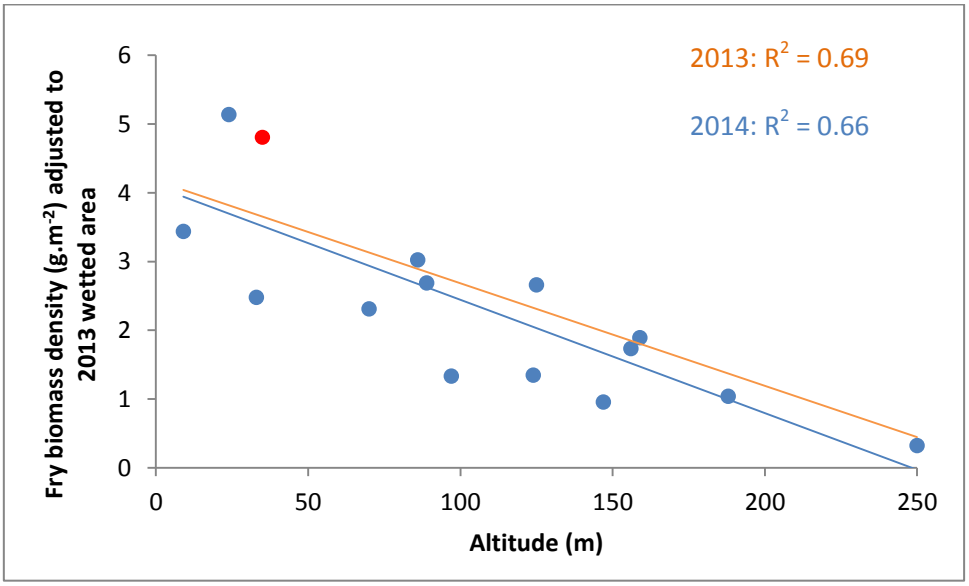

Figure 7. The relationship between altitude and biomass density of salmon fry for sites classed as "favourable" habitat for fry. The values for 2014 (in blue) have been expressed according to the wetted areas of sites as measured in 2013 to permit comparison between years. The Clow is marked in red. The overall relationship between altitude and fry biomass density for the same set of sites in 2013 (copied from Fig 8 of the report on the 2013 survey) is shown in orange.

The overall relationship between altitude and biomass density for 2014 is robust despite the large disparities between sites in both numerical density and fry size. In addition, the 2014 relationship between altitude and the biomass density of fry closely matches the equivalent relationship for 2013 (shown in orange) despite disparities in both numerical density and size between the fry of 2014 and those of 2013. However, the similarity of the relationships should be treated with caution because it may well arise from coincidence bearing in mind that biomass production is likely to vary among different growing years (eg. warmer v colder). The run of survey data for Caithness is too short to examine this possibility and no data are available from elsewhere.

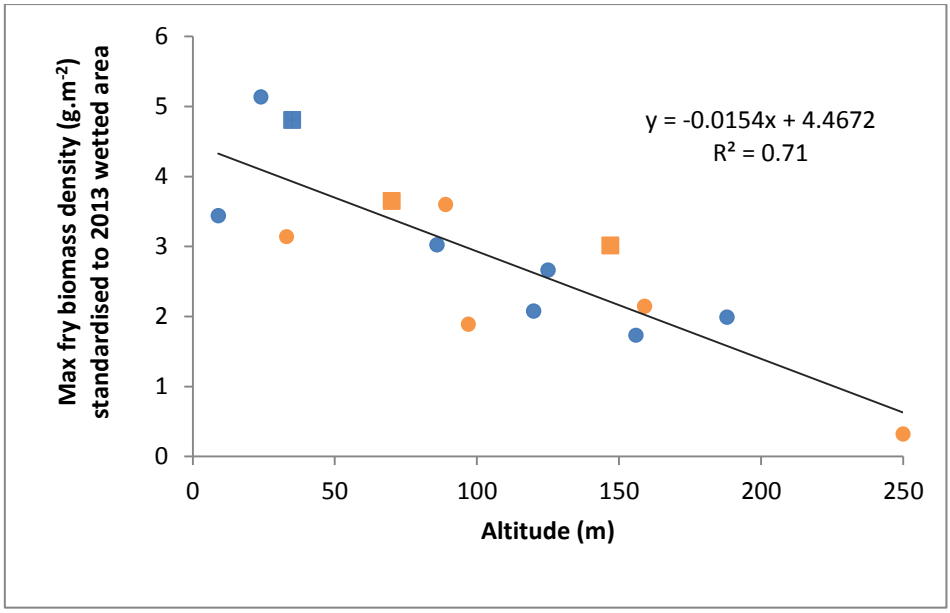

Figure 8. The relationship between altitude and the maximum observed biomass density (2013 or 2014) of salmon fry at sites classed as "favourable" habitat for fry. The values from 2014 are adjusted for differences in the wetted area of sites between years and standardised relative to wetted areas as measured in 2013. Values generated in 2013 are marked in orange: those from 2014 are marked in blue.

In Figure 8, information from 2013 and 2014 has been combined to eliminate some of the randomness that appears to affect the presence of fry at particular sites in particular years. In 2014, for example, fry density at The Clow was ranked among the highest values for all the survey sites although fry had been sparse there in 2013. Presumably, this difference reflects patchy patterns of spawning and variation between years in the availability for recruitment to particular sites. In order to reduce such effects, fry biomass density was compared for each site in 2013 and 2014 and the higher value selected as being closer to the potential maximum productive capacity of the site.

Figure 8 shows that maximum site values were generated equally in 2013 and 2014 (marked in orange or blue, respectively). The straight-line relationship represents all the points adequately and it explains around 70% of the observed variation in values. The three sites marked as squares showed evidence of growth depression among fry in one or other survey year – Dalemore (2013), Dalganachan (2013) and The Clow (2014) – suggesting that the sites were saturated or nearly saturated with fry in the year in question. It is possible therefore that the biomass values shown for these sites will not be greatly exceeded in future. Otherwise, Figure 8 should be regarded as a work in progress to be updated if and when individual sites prove capable of generating greater fry biomass than was achieved in 2013 or 2014.

In Figure 8, the mathematical expression of the relationship between altitude and expected density is given by the equation in the panel. The equation can be used to generate

expected values for fry density biomass for any given altitude and these values were used to generate the values shown in Table 13.

River	Site name	Observed - expected fry biomass density standardised on 2013 wetted area ($g.m^{-2}$)	
		2013	2014
Forss	Cnoc-glas	-1.70	-1.36
	Shurrery	0.50	-0.04
	Lythmore	1.04	0.20
Thurso	Rumsdale	0.13	-0.13
	Dalganachan	**0.81**	-1.25
	Dalnagleton	-1.33	-1.21
	The Fanks		
	Smerrary	-0.61	-0.12
	Dalemore	**0.26**	-1.08
	Hoy		
Wester	Barrock Mill	-4.22	-3.21
Wick	The Clow	-3.54	**0.88**
	Sheriff's	-0.82	-1.48
	Bilbster	-2.87	-0.89
Dunbeath	Achnaclyth	-1.90	-0.54
	Culvid	-1.08	-1.51
Berriedale	Gobernuisgach	-0.29	-0.30
	Corrichoich	-1.07	-0.79
	Braemore	-0.87	-0.33
	Strathcoull	-3.56	-2.55
Langwell	Wag	0.42	-0.53
	Aultibea	-0.61	0.12
	Coille Braigh	-2.87	-1.01

Table 13. Observed minus expected biomass densities of fry for 2013 and 2014 for sites for which data are available for both years.

Table 13 gives fry biomass production (observed minus expected) for both survey years. The most productive site proved to be Lythmore which in 2013 produced around 1g/ m^{-2} (ca. 25%) greater biomass of fry than expected. At the other extreme, even in its better year (2014) Barrock Mill produced only about 25% of the expected biomass value and the shortfall was 3.2 $g.m^{-2}$.

The 2014 data for 1+ parr is considered below in much the same way as the fry data have been above. In 2013, this general approach proved less successful when applied to the 1+ parr compared with the fry. Indeed, it is expected that older fish will pose greater difficulties for analysis. The 1+ parr have had more scope for redistribution over their two summers and their size reflects two, possibly contrasting, annual periods of growth rather than the single one experienced by fry. It is also likely that the 1+ parr compete on fairly equal terms with those of the variable number of older parr that remain after the smolts have departed but the Caithness data are not sufficient to address this point. In what follows, therefore, the exploratory approach developed for the 1+ parr of 2013 is repeated for 2014 and the 2013 and 2014 data are combined and compared.

River	Site name	Mean body length of 1+ parr (mm). Standard deviation in parentheses
Forss	Cnoc-glas	99.0 (10.03)
	Shurrery	103.6 (9.62)
	Lythmore	99.3 (11.07)
Thurso	Rumsdale	96.2 (8.89)
	Dalganachan	93.7 (10.72)
	Dalnagleton	102.0 (11.40)
	The Fanks	103.2 (8.96)
	Smerrary	106.9 (9.46)
	Dalemore	96.5 (9.58)
Wester	Barrock Mill	150.0 (-)
Wick	The Clow	90.5 (9.41)
	Sheriff's	90.3 (8.59)
	Bilbster	108.1 (9.12)
Dunbeath	Achnaclyth	94.0 (7.94)
	Culvid	88.2 (9.18)
Berriedale	Gobernuisgach	92.3 (8.83)
	Corrichoich	88.4 (8.62)
	Braemore	91.0 (6.44)
	Strathcoull	95.6 (6.93)
Langwell	Wag	102.4 (7.29)
	Aultibea	94.1 (6.92)
	Coille Braigh	93.4 (7.78)

Table 14. The mean body length of 1+ parr at each site. The standard deviation is given in parentheses.

Table 14 givess the average size of 1+ parr at each site. Parr were smallest at Culvid and Corrichoich. The largest fish by far were the very few fish present at the Barrock Mill site.

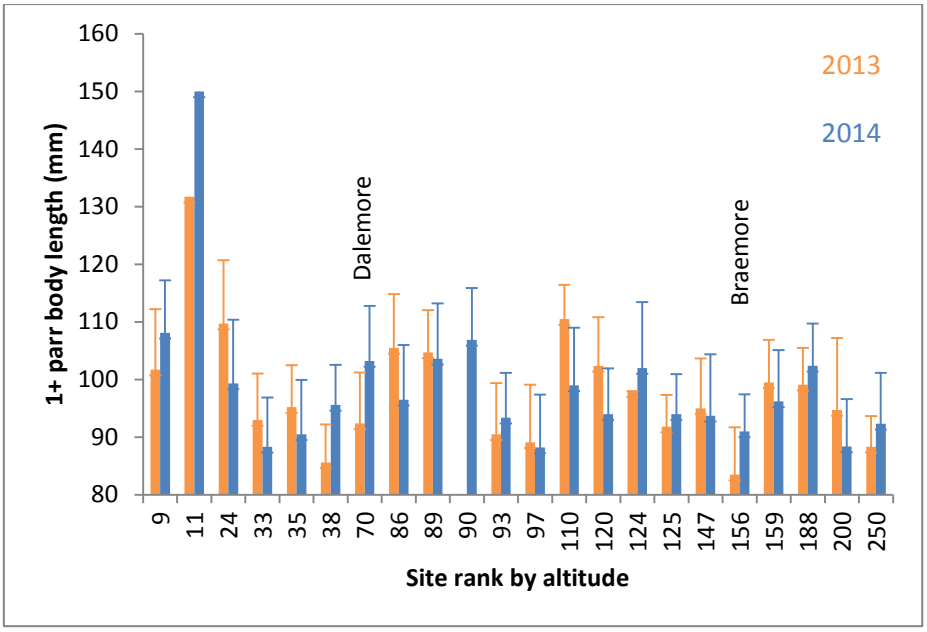

Figure 9. Graphical representation of mean body length of 1+ parr in 2014 (blue) and 2013 (orange) for sites ranked by altitude). The standard deviation for each value is indicated by the bar.

In Figure 9 the mean values for 1+ parr length in 2014 are compared with the corresponding value for 2013. No particular patterns are evident. However, at Dalemore and Braemore, the two sites where very high density was associated with small body size in 2013, the 2014 parr were notably larger, presumably as a result of less intensive competition at the lower density observed at both sites (see Table 11).

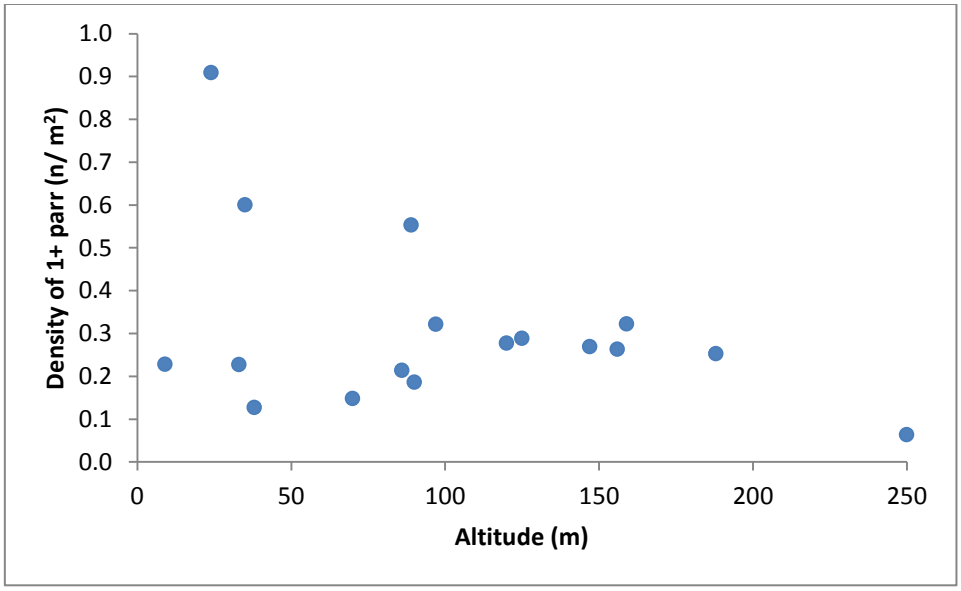

Figure 10. The relationship between site altitude and estimated true density of 1+ parr for sites classed as "favourable" habitat for parr. The anomalous site at Barrock Mill has been excluded.

Figure 10 shows the distribution of densities of 1+ parr against altitude. No relationship between the two is evident.

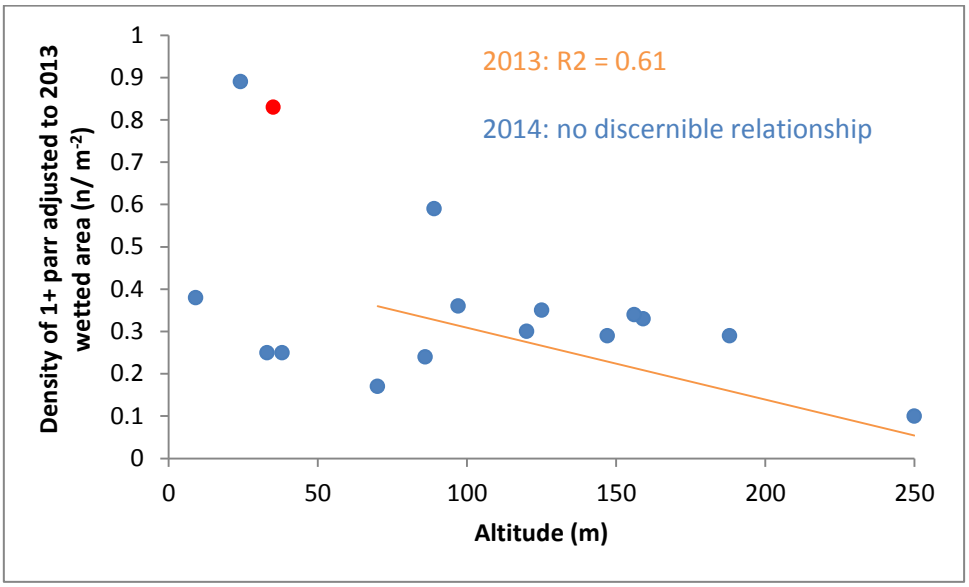

Fig 11. The relationship between site altitude and estimated true density of 1+ parr for sites classed as "favourable" habitat for parr. The values have been standardised to the wetted area as measured at each site in 2013. The relationship proposed for the equivalent values in 2013 is indicated in orange. The anomalous site at Barrock Mill has been excluded.

Figure 11 repeats Figure 10 but for each site the density value has now been standardised by expressing the number of fish relative to the wetted area as measured in 2013. This approach to standardisation offers several advantages for interpretation, as discussed above in the related context of the fry data. As for the fry, standardisation has improved conformity of the 1+ parr density in the context of the other sites particularly at the Bilbster site. However, the standardised data still show no obvious relationship to site altitude. The site at The Clow is marked in red to aid cross-reference with Figure 12.

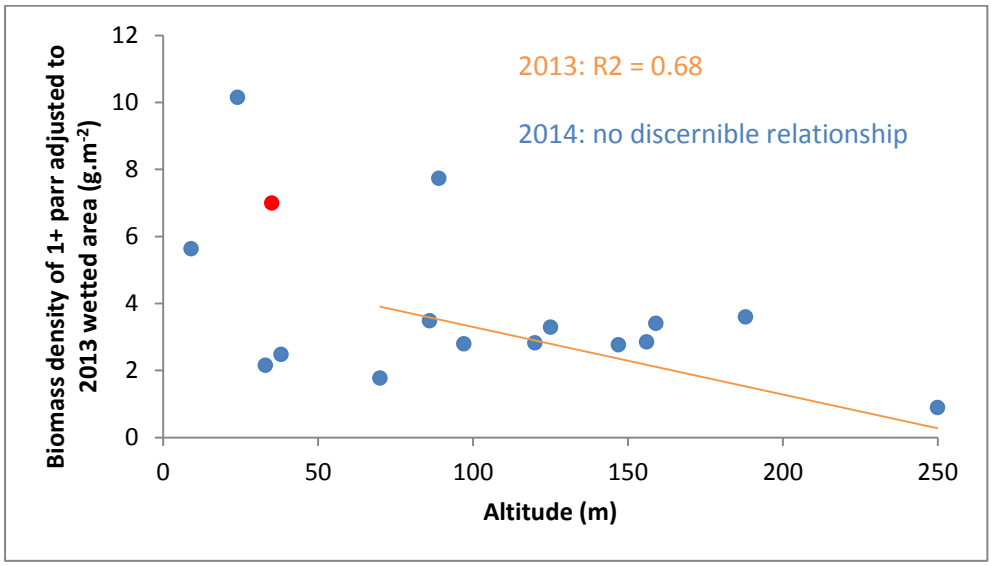

Figure 12. Biomass density values for 1+ parr considered against site altitude for sites of "favourable" quality for parr. The Clow is marked in red. The relationship proposed for the equivalent values in 2013 is indicated in orange. The anomalous site at Barrock Mill has been excluded.

Figure 12 shows biomass density values for 1+ parr against altitude and, again, no relationship is evident. The partial relationship proposed for 2013 is indicated in orange. The Clow (marked in red) showed an extreme value for 1+ density (see Figure 11) but, in Figure 12, biomass density for the Clow conforms more closely to the average value for all sites because the 1+ parr were relatively small, suggesting that the site was near saturation.

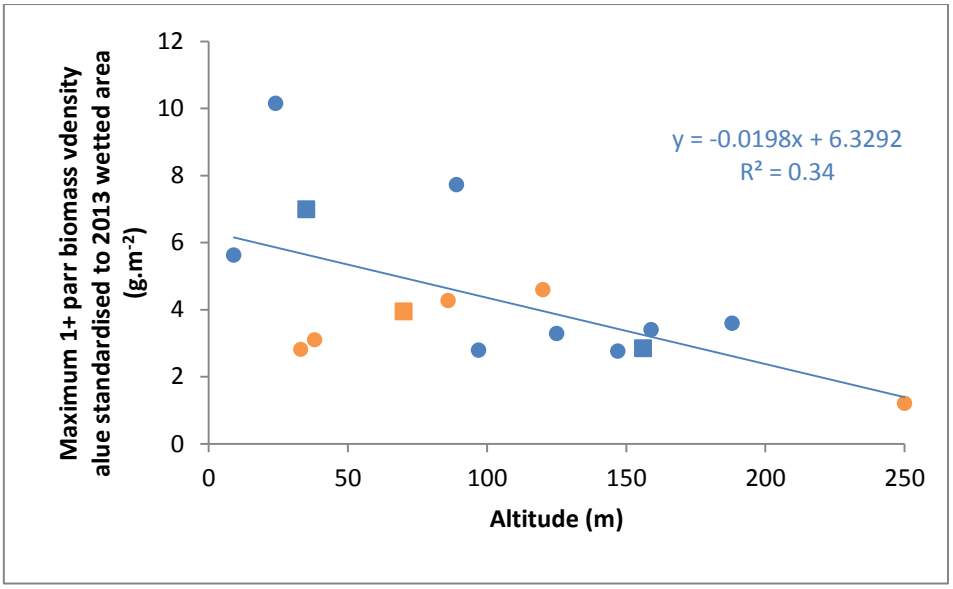

Figure 13. The relationship between altitude and the maximum observed biomass density (2013 or 2014) of 1+ parr at sites classed as "favourable" habitat for parr. The values from 2014 are adjusted for differences in the wetted area of sites between years and standardised relative to wetted areas as measured in 2013. Values generated in 2013 are marked in orange: those from 2014 are marked in blue. The anomalous site at Barrock Mill has been excluded.

Figure 13 shows the maximum value for 1+ parr biomass that was present in either 2013 or 2014 plotted against site altitude. Both survey years contributed substantial numbers of points. The points defined by squares are sites which showed evidence of saturation in either survey year – Dalemore and Braemore in 2013 and The Clow in 2014. The overall relationship between biomass density and altitude is only moderately robust. However, the mathematical relationship is defined in the panel and this was used to generate the values shown in Table 15.

River	Site name	Observed - expected 1+ parr biomass density ($g.m^{-2}$)	
		2013	2014
Forss	Cnoc-glas	-1.62	-2.23
	Shurrery	1.60	3.16
	Lythmore	1.21	4.29
Thurso	Rumsdale	-0.92	0.22
	Dalganachan	-0.87	-0.65
	Dalnagleton	-3.52	-3.50
	The Fanks		
	Smerrary	-0.35	-1.15
	Dalemore	**-0.99**	-3.18
	Hoy		
Wester	Barrock Mill	-6.11	-5.54
Wick	The Clow	-1.44	**1.36**
	Sheriff's	-2.85	-3.53
	Bilbster	-2.93	-0.53
Dunbeath	Achnaclyth	0.65	-1.13
	Culvid	-1.91	-1.62
Berriedale	Gobernuisgach	-0.17	-0.49
	Corrichoich	-0.27	0.11
	Braemore	**-0.47**	-0.39
	Strathcoull	-2.47	-3.10
Langwell	Wag	-0.61	0.99
	Aultibea	-1.44	-0.57
	Coille Braigh	-2.47	-2.09

Table 15. Observed minus expected biomass densities of 1+ parr for 2013 and 2014 for sites for which data are available for both years.

Table 15 shows the observed minus expected values for 1+ parr biomass The main features are the consistent under-performance in both years of several sites - Cnoc-glas, Dalnagleton, Barrock Mill, Sheriff's, Culvid, Strathcoul and Coille Braigh - relative to the others. Production at Shurrey and Lythmore was consistently greater than expected.

4. Discussion

The survey of 2014 was essentially a repeat of the work carried out in 2013. Most of the sites fished were common to both survey years and the sites themselves were exactly replicated based on photographs and bank measurements. All this makes the data doubly valuable in that it provides both a basis for assessment of juvenile salmon populations in 2014 and, for the first time, a solid basis for comparison between consecutive years.

Judged according to Godfrey's reference values, 17 of the 22 sites surveyed held "excellent" densities of fry indicating that the number of spawners, their distribution and the availability of recruiting fry at hatch in 2014 were also excellent. In 2013, inadequate fry recruitment had been noted at The Clow (Wick), Strathcoull (Berriedale) and Coille Braigh (Langwell) but in 2014 fry densities were "good" or "excellent" at the same sites. In any case, the deficiencies of fry recruitment noted in 2013 had already been resolved by young fish moving in because by the 1+ parr stage densities were "good" or "very good". No similar instances of sporadic deficiencies in fry recruitment were identified in 2014. The only consistent issue of concern was at Barrock Mill where, as in 2013, fry numbers were grossly deficient.

For parr, Godfrey's reference values classed 10 of 22 sites as being "exceptional" or "very good" and nine as being "average" or "good" condition. Again, the only issue of concern was at Barrock Mill where parr numbers were deficient - as in 2013. The few fish present at Barrock Mill grow quickly and smolt at a young age and scale-reading shows that all the parr are aged 1+. Taken together therefore the two survey years indicate that spawning in the vicinity of Barrock Mill has been consistently inadequate since the 2012 spawning season. Indeed, since 1+ parr were present only at low density in 2013 the problem probably extends back further to include the 2011 spawning year.

From a technical point of view, there is a problem with Godfrey's critical values for classifying densities of fry. Thus, values of up to 0.67/ m^2 are allocated five categories ranging from "poor" to "very good" but all values greater than 0.67 are allocated to only a single, "exceptional" category. Most of the 2014 classifications of fry density fell within the "exceptional" category. The actual values covered by the "exceptional" classification ranged from the 0.67/ m^2 threshold proposed by Godfrey to the high value of 2.5/ m^2 observed for the first electric fishing pass at Lythmore. This means that the existing critical values are set too low. More informative classifications could be obtained by raising the critical quintile values based on contemporary data. In this way, the classification range would more evenly match the range of values now being encountered and fewer sites would be allocated to the same high class. For parr density, the existing set of critical quintile values appears to be appropriate since site classifications fall rather evenly over the six available categories.

On the whole, estimated true density values from 3-pass fishing show good correspondence with 1st pass values. Bilbster was an exception and was under-rated for parr densities based on the 1st pass figures. This was probably because Bilbster was fished on rising water caused by a thunderstorm higher in the catchment which appeared to reduce the efficiency of capture of parr although fry were not affected in the same way.

Fry densities exceeded the values for 2013 at 14 of the 21 sites for which data is available for both years. In 2014, the median value for fry density across all sites was 1.34/ m^2, a very large increase (about 40%) on 2013. Fry were also more evenly spread than in 2013. For 1+ parr, the average values for density were about the same in both years. The range of values was greater in 2014 than in 2013 and very high values were found at Shurrery, Lythmore and The Clow. In fact, the latter was probably near saturation for both fry and parr.

In summary, therefore, salmon populations in the Caithness rivers were in a favourable condition overall and even better than those of 2013, especially for fry. The age-structure of the parr population was rather simple because the majority of the fish remaining in the rivers after the smolts had left were aged only 1+. However, the smaller size of the 2014 fry is likely to result in more balanced parr populations in future years - greater numbers of 2+ fish in 2016 and a greater proportion of 3-year-old smolts in 2017 - spreading both risk and advantage over a greater number of years. The only consistent problem relates to the Barrock Mill site which, as in 2013, was grossly deficient in both parr and fry.

The second part of this discussion is more speculative and it concerns the possible use of biomass density to obtain more precise assessments. As discussed in the 2013 report, biomass density tends to be less variable than numerical density because high numerical density tends to be associated with small fish size when the site in question nears saturation. Consideration of biomass density may open the way to replacing simple site classifications - like those discussed above - with more detailed responses to more probing questions. For example - How much better was 2014 than 2013? Could it have been better still? How much better could it have been?

As in 2013, there were strong relationships between altitude and both fry density and fry biomass density. The Clow was a high outlier for fry density and a low outlier for fry size and as a result the site conformed better to the biomass density than to the numerical density relationship. For the case of 1+ parr, and unlike 2013, there was no discernible relationship between altitude and density or between altitude and density biomass. However, The Clow was also a high density outlier for 1+ parr and the parr were small. As a result, The Clow conformed more closely with average values for 1+ biomass density rather than numerical density. It follows from this that The Clow was probably near saturation for both fry and for 1+ parr. The Clow was the only site showing either condition in 2014 but similar cases were identified at other sites in 2013.

The results for 2013 and 2014 were combined to produce single relationships between altitude and biomass density for fry and for 1+ parr. The relationships were used to rank sites by whichever was greater of the 2013 or 2014 values for the difference between observed and expected biomass density (Figures 14 and 15, below). This approach is intended to pinpoint potential rather than achieved biomass values and to reduce the effects of random restrictions on recruitment, particularly restrictions on fry associated with patchy spawning patterns. Thus, the highest ranked sites have proved capable of high biomass production in one or other or both of the 2013 or 2014 survey years. The lowest ranking sites have under-performed in both survey years.

The current rankings are based only on the two annual surveys completed so far and the picture may change in future if more data are added. The diagrams below must therefore be regarded as works in progress. The Fanks and Hoy sites are included although each was surveyed only in one year.

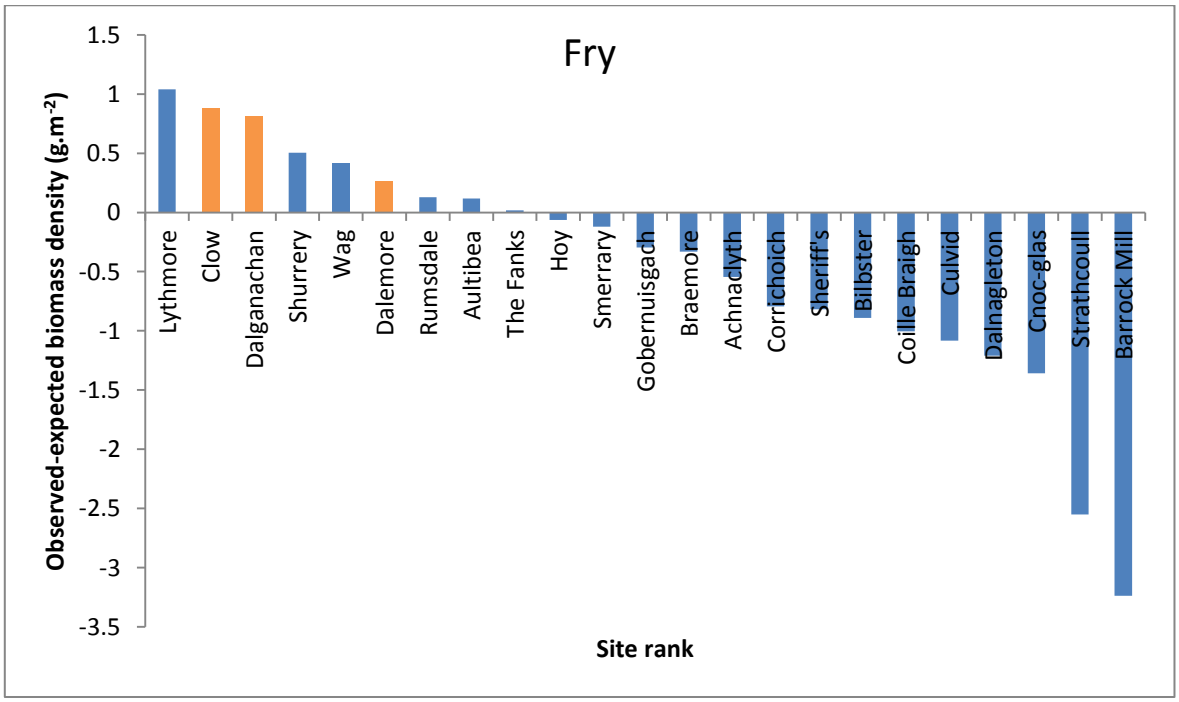

Figure 14. Sites ranked according to proven capacity to produce biomass of fry.

Figure 14 shows, for example, that Lythmore was rated highest for fry biomass production having proved capable of producing around 1g/ m^2 more biomass than expected for its altitude in its better survey year. Barrock Mill was rated lowest, producing around 3g/ m^2 less biomass than expected, even in its better year.

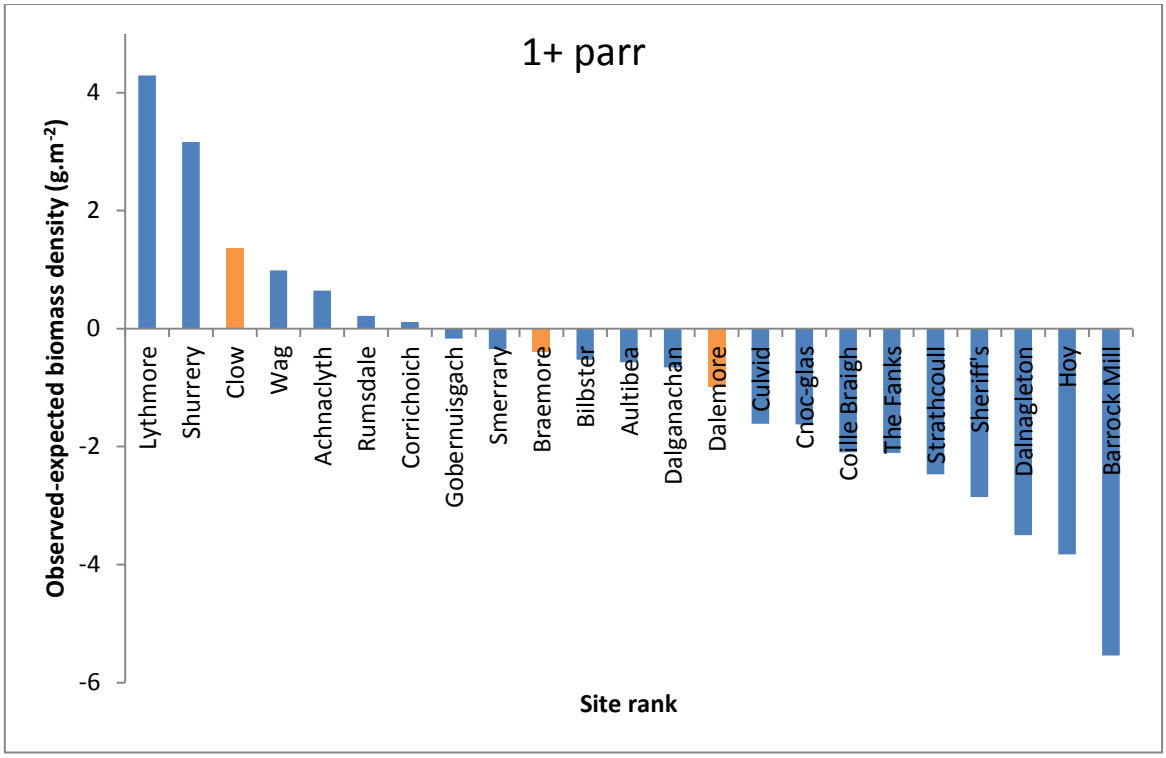

Figure 15. Sites ranked according to proven capacity to produce biomass of 1+ parr.

Figure 15 shows that Lythmore was also rated highest for 1+ parr, proving capable of producing about 4 g.m^{-2} greater biomass than expected in its better year. Barrock Mill was again ranked lowest under-producing by around 5 g.m^{-2}.

In both the above figures, the sites marked in orange are those that showed evidence of reduced fish size in one or other of the survey years, indicating high levels of competition. The value shown for the sites marked in orange is probably therefore somewhere near maximal. None of the sites marked in blue showed evidence of impaired fish growth. So, for this latter group of sites, greater biomass values are likely to be possible if and when circumstances are more conducive to production. Nevertheless, even at this early stage it is of interest to speculate on what aspects of the lowest-ranking of the sites might be holding back fish production and whether any potential causes can be identified for further investigation.

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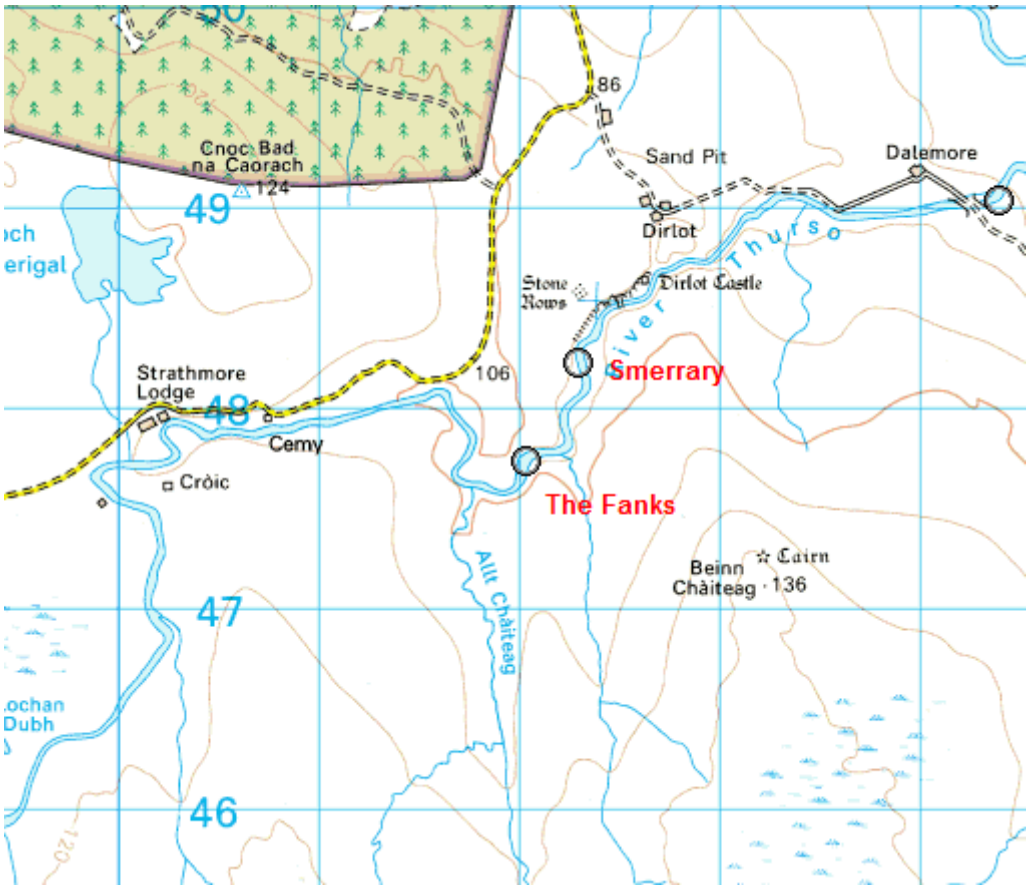
Reference.

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

Appendix

The Fanks, River Thurso

The Fanks: site dimensions			
Section left bank (m)	**Mean channel wet width (m)**	**Wetted area (m^2)**	**Streambed area (m^2)**
14.0	10.0	140	140



The Fanks, River Thurso