Juvenile Salmon in the Caithness Rivers:

Electric-fishing Surveys of 2013-15.

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Executive Summary

1. This report brings together electric-fishing data gathered by the Board's team in 2013, 2014 and 2015. Three-pass depletion electric-fishing was used in order to estimate true numerical density for each age-class, using scale-reading to allocate individuals to their year-class. Body length was measured. In most cases, the same lengths of stream were fished in successive years. In all, 26 sites were surveyed in one or more year over an altitudinal range extending to 250m.

2. The main aim of this report is to assess the status of juvenile salmon in the Caithness rivers over the period covered by the three survey years.

3. There are five key outputs.

> a. Table 3, on Page 10, shows Zippin estimates of the true density of 0+ and 1+ parr at each site for each survey year. The values are based on 3-pass electric-fishing. Densities are expressed in terms of the standard wetted area values of each site - see Index of EF sites 2013-15.
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> b. Table 4, on Page 11, shows the mean body length of 0+ and 1+ parr at each site for each survey year.
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> c. Table 6, on Page 13, is repeated from 2015 Survey of Juvenile Salmonids in Caithness Rivers and shows colour-coded assessments of the numerical density of 0+ and 1+ parr for each site and year. The colour-coded ratings are derived from comparisons with the critical quintile values proposed by Godfrey (2005[1]) and they are therefore based only on the first pass of three-pass electric-fishing.
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> d. Table 8, on Page 24, shows colour-coded assessments of the true density values for 0+ and 1+ parr; the values are based on three-pass electric-fishing. Density values for each site and each year are expressed as a percentage of the maximum value that is predicted to be attainable based on the site's altitude.
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> e. Values for biomass density are derived by combining the average weight with the numerical density for each year-class. The values are expressed as grams of body weight per square meter of wetted stream area. Table 13 (Page 37) and Figure 19 (Page 38) show that, when compared with numerical density values for 0+ or 1+ parr, total biomass density (ie. all age-classes combined) is the superior measure of the status and performance of sites.

[1] J.D.Godfrey (2005). Site condition monitoring of Atlantic salmon SACs. Report by the SFCC to Scottish Natural Heritage, Contract F02AC608.

4. It is concluded that the numerical density of each of the age-classes present at any of the Caithness sites is dependent on the local availability of recruits, habitat quality and the site's altitude. In addition, the average body size and/ or the numerical density of the constituent year-classes is affected by the competitive environment formed by interactions between all the year-classes that are present. This means that the numerical density of any age-class cannot be fully evaluated without considering the status of the other year-classes that are also present.

5. Given the large number of variables that affect the numerical density of year-classes, a statistical modelling approach is appropriate for site assessment. However, this is outside the reach of the Board and the existing data set is probably not large enough.

6. As an expedient, the Figures 21.1 – 21.26 (beginning on Page 44) show the total biomass densities attained at each site and the proportional contributions made to the total by the three age-classes (0+ fish, 1+ parr and older parr). The equivalent values for numerical density are also shown to aid comparison.

8. The summary site assessments accompanying each figure in the Figure 21 series are largely based on the biomass density values.

9. The majority of the Caithness sites consistently attained biomass density values that are likely to be near to, or at, the maximum possible value for the site. The majority of the remaining sites proved capable of achieving relatively high site values for biomass density but did so less consistently.

10. Only the Barrock Mill site on the River Wester consistently under-performed, given its low altitude and the seemingly high quality of its habitat, probably due to consistently inadequate levels of recruitment.

Introduction

In 2013, the Caithness District Salmon Fishery Board resumed its electric-fishing programme after a lapse of several years. The aim was to obtain up-to-date information on the status of juvenile salmon populations in the Caithness rivers. Electric-fishing survey data are potentially informative in two ways. Firstly, densities of young salmon, and especially 0+ fish (fished that hatched in the year of survey), are a partial reflection of spawning sufficiency in previous years. Secondly, 0+ and parr densities indicate likely future levels of smolt recruitment and are therefore a partial predictor of the fisheries later on.

The first in the present series of electric-fishing surveys was carried out in 2013. The survey was repeated in 2014 and the final survey of the intended series was completed in 2015. Each survey was reported on separately and these documents are posted on the Board's web-site. The Board adopted the most rigorous survey methods and applied them consistently. The present report brings together the data collected in all three surveys.

Two general points emerged from the annual surveys and these have been used to focus this report. First, 0+ trout and trout parr were absent or infrequent at almost all the survey sites in each of the survey years and trout have therefore been excluded from consideration in what follows. Second, in each of the survey years and at all the survey sites, 0+ salmon and 1+ parr (fish hatched the year prior to the survey) dominated the fish populations; 2+ and older parr were generally infrequent or absent. This indicates that most young salmon leave the Caithness rivers as two-year-old smolts. Because of this, the residual densities of 2+ and older salmon parr are not likely to be informative and this report therefore largely focusses on the 0+ salmon and the 1+ salmon parr.

There are a number of problems associated with interpreting fish survey data. Fish densities are set in part by recruitment and partly by habitat quality. Habitat quality is partly determined by physical parameters such as streambed roughness, gradient and bankside cover which affect opportunities for shelter and partly by hydrochemistry and temperature which affect food abundance. The social/ competitive environment formed by the fish themselves is also a factor. Unfortunately, it is not possible to dissociate all these effects and, as a result, assessment is usually based on comparison with a standard of some type.

In all the Board's previous annual surveys, sites have been rated and compared using the set of reference values for fish density proposed by Godfrey (2005[2]). Godfrey gives two sets of cut-off values for rating either 0+ or parr densities. The cut-off values generate five site-ratings for 0+ fish or parr that cover the range of possible site conditions from "poor" to

[2] J.D.Godfrey (2005). Site condition monitoring of Atlantic salmon SACs. Report by the SFCC to Scottish Natural Heritage, Contract F02AC608.

“very good”. The colour-coded ratings for 0+ and parr densities given in previous Board reports have been produced in this way.

However, there are a number of limitations to this approach and the effects of some of these have become evident during the course of the Board’s work. If a new, more appropriate set of reference values could be derived for the Caithness survey sites, it might prove possible to provide a more telling account of the status of Caithness salmon, and the Caithness rivers, than has previously been possible.

To this end, the Board has carried out rigorous electric-fishing surveys each year since 2013. All the surveys were carried out at the same time of year (September). The same lengths of stream were fished and re-fished in succeeding years, using exact positioning of the stop-nets that prevent fish leaving or entering the survey area to precisely define each site’s boundaries. Three-pass depletion electric-fishing was used in order to generate high quality estimates of fish density for each age-class, using scale-reading to allocate individuals to the years when they were spawned. Body length was determined for all parr and for a large sample of 0+ fish in order to gauge growth performance. The aim of this report is to produce a definitive assessment of juvenile salmon populations based on the data obtained over the last three years.

Data.

All the data used in this report are drawn from the previous annual reports[3] and have been re-calculated when necessary to avoid the propagation of errors.

Density values for 1+ parr are based on Zippin estimates of the true density of parr of all ages. They have been adjusted downwards according to the proportion of 1+ parr in the total parr group. This approach exploits the greater number of parr of all ages to generate the most accurate Zippin estimates of capture efficiency for 1+ parr, on the assumption that all parr are equally catchable.

As a prelude to this report, the accuracy of estimates of the size of the survey sites was re-considered. This is a key matter because the report centres on comparisons of fish density (ie. the number of fish per square meter of wetted stream area). Thus, the electric-fishing programme provides the numbers of fish caught each year in the defined length of stream that constitutes each standard survey site. However, the survey sites are all of different area because they are of variable length and width. To compensate for this, fish numbers are expressed as density values and these are directly compared.

In previous reports, fish densities were calculated by dividing the number of fish by the wetted area of the site as determined when the electric-fishing surveys were carried out. However, low water is generally favourable for electric-fishing and the streams were often

[3] http://caithness.dsfb.org.uk/publications/

low when the surveys were carried out. As a consequence, the wetted areas of the survey sites will often have been atypically small due to reduced stream widths. In particular, the 2013 survey was carried out at the end of an unusually dry summer.

Presumably fish move closer together when river levels fall and the stream area contracts and, presumably, they spread out again when normal conditions return after rainfall. So, using measures of site area obtained in low water conditions will tend to give higher values for fish density than would typically be the case and it will tend to exaggerate the real status of the fish populations. Moreover, some types of survey site are affected by changes in river height more than others. Thus, the surface area of deeply entrenched sites is more constant than the surface area of sites fringed, for example, by shallow gravel bars or bedrock shelves from which the stream rapidly withdraws when water levels fall. This means that the upwards bias of density values caused by using area measurements made in low water conditions will affect some sites more than others making comparisons between sites problematic.

Therefore, in order to eliminate or reduce these imbalances, the wetted dimensions of the survey sites were re-measured under average, rather than low, water conditions. This work was done in late autumn, 2015 and a more systematic approach than previously was used to produce more precise values. The new measurements of the dimensions of each of the survey sites and the methods used to obtain them are documented in a separate report which is also posted on the Board's web-site[4]. The new standard values for wetted area are considered to be definitive in what follows. They have been used to calculate the fish density for each site in 2015, and to re-calculate the values given for 2013 and 2014 in previous reports, in order to generate density estimates that can be compared among sites and years. As a result of these re-calculations some of the values given in this report differ from those cited in previous reports.

In all, 26 sites were surveyed in one or more year, as per Table 1.

[4] Index of EF sites 2013-15

River	Site name	2013	2014	2015
Forss	Cnoc-glas	√	√	√
	Shurrery	√	√	√
	Lythmore	√	√	√
Thurso	Rumsdale	√	√	√
	Dalganachan	√	√	√
	Dalnagletin	√	√	√
	The Fanks		√	√
	Smerrary	√	√	
	Tacher			√
	Dalemore	√	√	√
	Inshag			√
	Hoy	√		√
Wester/Lyth	Barrock Mill	√	√	√
Wick	Acharole			√
	The Clow	√	√	√
	Sheriff's	√	√	√
	Bilbster	√	√	√
Dunbeath	Achnaclyth	√	√	√
	Culvid	√	√	√
Berriedale	Gobernuisgach	√	√	√
	Corrichoich	√	√	√
	Braemore	√	√	√
	Strathcoull	√	√	√
Langwell	Wag	√	√	√
	Aultibea	√	√	√
	Coille Braigh	√	√	√

Table 1. Survey sites fished each year.

Table 2 identifies the survey sites by name, catchment and OS co-ordinates. Site altitude, average width and the standard values for site wetted area (as determined in 2015) are also specified.

River	**Site name**	**O.S.**	**Alt** (m)	**Width (m)**	**Wetted area (m^2)**
Forss	Cnoc-glas	ND 042 523	110	6.7	193
	Shurrery	ND 039 578	89	6.7	90
	Lythmore	ND 047 663	24	10.5	184
Thurso	Rumsdale	NC 988 408	159	8.0	182
	Dalganachan	ND 006 391	147	5.1	149
	Dalnagleton	ND 052 424	124	7.8	265
	The Fanks #	ND 120 478	91	10.1	141
	Smerrary	ND 123 482	86	*	*
	Tacher	ND 171 469	80	3.9	131
	Dalemore #	ND 144 491	70	5.5	269
	Inshag	ND 146 488	68	4.8	111
	Hoy	ND 141 607	20	*	*
Wester	Barrock Mill	ND 296 626	11	7.7	173
Wick	Acharole	ND 212 510	56	3.6	105
	The Clow	ND 233 524	35	5.7	160
	Sheriff's	ND 255 525	33	7.7	170
	Bilbster	ND 281 538	9	15.5	387
Dunbeath	Achnaclyth	ND 105 337	120	10.5	129
	Culvid	ND 123 325	97	12.9	215
Berriedale	Gobernuisgach	NC 984 312	250	9.5	131
	Corrichoich	ND 034 297	200	10.7	134
	Braemore	ND 074 304	156	13.0	179
	Strathcoull	ND 103 245	38	9.8	116
Langwell	Wag	ND 016 260	188	9.0	212
	Aultibea	ND 046 236	125	10.9	241
	Coille Braigh	ND 074 228	93	14.0	171

*Table 2. Site co-ordinates, altitude, average width and area. Side channels are indicated (#). Smerrary and Hoy are wide main river sites. In these cases, the site locations are fixed but the area fished varies according to operational conditions and must therefore be determined separately on each occasion (denoted by *).*

Tables 3 and 4 contain the biological data used in this report.

Table 3 lists the density values for 0+ and 1+ parr by year for each survey site. The median values for 0+ density were 0.68, 1.17 and 0.87.m^{-2} in 2013, 14 and 2015, respectively. The corresponding values for 1+ parr were 0.21, 0.22 and 0. 26.m^{-2}.

Site	**Estimated true density (n.m^{-2}) by standard site area**						
	0+				**1+ Parr**		
	2013	**2014**	**2015**		**2013**	**2014**	**2015**
Cnoc-glas	0.36	1.10	1.02		0.15	0.15	0.15
Shurrery	1.60	1.71	1.76		0.36	0.57	0.88
Lythmore	1.74	3.12	0.88		0.42	0.87	0.65
Rumsdale	1.05	1.26	0.93		0.16	0.31	0.29
Dalganachan	2.35	0.74	0.73		0.24	0.26	0.19
Dalnagleton	0.67	0.77	0.82		0.02	0.02	0.00
The Fanks		1.78	4.53			0.19	0.29
Smerrary	1.45	1.71			0.30	0.21	
Tacher			2.09				0.18
Dalemore	3.27	1.20	3.34		0.35	0.12	0.23
Inshag			0.87				0.29
Hoy	1.72		1.68		0.17		0.50
Barrock Mill	0.03	0.13	0.09		0.02	0.01	0.03
Acharole			1.55				0.14
The Clow	0.14	3.25	1.53		0.27	0.61	0.73
Sheriff's	1.77	1.72	2.63		0.26	0.24	0.54
Bilbster	0.36	1.04	0.58		0.14	0.21	0.13
Achnaclyth	0.31	1.27	0.62		0.26	0.27	0.48
Culvid	1.44	1.15	0.87		0.28	0.33	0.34
Gobernuisgach	0.25	0.37	0.14		0.05	0.08	0.11
Corrichoich	0.23	0.44	0.47		0.17	0.25	0.19
Braemore	1.18	1.18	0.51		0.37	0.26	0.38
Strathcoull	0.18	0.79	0.35		0.34	0.12	0.46
Wag	0.68	0.39	0.03		0.13	0.24	0.14
Aultibea	0.65	0.97	0.12		0.11	0.20	0.26
Coille Braigh	0.08	1.40	0.18		0.16	0.18	0.25

Table 3. Estimated true densities of 0+ and 1+ parr expressed according to the standard value for the wetted area of stream as determined in 2015.

Table 4 gives the mean body lengths of both 0+ and 1+ parr present at each site in each survey year; the standard deviation (a measure of the variation within the group) is given in parentheses.

Site	Mean body length (SD)					
	0+			1+ Parr		
	2013	2014	2015	2013	2014	2015
Cnoc-glas	64.2 (5.15)	49.7 (4.88)	57.4 (5.53)	110.5 (5.95)	99.0 (10.0)	102.0 (8.43)
Shurrery	60.8 (5.41)	54.5 (5.94)	50.3 (5.20)	104.7 (7.36)	103.6 (9.62)	91.9 (8.21)
Lythmore	61.4 (8.08)	54.6 (6.29)	55.9 (6.79)	109.7 (11.0)	99.3 (11.1)	103.7 (10.1)
Rumsdale	57.5 (5.98)	52.6 (5.29)	52.1 (4.64)	99.5 (7.37)	96.2 (8.89)	90.9 (8.34)
Dalganachan	50.6 (4.70)	50.9 (4.41)	46.3 (3.67)	95.0 (8.65)	93.7 (10.7)	84.5 (7.31)
Dalnagleton	51.7 (4.45)	50.6 (6.31)	47.1 (5.21)	98.0 (+)	102.0 (11.4)	99.0 (+)
The Fanks		56.0 (5.62)	51.6 (4.89)		103.2 (8.96)	104.1 (8.27)
Smerrary	56.4 (4.82)	54.0 (6.42)		105.5 (9.31)	106.9 (9.46)	
Tacher			49.9 (5.10)			96.7 (8.25)
Dalemore	46.2 (4.46)	54.4 (5.28)	53.3 (5.18)	92.4 (8.81)	96.5 (9.58)	103.2 (8.25)
Inshag			54.9 (5.80)			97.4 (10.8)
Hoy	61.9 (4.65)		63.8 (6.13)	101.6 (9.12)		103.1 (9.19)
Barrock Mill	64.4 (+)	89.3 (10.9)	77.3 (4.61)	131.7 (+)	150.0 (+)	146.7 (9.31)
Acharole			52.8 (5.77)			
The Clow	60.3 (3.47)	49.0 (5.01)	53.1 (3.75)	95.2 (7.27)	90.5 (9.41)	91.2 (8.23)
Sheriff’s	55.4 (5.94)	52.3 (5.04)	55.8 (6.52)	93.0 (8.06)	90.3 (8.59)	97.8 (13.2)
Bilbster	59.9 (6.79)	56.3 (7.27)	61.5 (6.77)	101.7 (10.5)	108.1 (9.12)	112.3 (11.6)
Achnaclyth	60.4 (4.67)	54.5 (4.56)	49.9 (4.85)	102.4 (8.39)	94.0 (7.94)	90.2 (8.30)
Culvid	52.2 (4.51)	50.1 (5.54)	49.1 (3.81)	89.1 (9.99)	88.2 (9.18)	86.9 (8.91)
Gobernuisgach	51.3 (4.90)	49.0 (5.21)	54.5 (4.52)	88.3 (5.34)	92.3 (8.83)	104.1 (7.11)
Corrichoich	51.6 (6.48)	51.9 (4.40)	51.3 (3.66)	94.7 (12.5)	88.4 (8.62)	89.8 (7.63)
Braemore	47.4 (4.23)	53.0 (4.20)	53.5 (4.09)	83.5 (8.22)	91.0 (6.44)	88.6 (7.54)
Strathcoull	53.8 (2.80)	53.7 (6.56)	50.8 (4.32)	85.6 (6.61)	95.6 (6.93)	89.9 (9.40)
Wag	64.5 (3.97)	63.0 (3.33)	61.2 (3.92)	99.1 (6.40)	102.4 (7.29)	103.4 (9.74)
Aultibea	58.9 (5.04)	57.4 (5.21}	55.4 (4.25)	91.8 (5.51)	94.1 (6.92)	85.5 (8.72)
Coille Braigh	59.5 (5.07)	53.2 (5.00)	53.7 (3.07)	90.5 (8.87)	93.4 (7.78)	88.2 (8.03)

Table 4. Mean body length of 0+ and 1+ parr. The standard deviation (SD) is given in parentheses. + indicates that the number of values is insufficient to calculate the SD.

Assessment Methods

External reference values.

In previous Board reports, assessment was mainly based on six categories for density that were defined using the critical quintile values given by Godfrey for 0+ salmon or parr (as per Table 5, below). Godfrey's reference values are for northern rivers that are more than 6m in width. 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
0+	**0.05**	**0.13**	**0.28**	**0.33**	**0.67**	> 0.67
Parr	**0.04**	**0.07**	**0.13**	**0.19**	**0.28**	> 0.28

Table 5. Critical quintile values for classification of observed density ($n.m^{-2}$) of 0+ salmon or parr based on single-pass fishing (Godfrey, 2005).

Table 6 is modified from the Board's annual survey report for 2015. The table shows ratings for the densities values achieved by 0+ or parr at each site in each of the survey years. The sites are rated according to Godfrey's criteria and colour-coded in bands, as per Table 5.

Site	Salmon						
	0+				Parr		
	2013	2014	2015		2013	2014	2015
Cnoc-glas							
Shurrery							
Lythmore							
Rumsdale							
Dalganachan							
Dalnagleton							
The Fanks							
Smerrary							
Tacher							
Inshag							
Dalemore							
Hoy							
Barrock Mill							
Acharole							
The Clow							
Sheriff's							
Bilbster							
Achnaclyth							
Culvid							
Gobernuisgach							
Corrichoich							
Braemore							
Strathcoull							
Wag							
Aultibea							
Coille Braigh							

Table 6. Comparisons of 0+ and parr densities 2013, 2014 and 2015 based on single pass fishing and using Godfrey's proposed critical percentile values as external reference values. Colour codings as per Table 5.

Godfrey's method is very useful in practice but it has limitations, as follows, and these raise issues that the remainder of this report considers.

1. Godfrey's ratings are based only on 1st-pass fishing: 3-pass fishing is inherently more accurate.

2. Godfrey's procedure for parr is based on mixed age classes. However, the Board's data includes the ages of individual fish determined from scale reading. This allows assessment of the 1+ parr separately from the older parr age-classes for which densities are affected by the prior emigration of smolts.

3. Godfrey’s cut-off values are based on average values determined for sites of variable, but unknown, habitat quality.

4. Godfrey’s rating bands are based on data obtained some time ago for a different set of survey sites and probably using a different electric-fishing protocol.

5. The range of values covered by Godfrey’s site-ratings cannot be related to spawning sufficiency and even the highest critical values may be set too low.

As a result of one or more of the effects listed in 3 to 5, above, it previously proved necessary to introduce a sixth site-rating category (“excellent”) for the Caithness rivers because many of the observed density values in the Board’s rivers exceeded the maximum value proposed by Godfrey. This has consistently been the case for both 0+ fish and parr in each survey year, suggesting that Godfrey’s criteria are indeed set too low to provide a stringent assessment of either age-class in current Caithness conditions. Godfrey’s site ratings for 0+ appear to be particularly undemanding since Table 6 shows that a large proportion (around 40%) of the Board sites is rated in the new, “excellent” category.

Internal reference values

The Board now has data for three consecutive years, many of which are exact repeats of the same survey sites. It is therefore worth beginning to consider variation in fish density for single sites in different years, with a view to using each site as its own reference standard.

As a starting point, densities of 0+ fish or parr have been compared among years by expressing the values for each year as a percentage of the maximum value observed at the same site in any of the survey years; the highest value at every site is set to be 100%. These relative values are shown for 0+ fish in Figure 1 and for 1+ parr in Figure 2. This form of presentation emphasises the functional characteristics of the survey sites rather than specifically focussing on the densities of the fish that were actually present.

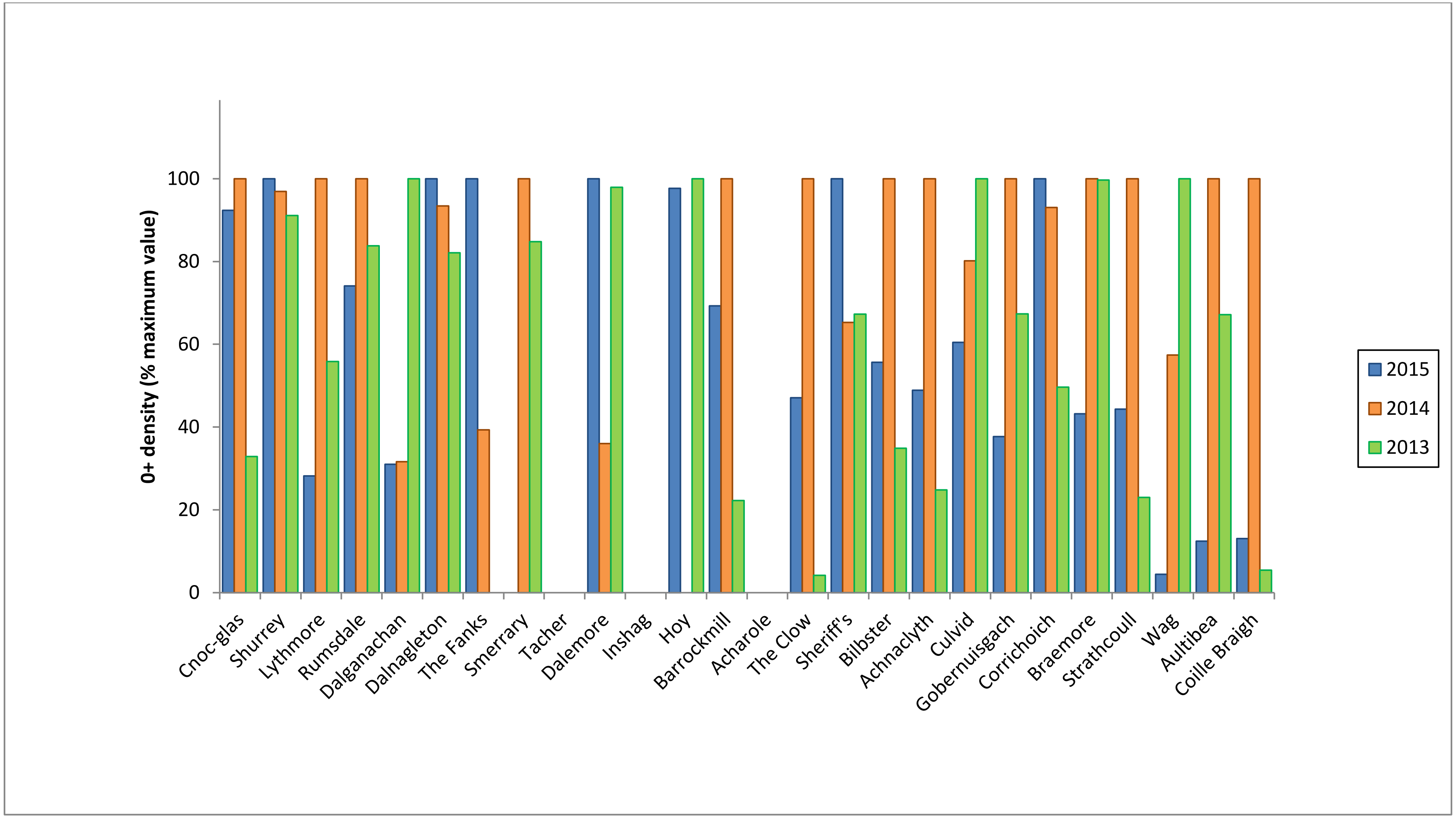


Figure 1. Densities of 0+ fish expressed as a fraction (%) of the maximum value observed at each site (set to be 100%). Sites for which were examined only in one survey year are excluded.

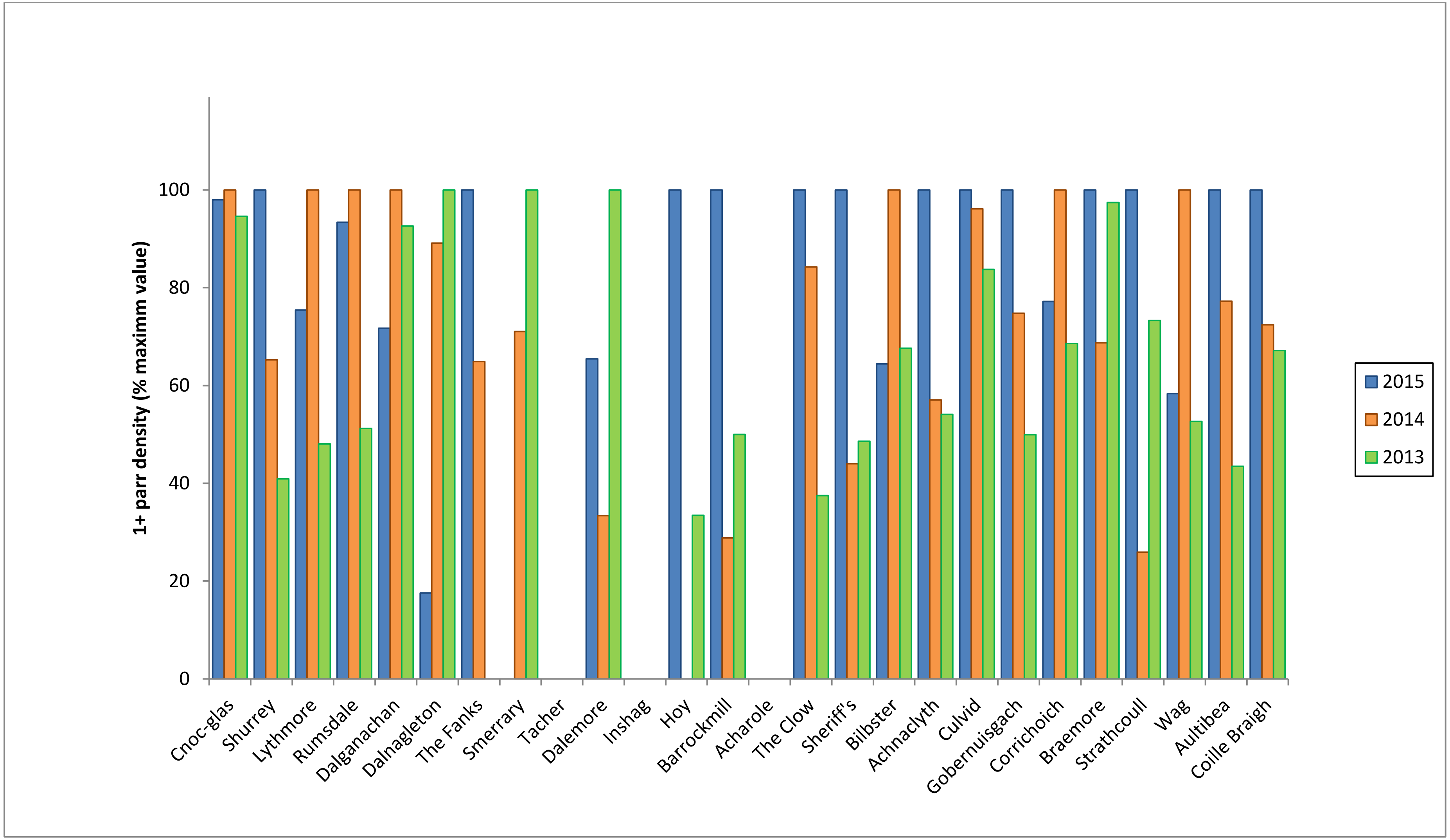


Figure 2. Densities of 1+ parr expressed as a fraction (%) of the maximum value observed at each site (set to be 100%). Sites that were examined only in one survey year are excluded.

Figures 1 and 2 show that the relative densities of 0+ fish or 1+ parr differed markedly among years at most sites. None of the sites showed visible changes to habitat quality between 2013 and 2015. Presumably, therefore, the observed variation in density at particular sites is attributable to annual variation in recruitment at, or near, the site in question.

Site	0+ (% max density)				1+ parr (% max density)		
	2013	2014	2015		2013	2014	2015
Cnoc-glas	33	100	92		95	100	98
Shurrery	91	97	100		41	65	100
Lythmore	56	100	28		48	100	75
Rumsdale	84	100	74		51	100	93
Dalganachan	100	32	31		93	100	72
Dalnagleton	82	93	100		100	89	18
The Fanks		39	100			65	100
Smerrary	85	100			100	71	
Tacher							
Inshag							
Dalemore	97	36	100		100	33	65
Hoy	98		100		33		100
Barrock Mill	22	100	69		50	29	100
Acharole							
The Clow	4	100	47		38	84	100
Sheriff's	100	65	67		49	44	100
Bilbster	35	100	56		68	100	64
Achnaclyth	25	100	49		54	57	100
Culvid	100	80	60		84	96	100
Gobernuisgach	67	100	38		50	75	100
Corrichoich	50	93	100		69	100	77
Braemore	100	100	43		97	69	100
Strathcoull	23	100	44		73	26	100
Wag	100	57	4		53	100	58
Aultibea	67	100	12		43	77	100
Coille Braigh	5	100	13		67	72	100

< 20%	20- 39%	40 – 59%	60 - 79%	80 -100%

Table 7. Density values for 0+ fish and 1+ parr expressed as a percentage of the maximum value observed at the same survey site.

Table 7 repeats the values shown in Figures 1 and 2 and colour-codes them in order to facilitate visual comparison of variation among years and sites. Some noteworthy patterns are evident, as follows

1. 2014 was a high-functioning year for 0+ fish in the Caithness rivers in general, as judged by the preponderance of blue colour-codes in the central column of the left-hand panel.

2. Judged on the same basis, and as a consequence perhaps, 2015 was probably a high functioning year for 1+ parr although the difference between columns in the right-hand panel appears to be less marked.

3. Low density of 0+ fish in any year was not always or totally reflected in low density at the 1+ stage, as shown by the greater frequency of red or orange colour codes in the left-hand panel as compared with the right hand one.

In other regards, the low 0+ value at Cnoc-glas in 2013 may be anomalous since this was the only site or year in which juvenile 0+ trout competed with salmon 0+ in roughly similar numbers (see 2013 Annual Report). The 1+ value for Dalnagleton in 2015 may be an artefact due to the very low numbers of parr present at the site in every survey year.

The approach depicted in Table 7 gives an indication of year-to-year variation in functionality within sites. However, since the maximum value at all the sites is set to the same value of 100% any absolute differences are obscured.

Correcting for site altitude.

As discussed in the 2013 and 2014 survey reports, site altitude appears to be a partial determinant of both 0+ and 1+ parr densities with values tending to be lower at higher altitude sites

High altitude streams are inherently smaller than sites lower in the river network and access by spawners to very small streams is sometimes restricted. Restricted access and low egg deposition might therefore be expected to affect high altitude sites more than low altitude ones. However, none of the Caithness sites are on very narrow streams. Indeed, the sites have been deliberately chosen to be in the more substantial parts of the main stream network. Most of the Caithness sites are more than 6m wide and only Acharole is less than 4m in width (see Table 2). So, it seems quite likely that the restrictive effect of altitude is on 0+ and parr production rather than on spawning. The same effect was also noted by Godfrey so it is probably a general one extending beyond Caithness.

Any ceiling on densities imposed by altitude is evident only from the upper boundary to the scattered distribution that results from plotting the fish density values for each site against the site's altitude. The scatter partly arises because physical habitat quality is variable and this affects the densities of fish achieved, even in sites of equivalent altitude. In addition, no sites achieve their full potential to hold fish in every year, as Table 7 shows, and this will lead to scatter, too.

It is inherently difficult to objectively define the limits of a scatter pattern. Preliminary attempts to do so in 2013 and 2014 involved excluding sites judged to be of low habitat quality, or judged to be anomalous. This procedure removed some of the low values from consideration. A regression line was then fitted through the remaining data for each year. In the case of 0+ at least, the fitted lines were very similar for both years. However, the exclusion approach is overly subjective and, by definition, the resulting regression line lies below, rather than on, any upper boundary to the scatter of values.

In summary, therefore, the 2013-14 data for the Caithness rivers indicated that it is not possible to assess fish densities without considering altitude because low altitude sites appear to consistently support more fish than high altitude sites. To make further progress, an alternative to Table 6 is required in which due allowance is made for the limits imposed by altitude. If this ceiling can be defined in some way, it will be possible to replace the uniform 100% values in Table 6 with a range of site-specific values that factor-in altitude.

Figure 3 shows all of the density values for 0+ fish in each survey year. As discussed above, the distribution of points is scattered and wedge-shaped with the greater values occurring at low altitude sites. Lower altitude sites do not always attain high values because, for example, some of them are of lower habitat quality. Sites at higher altitude never attained the high density values often present at low altitudes.

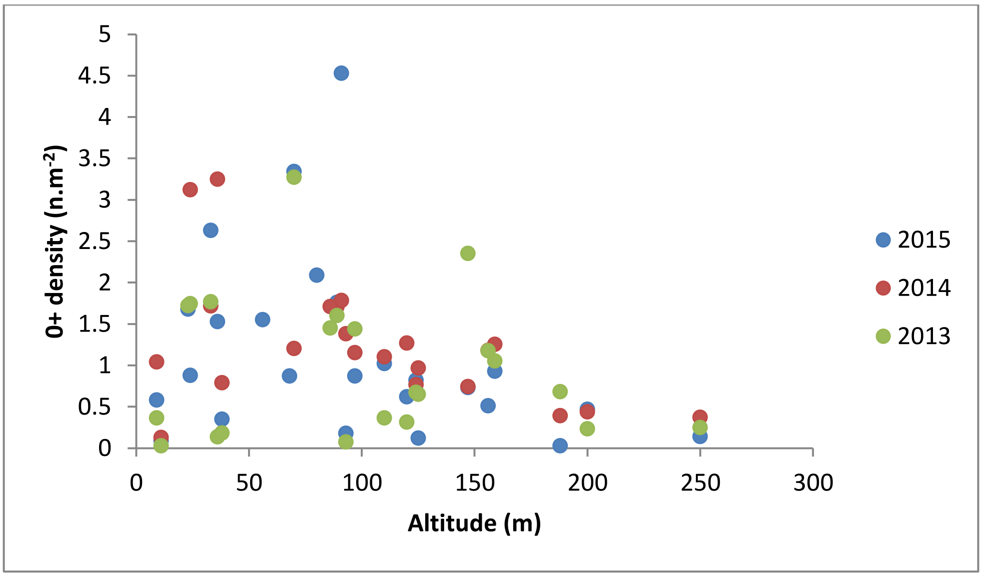


Figure 3. Densities of 0+ fish in each survey year against site altitude.

The wedge-shaped pattern evident in Figure 3 is potentially distorted by the repeated inclusion of data from the same site. In Figure 4, therefore, only the maximum density value for each site is shown. These are the 100% values shown in Table 7 with the addition of values for the Tacher, Inshad and Acharole sites which could not be included in Table 7 because they were surveyed only in a single year.

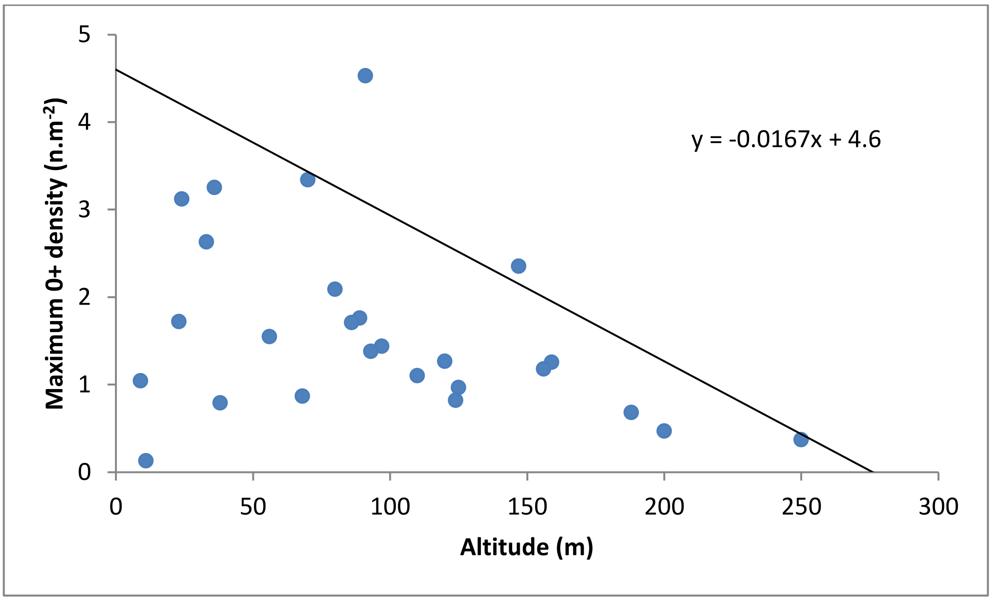


Figure 4. The maximum density of 0+ observed at each of the survey sites against site altitude.

In Figure 4 a proposed upper boundary for the wedge-shaped distribution has been set by eye. The line captures the major part of the distribution of points, excepting only two (for the sites at 91 and 147m). It is proposed that the line should be treated as an operational representation of the maximum density value likely to be attainable for 0+ fish at any particular altitude; full attainment will be conditional on good habitat quality and full recruitment. The equation describing the line is inset on the figure. Based on site altitude, this equation has been used to predict the maximum attainable density of 0+ for each of the survey sites.

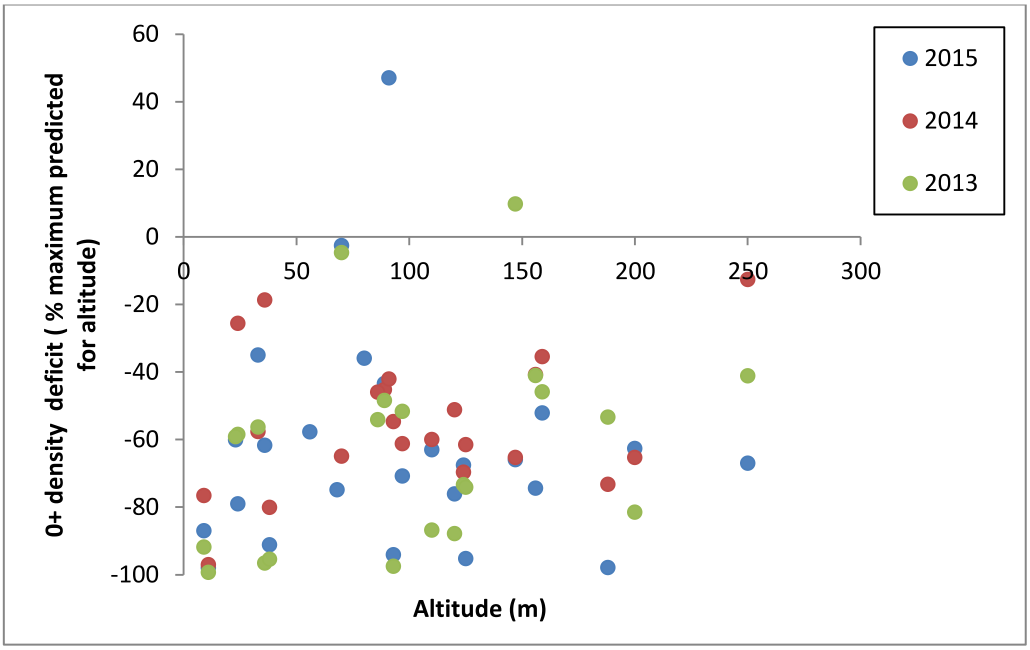


Figure 5. The extent of the shortfall in 0+ density (%) from the values predicted from site altitude. All the points for each of the years in included.

On this basis, the data shown in Figure 3 have been re-cast to show the extent to which the observed density of 0+ in any year fell short of (or occasionally exceeded) the predicted maximum attainable value for that site. The extent of the deficit for any site in each of the survey years is shown in Figure 5.

Figures 6, 7 and 8 show the equivalent data for 1+ parr and are similar in all respects.

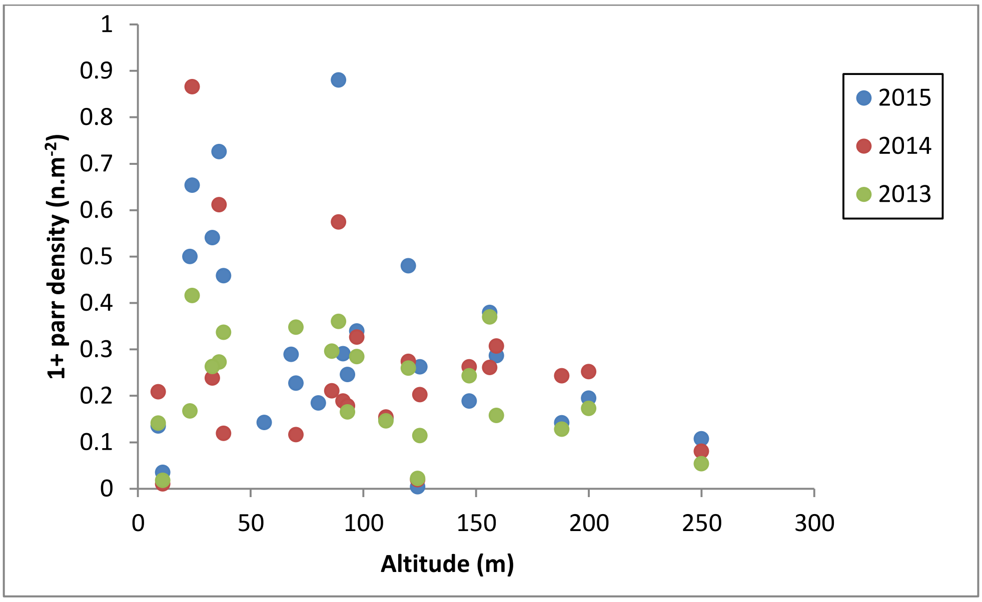


Figure 6. Densities of 1+ parr in each survey year against site altitude.

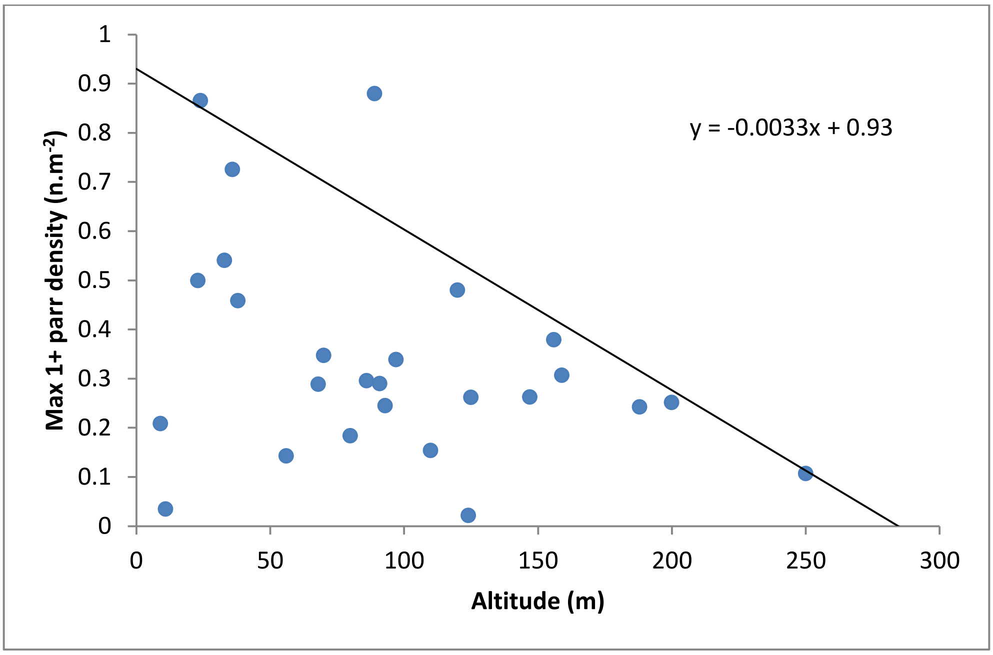


Figure 7. The maximum density of 1+ parr observed at each of the survey sites against site altitude.

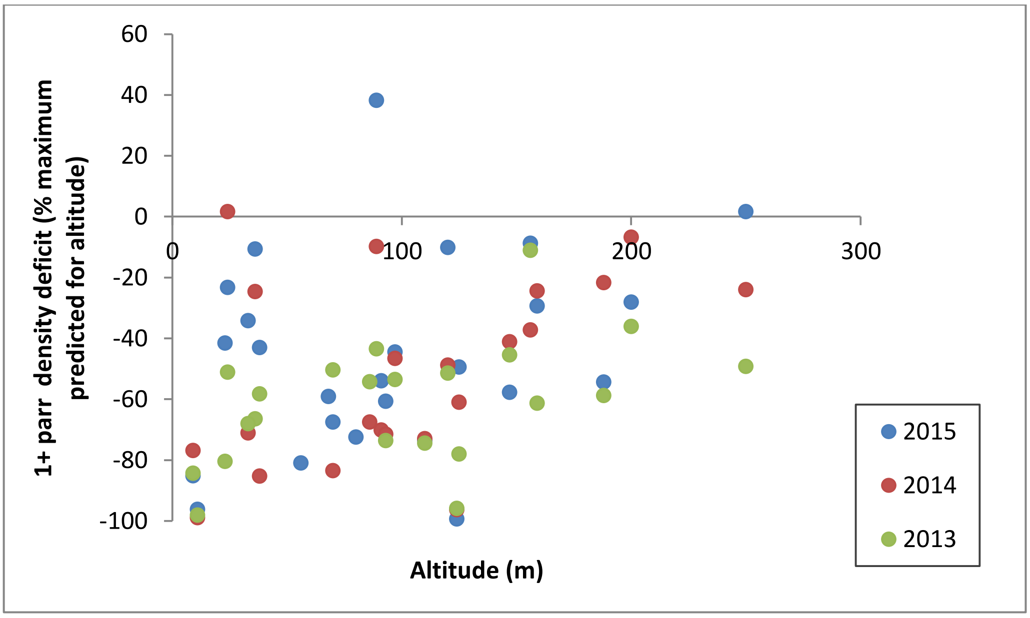


Figure 8. The extent of the shortfall in 1+ parr density (%) from the values predicted from site altitude. All the points for each of the years in included.

There are two inherent risks in the predictive approach. Firstly, the lines set by eye as boundaries may be set too high or too low. If either is the case, it will affect absolute measures of shortfall (those shown in Figures 5 and 8) but not the relative values between sites. Under these circumstances it will remain valid to compare sites in different years or to compare sites at different altitudes. The second risk is that the slopes of the boundary lines are inappropriate. This is potentially more serious because any error in setting the slope will affect lower and higher altitude sites differently. Figures 5 and 8 suggest that the slopes imposed on the distribution of data points are probably fairly accurate for 0+ and, perhaps to a lesser extent for 1+ parr, since the spread of values at higher or lower altitudes is roughly equivalent.

The accuracy of the predictive approach is set by the number of data points that are available and their distribution across the full range of altitudes. If the Board obtains survey data for future years, additional points could be added to the data sets shown in Figures 4 and 7 in order to refine the boundary lines and to increase the accuracy of the predictive equations.

Table 8 shows the values for 0+ and 1+ parr density expressed as a percentage of the predicted maximum attainable value for the site's altitude. The values are essentially those shown for 0+ in Figures 5 and for 1+ parr in Figure 8. However, 100 has been added to each of the % deficit values (most of which are negative) shown in the figures to generate a positive value for the percentage of the predicted maximum that was actually attained. The cell values are graded and colour-coded, as before.

Site	0+ density (% maximum predicted for altitude)				1+ parr density (% maximum predicted for altitude)		
	2013	2014	2015		2013	2014	2015
Cnoc-glas	13	40	37		26	27	27
Shurrery	52	55	57		57	90	138
Lythmore	42	74	21		49	102	77
Rumsdale	54	65	48		39	76	71
Dalganachan	107	35	34		55	59	42
Dalnagleton	27	30	32		4	3	1
The Fanks		58	147			30	46
Smerrary	46	54			46	32	
Tacher			64				28
Inshag			25				41
Dalemore	95	35	97		50	17	33
Hoy	41		40		20		58
Barrock Mill	1	3	2		2	1	4
Acharole			42				19
The Clow	3	81	38		34	75	89
Sheriff's	44	42	65		32	29	66
Bilbster	8	23	13		16	23	15
Achnaclyth	12	49	24		49	51	90
Culvid	48	39	29		47	53	56
Gobernuisgach	59	87	33		51	76	102
Corrichoich	19	35	37		64	93	72
Braemore	59	59	26		89	63	91
Strathcoull	5	20	9		42	15	57
Wag	47	27	2		41	78	46
Aultibea	26	39	5		22	39	51
Coille Braigh	3	45	6		26	29	39

< 20%	20- 39%	40 – 59%	60 - 79%	80 -99%	>100%

Table 8. The densities of 0+ and 1+ parr, by site and year, relative to the proposed ceiling values imposed by site altitude. The values are expressed as percentages.

The colour-coded ratings in Table 8 are inevitably lower than those shown in Table 6. But, if the proposed altitude ceilings are appropriate and sufficiently accurate, the new ratings describe the functionality of sites more rigorously and in greater detail than before. The high average status of sites with regard to 0+ fish in 2014 (first evident from Table 7) remains evident in Table 8, as judged by the balance of colour codes in the central column of the left-hand panel relative to the other columns. The high status of 1+ parr in 2015 is less evident in Table 8 than in Table 7.

The relationship between 0+ densities and 1+parr densities the following year is examined more critically in Figures 9 and 10.

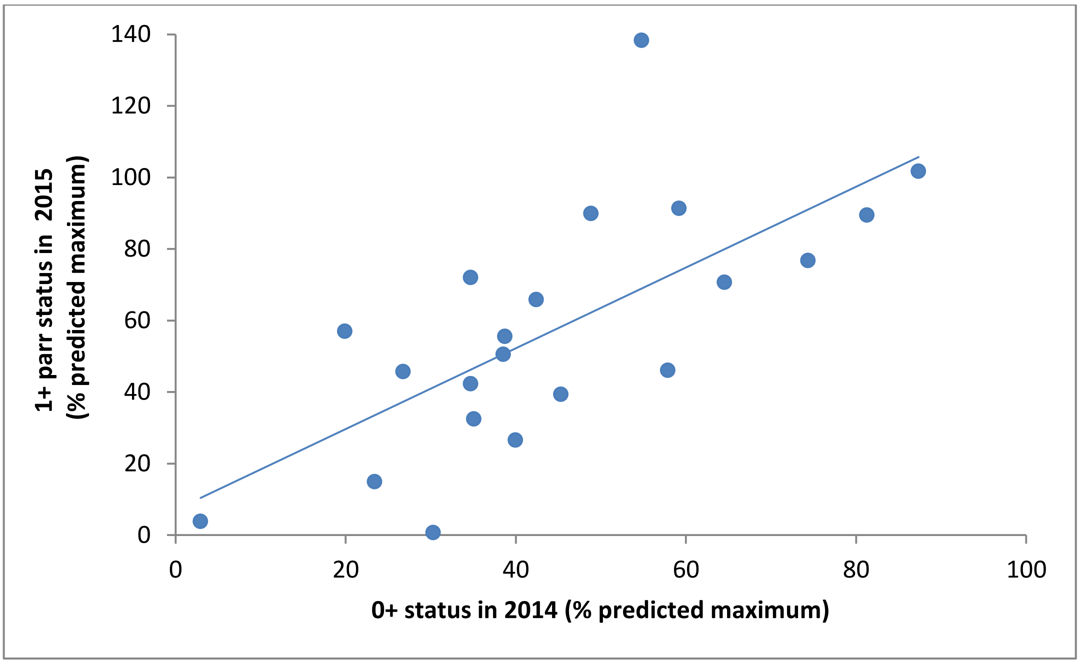


Figure 9. The relationship between the status of 0+ and the status of 1+ parr in successive years: 2014 to 2015.

Figure 9 confirms the relationship between 0+ and 1+ parr using the data for the 0+ of 2014 and the 1+ parr of 2015. High status for 0+ density at any site was associated with high density for 1+ parr at the same site in the following year – although the relationship is rather imprecise.

Figure 10 shows that a similar relationship was not evident between the 0+ fish of 2013 and the 1+ parr of 2014.

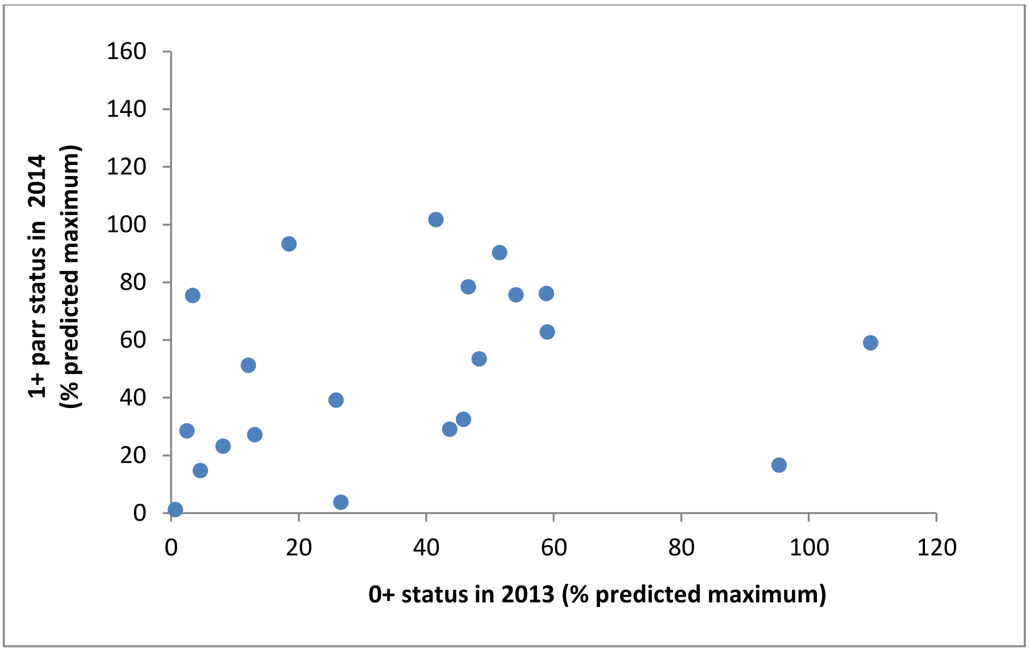


Figure 10. The relationship between the status of 0+ and the status of 1+ parr in successive years: 2013 to 2014.

No additional comparisons are possible because there are data for only three years. However, the difference between Figures 9 and 10 may perhaps be explained by differences in the densities and/or distribution of 0+ fish in 2013 and 2014, as shown in Figure 11.

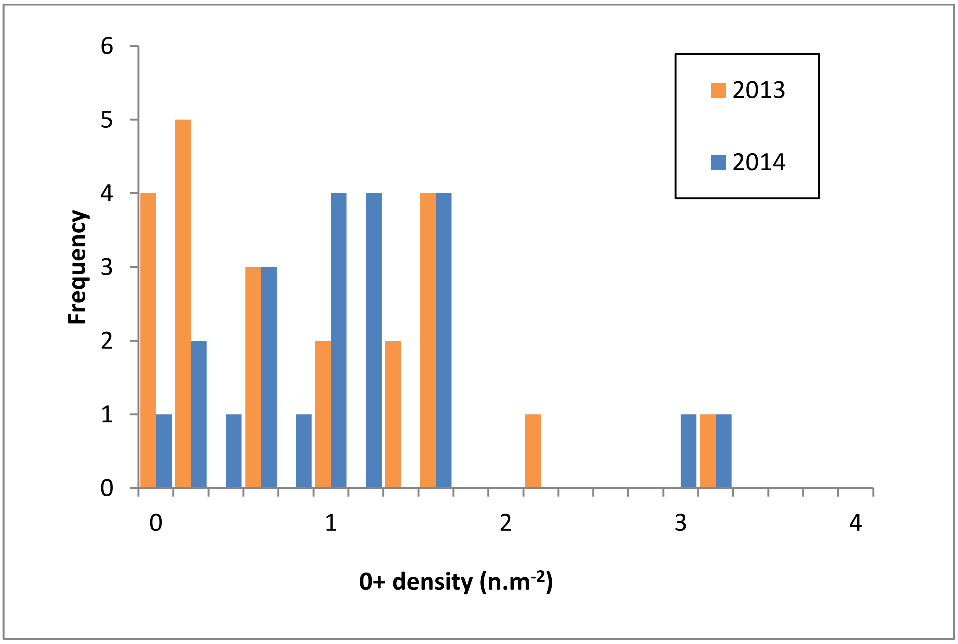


Figure 11. Frequency distribution of 0+ density values for 2013 and 2014.

Figure 11 shows that 0+ fish were more numerous and more evenly spread in 2014 than in 2013. The mean density of 0+ across all the survey sites was 0.98 per m^2 in 2013 and 1.25

per m^2 in 2014, an increase of about 25%. The corresponding median values differed to a much greater extent at 0.68 and 1.17 per m^2, respectively, reflecting the uneven distribution of 0+ in 2013. The greater availability of 0+ fish in 2014 would be expected to push 1+ densities in 2015 upwards at a greater number of sites and the more even distribution of 0+ in 2014 would be expected to reduce the variability of the 1+ response in 2015 – as Figures 9 and 10 suggest may be the case.

Table 9 returns to consideration of variation in the intrinsic capacity of sites to support young fish. The table shows the maximum achieved value for density for 0+ fish and 1+ parr at each site, relative to the proposed ceiling imposed by altitude. Systematic differences in these values will be partly due to variation in site habitat quality and/or differences in the numbers of fish recruiting to any site.

Site	Density (% maximum predicted for altitude). Maximum value achieved.	
	0+	**1+ parr**
Barrock Mill	3	4
Strathcoull	20	57
Bilbster	23	23
Inshag	25	41
Dalnagleton	32	4
Corrichoich	37	93
Aultibea	39	51
Cnoc-glas	40	27
Hoy	41	58
Acharole	42	19
Coille Braigh	45	39
Wag	47	78
Culvid	48	56
Achnaclyth	49	90
Smerrary	54	46
Shurrery	57	138
Braemore	59	91
Tacher	64	28
Rumsdale	65	76
Sheriff's	65	66
Lythmore	74	102
The Clow	81	89
Gobernuisgach	87	102
Dalemore	97	50
Dalganachan	107	59
The Fanks	147	46

< 20%	20- 39%	40 – 59%	60 - 79%	80 -99%	>100%

Table 9. Comparison of the maximum values achieved for 0+ and 1+ parr relative to the proposed ceilings on fish density imposed by altitude. The survey sites are ranked according to the values for 0+ fish.

Several noteworthy points emerge from Table 9.

1. There is a general correspondence between 0+ and 1+ parr rankings, judged by the preponderance of blue and green values in the lower part of both columns. This means that high-status 0+ sites tend also to be high-status for 1+ parr.

2. Dalemore, Dalganachan and The Fanks are the highest ranking sites for 0+ but their ranking for 1+ parr appears to be anomalously low.

3. Barrock Mill is ranked lowest for both 0+ and 1+ parr and, in both cases, the maximum density level achieved over three survey years is less than 5% of the predicted maximum. The site appears to be of relatively high habitat quality. Therefore, it is probable that 0+ numbers are consistently limited by low recruitment (probably arising from low egg deposition) and that 1+ recruitment is severely constrained by the general lack of recruiting 0+.

4. The large disparity between 0+ and 1+ parr rankings for Strathcoull and Corrichoich may be explained by the high energy nature of both sites. In each case, the streambed comprises only boulders or large rocks. These afford adequate shelter for parr but both sites have been stripped by flood-water of the finer material that affords shelter for 0+ fish in particular and/ or suitable ground for spawning.

5. The disparity in the 0+ and 1+ parr rankings for Acharole and Tacher may result from their having been surveyed only once (in 2015). Additional survey work in future years might well reduce any mismatch.

6. Gobernuisgach is classed as a high-status site for both 0+ and 1+ parr but, because of its high altitude, fish of both classes are present only at low density (see Table 1). In the same way, the low-altitude site at Bilbster is classed as being of only low status for 0+ despite their being present at relatively high density.

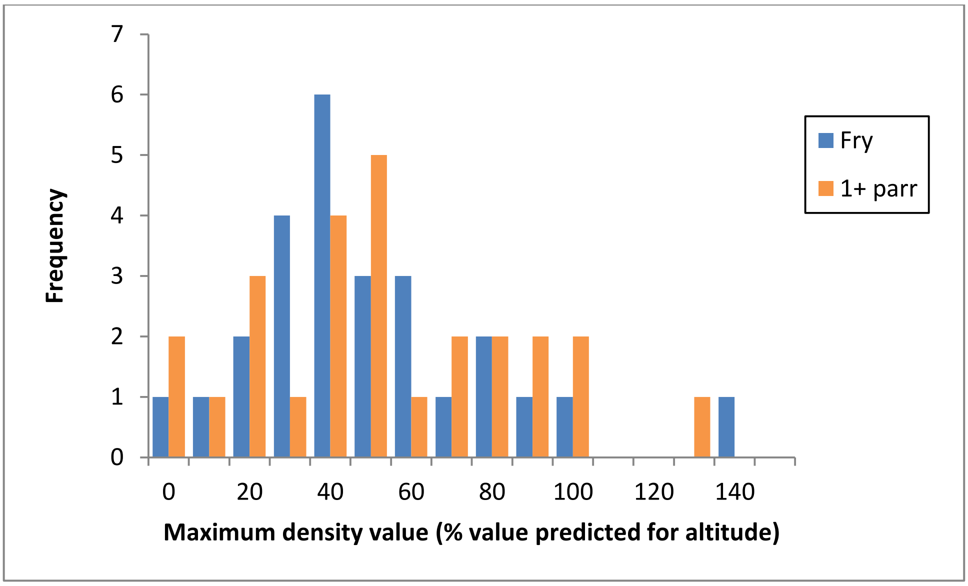


Fig 12. The frequency distribution of site status values for 0+ and 1+ parr.

Figure 12 shows that the values for maximum density observed for 0+ fish and 1+ parr both show approximately normal distributions. The distributions for both age classes are also approximately equivalent. The median values for 0+ and 1+ parr were 49% and 56% respectively and the corresponding average values were 56 and 59%. Therefore, between 2013 and 2015, and at their best, the Caithness sites proved capable of supporting both 0+ and 1+ parr at an average value of about 50% of the proposed ceiling values for density imposed by altitude. Some of the shortfall may be due to consistent, sub-maximal recruitment – perhaps in sites remote from spawning. However, since average 0+ recruitment was very high indeed in 2014 (1.25 per m^2), it is likely that many sites were charged with fish to near capacity. In this case, the values shown in Fig 12 may be near to the highest values that are likely to be achievable. In this case, and bearing in mind that the negative effects of altitude on fish density have been eliminated or reduced by the data treatment, most of the residual shortfall evident in Figure 12 will be attributable to variation in habitat quality.

Incorporating body size.

In previous annual reports it was noted that both 0+ and 1+ parr at Barrock Mill, where fish are consistently present only at very low densities, were much larger than fish of the same age at any of the other locations. Large size at low density suggests that low levels of competition free fish to grow more rapidly, nearer to their maximum capacity to do so. Equally, at some sites, 0+ or 1+ parr were anomalously small when their densities were very high, suggesting that performance may sometimes be constrained by the effects of competition. The 2015 survey provided a further opportunity to explore this idea.

Figure 13 repeats the data shown in Table 3 for 0+ fish and Figure 14 shows the equivalent data for 1+ parr.

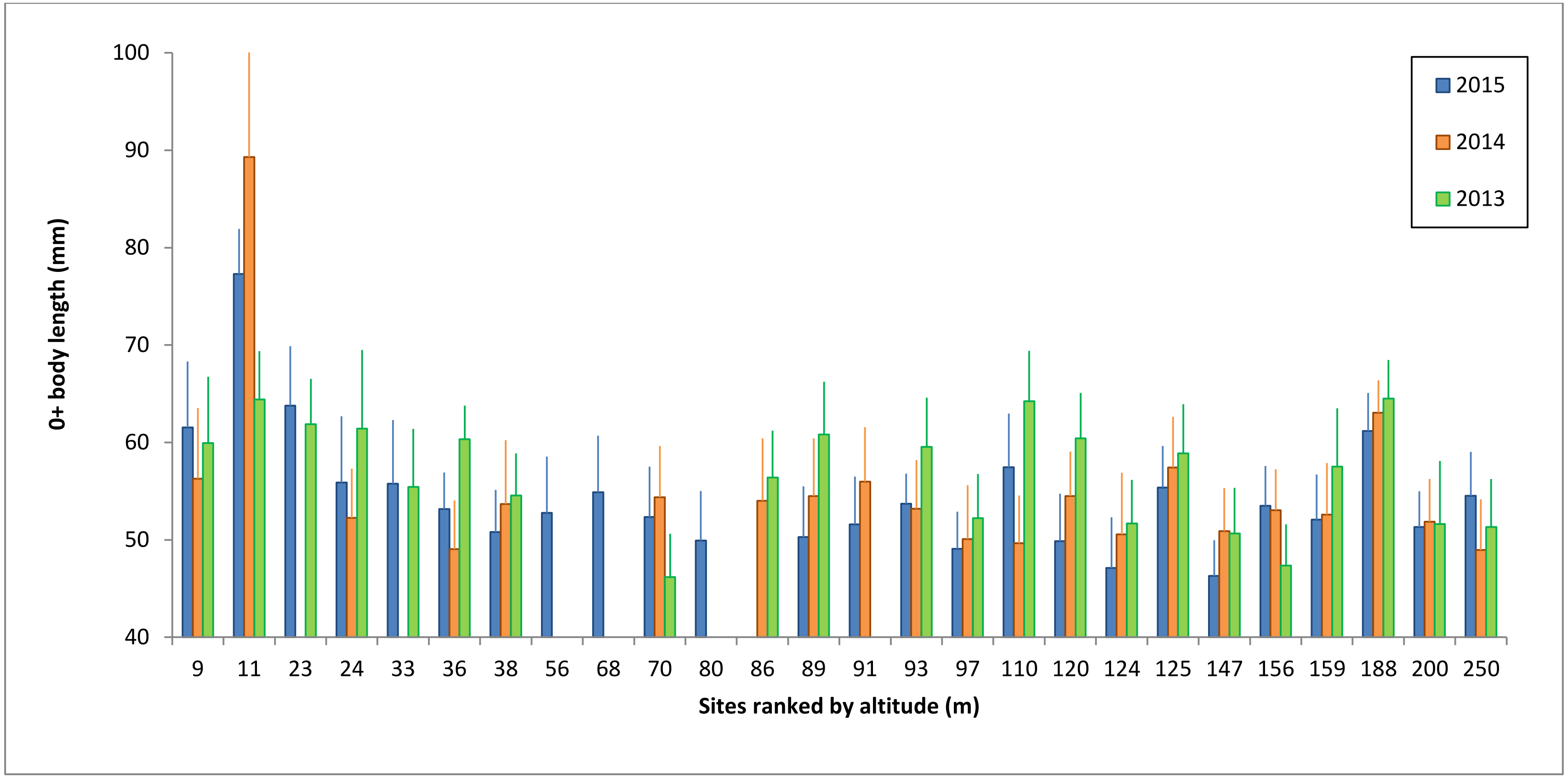


Figure 13. Mean body length of 0+ fish for sites ranked by altitude (the SD is indicated).

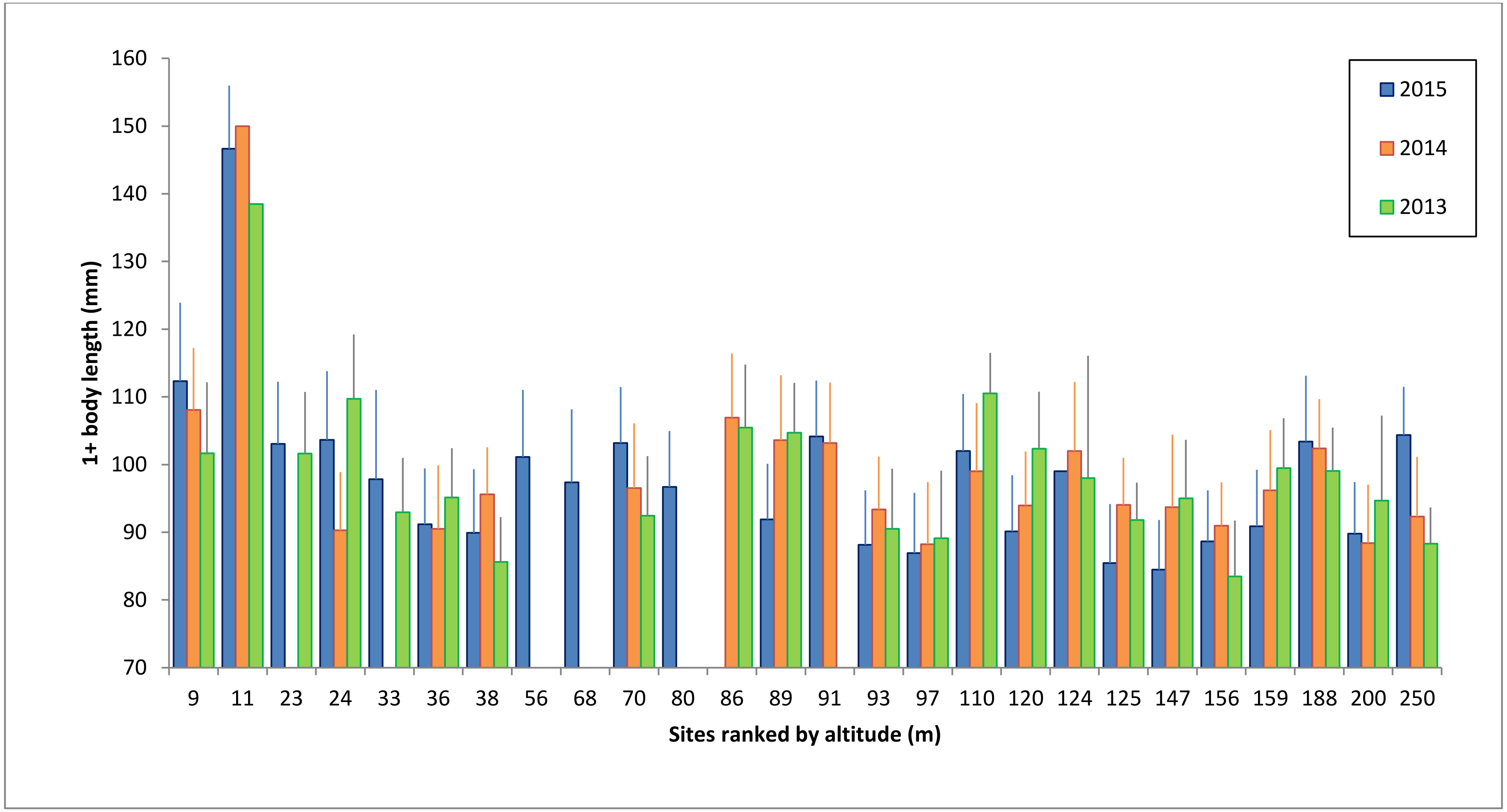


Figure 14. Mean body length of 1+ parr for sites ranked by altitude (the SD is indicated).

Figures 13 and 14 show that there was substantial variation in average body length both within and between sites. However, there is no obvious relationship between the altitude of a site and the average body length of either 0+ or 1+ parr living there. Nor are there are obvious systematic differences in body length between survey years for either age class.

Adopting a more pragmatic approach, the 2015 survey provided several new scenarios which can be inspected for evidence that fish density and fish size are linked. As in 2013 and 2014, low densities of very large 0+ and 1+ parr were present at Barrock Mill (at 11m in Figures 13 and 14) in 2015. On the other hand, despite the exceptionally high density of 0+ fish (4.5. m^{-2}) at The Fanks site (91m), no marked effect was apparent on the size of the fish. Additionally, 0+ densities at Wag (188m), Coille Braigh (93m), Strathcoull (38m) and Aultibea (125m) sites were all much lower than in previous years but no marked increase in 0+ size was apparent. In other words, inspection of the 2015 survey data did not provide any new support for the idea that competition and fish size are linked.

However, all these comparisons are limited to considering competition within single age-classes. As pointed out in a previous report, it could also be, for example, that the number and/ or size of the parr already present at any site affects the recruitment of the new class of 0+ and/or their subsequent growth. It may also be possible that the performance of the existing parr is affected by the recruiting 0+. Furthermore, 1+ parr will have experienced two somewhat independent phases of competition in its two years of stream life and its size in its second year probably reflects this history in some complex way.

A potential solution to handling numerous inter-linked variables is to model the data using statistical techniques. Deploying a modelling approach in the context of assessment requires specialist skills and resources that are beyond the reach of the Board itself. However, MSS is currently working on related modelling projects and it may be that these will eventually become available for modelling the Board's data.

In the interim, some of the advantages of being able to examine multiple variables can be gained by examining biomass, and particularly biomass density. Biomass density combines numerical density and body size to give the weight of fish (rather than their number) per unit wetted area of stream. The actual weights of the fish are not known but their body lengths are determined during surveys and body length can be converted to body weight using the formula derived by Shackley (see 2013 Annual Report). Furthermore, since the age of all the fish captured in the surveys is known from scale-reading, biomass density can be calculated separately for each of the age-classes present at any survey site. The biomass approach emphasises the performance of fish and the performance of survey sites; it emphasises the levels of fish production that sites achieve, rather than limiting assessment to consideration only of the number of fish that are present.

Figures 15, 16 and 17 show the total biomass density values for each site in 2013, 2014 and 2015, respectively. The values are expressed as grams per square meter of wetted stream area. The separate contributions of 0+, 1+ parr and older parr are indicated. The latter mainly comprise 2+ parr although a few 3+ parr and one 4+ parr are also included. (Appendix 1 lists the primary data for parr older than 1+ at each site in each year). The data for older parr have been treated in the same way as for 1+ parr to generate estimates of biomass density for each survey site in each year. As stated previously, older parr are generally sparse throughout Caithness. However, since they are relatively large they contribute substantially to the values for total biomass density at some of the sites.

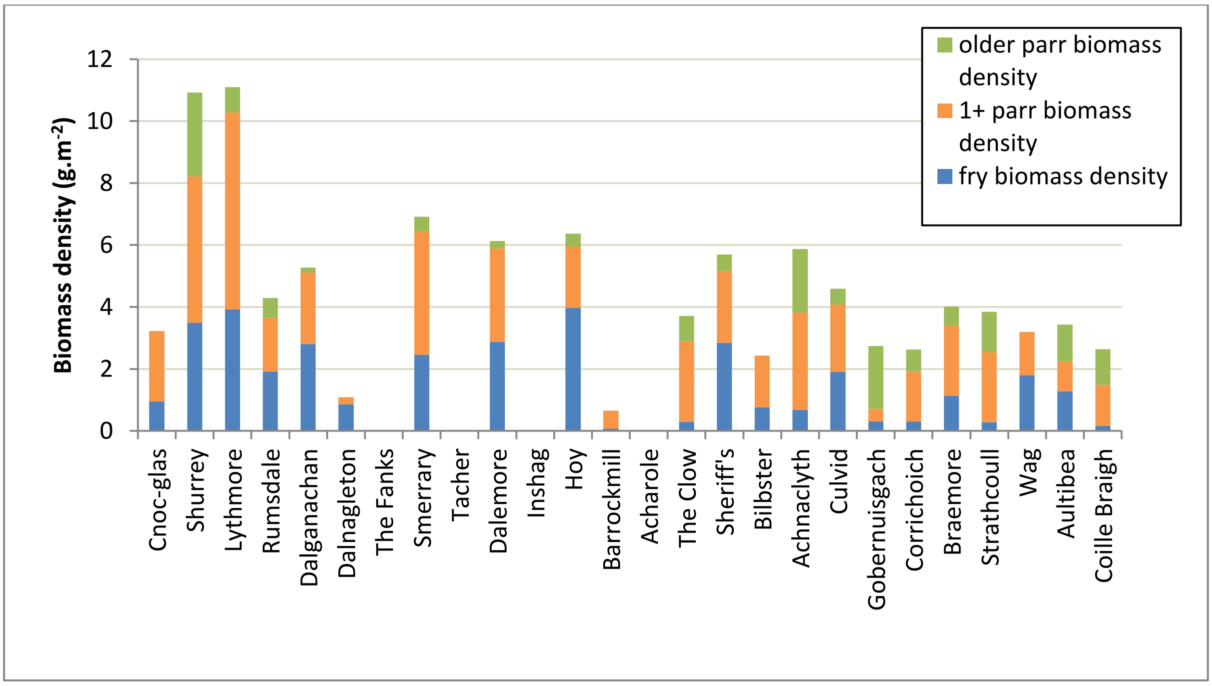


Figure 15. Total fish biomass densities for each survey site in 2013. The individual contributions of 0+, 1+ parr and older parr are indicated.

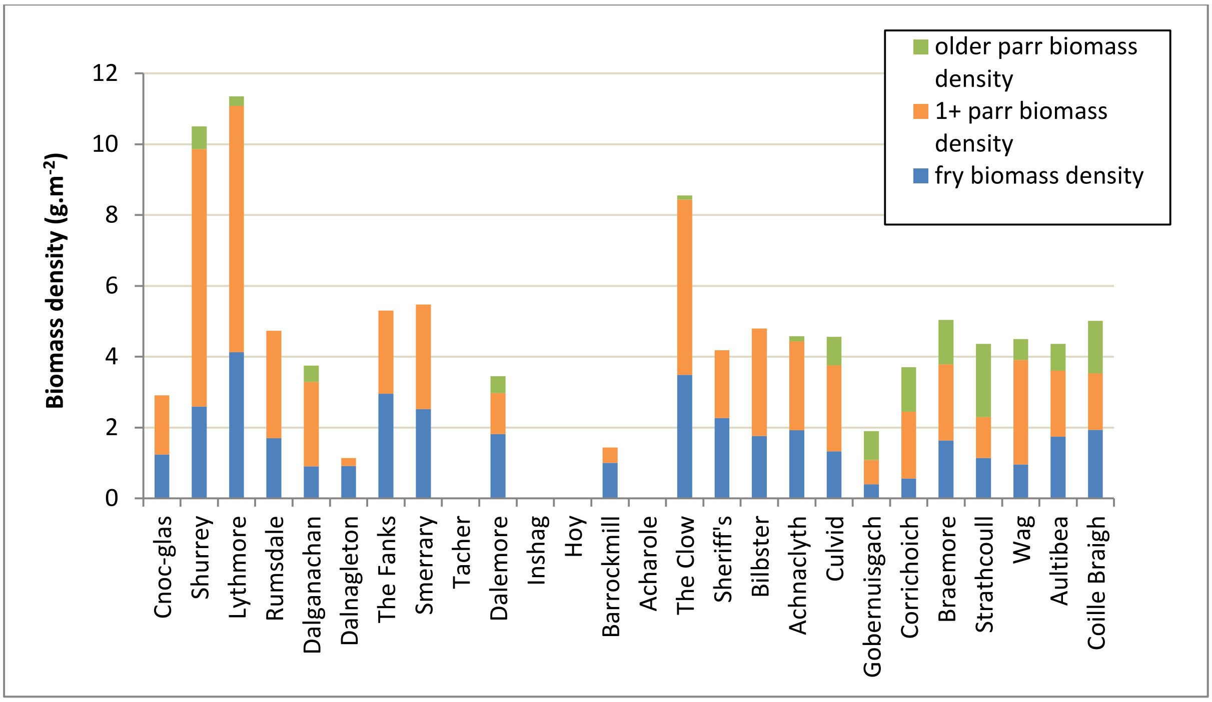


Figure 16. Total fish biomass densities for each survey site in 2014. The individual contributions of 0+, 1+ parr and older parr are indicated.

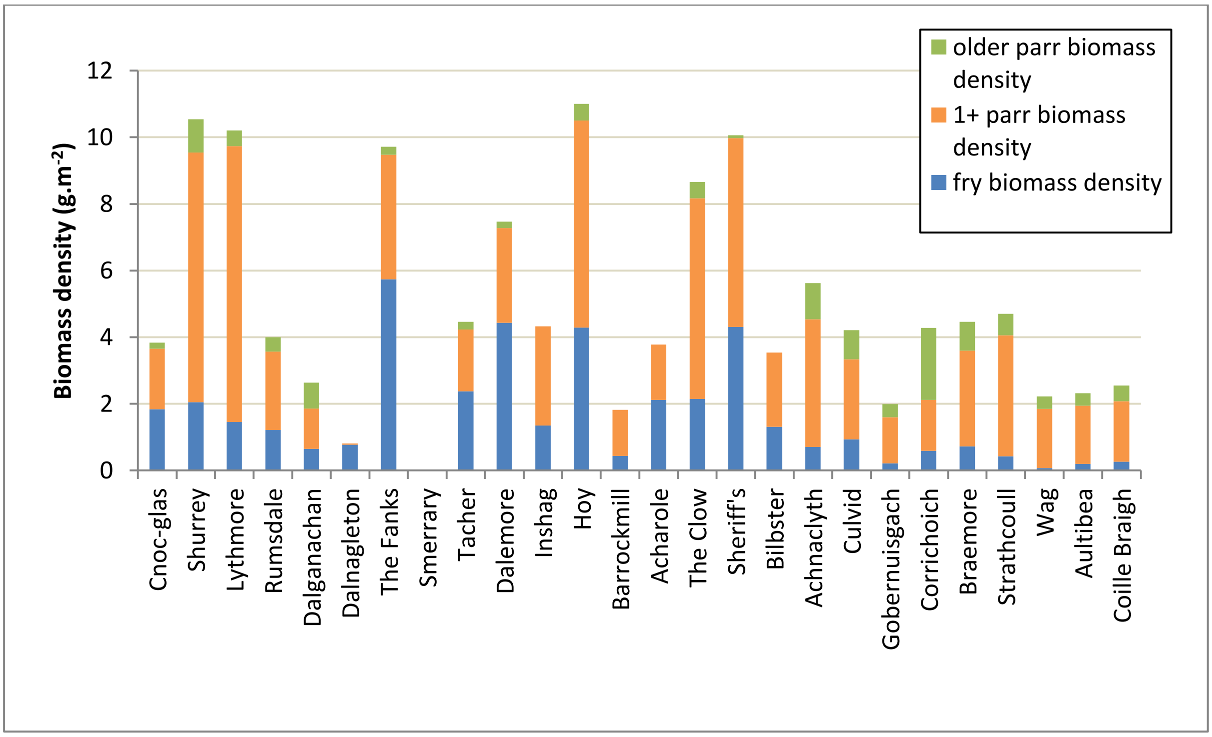


Figure 17. Total fish biomass densities for each survey site in 2015. The individual contributions of 0+, 1+ parr and older parr are indicated.

Figures 15 - 17 show that total biomass density varied widely between sites every year. The separate contributions made by each of the three year-classes varied markedly between sites in any given year and, to a lesser extent, between years for any particular site.

Figure 18 shows the total biomass density at each site for all survey years; the survey sites are ranked by altitude. Wide variation is apparent between sites. There is no clear relationship between altitude and total biomass density although values at higher altitudes tend to lie in the lower part of the total range of values. Values at Shurrery, Rumsdale and Braemore, for example, varied very little between years; sites like Dalemore and Bilbster varied widely between years.

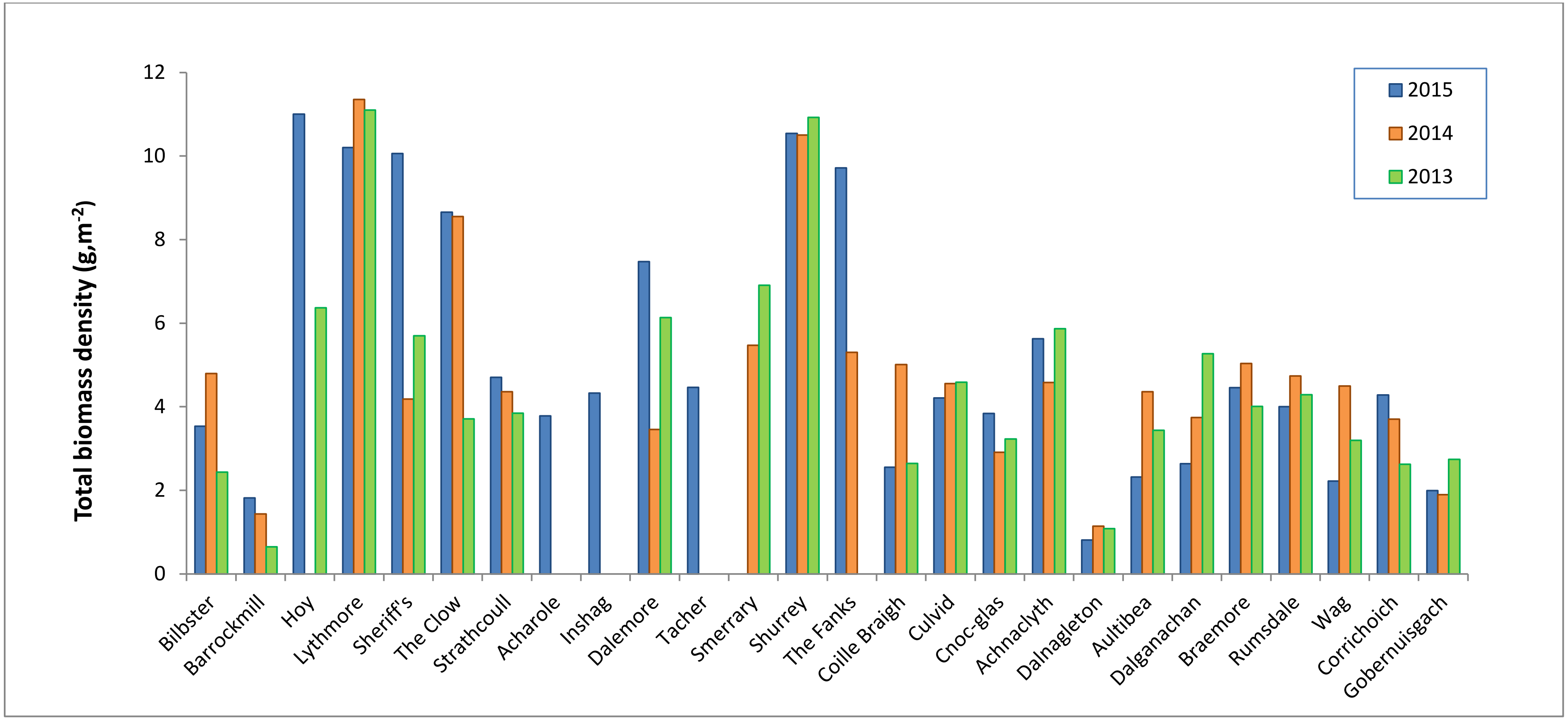


Figure 18. Total biomass density for each site in each of the three survey years. The sites are ranked by increasing altitude.

In Table 13 the total biomass density for each year has been expressed as a percentage of the maximum value observed at the same site in any of the survey years. The percentage values have been allocated to bands and colour-coded, as before.

Site	Biomass (% max value observed)		
	2013	2014	2015
Cnoc-glas	84	76	100
Shurrery	100	96	97
Lythmore	98	100	90
Rumsdale	85	100	91
Dalganachan	100	71	50
Dalnagleton	95	100	71
The Fanks		55	100
Smerrary	100	79	
Tacher			
Inshag			
Dalemore	82	46	100
Hoy	58		100
Barrock Mill	36	79	100
Acharole			
The Clow	43	99	100
Sheriff's	57	42	100
Bilbster	51	100	74
Achnaclyth	100	78	96
Culvid	100	99	92
Gobernuisgach	100	79	63
Corrichoich	61	87	100
Braemore	89	100	80
Strathcoull	82	93	100
Wag	71	100	49
Aultibea	79	100	53
Coille Braigh	53	100	51

< 20%	20- 39%	40 – 59%	60 - 79%	80 -100%

Table 13. Total biomass density for each site expressed as a fraction (%) of the maximum value (set to 100%) observed at the same site in any of the survey years. The sites at Tacher, Inshag and Acharole are excluded because they were surveyed only once.

Table 13 shows sets of matching blue or green colour code for many of the sites. This indicates that the distribution of biomass density values is more compact than the equivalent values for 0+ or 1+ parr density shown in Table 7.

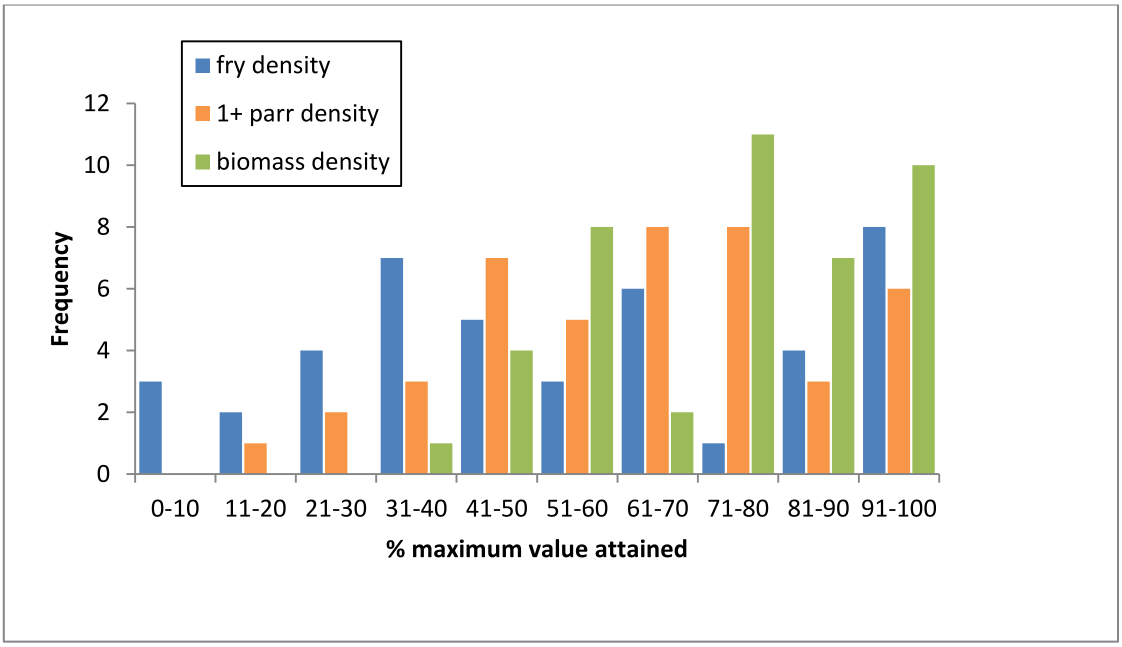


Figure 19. Frequency distribution of values for 0+ and parr density (as presented in Table 7) and total biomass density (as presented in Table 13). The values set to be 100% at each site have been excluded. The Inshag, Tacher and Acharole sites are excluded because they were sampled only once.

Figure 19 demonstrates this more clearly. The extent to which 0+ density values deviate from the maximum value observed at the same site varies widely, the 1+ parr densities vary less but the values for total biomass density vary least of all. This indicates that biomass does, indeed, capture some important aspect of site performance that is not captured by numerical density values for 0+ fish or for 1+ parr.

This can be examined further by comparing the original data for fish density (as per Table 3) with the corresponding values for biomass density. Figures 20a and b, respectively, show numerical and biomass density values for Lythmore on the River Forss. The values for the older parr are based on those specified in Appendix 1. Lythmore has been chosen as an initial illustration because it consistently showed the highest total biomass densities achieved at any of the Caithness sites and was probably near saturation. However, the corresponding values for all the sites are given in the Site Assessment section which follows.

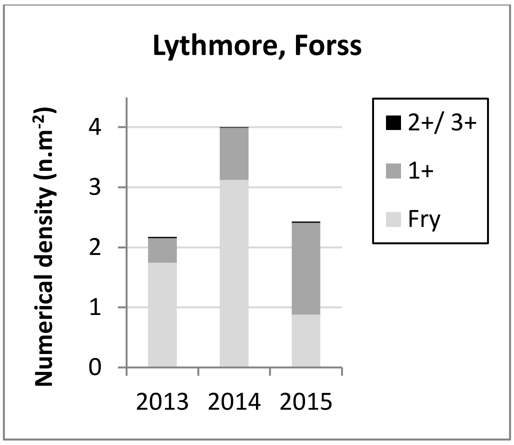


Figure 20a. Numerical density values by age-class and year for Lythmore.

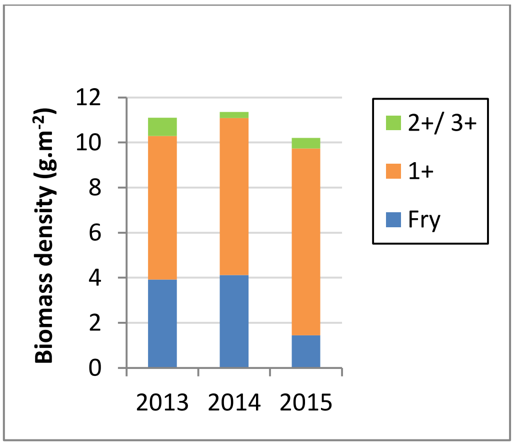


Figure 20b. *Biomass density values by age-class and year for Lythmore.*

Figure 20a shows wide variation between years in the numerical density of 0+ fish (0.88 – 3.12.m^{-2}) and 1+ parr (0.41-1.53.m^{-2}). In both cases, however, the differences in density are tracked, or partially tracked, by variation in body size.

Thus in 2013, when 0+ were moderately abundant and 1+ parr were few in number the average body length of 0+ was 61mm. In 2014, when 0+ were most abundant, their average body length was only 55mm. In 2015, when 0+ were few in number but 1+ parr were most abundant, the average length of 0+ was 56mm.

In 2013, 1+ parr were few in number and their average length was 110mm. In 2014, when more parr were present and 0+ density was also high the average length of 1+ parr was only 99mm. In 2015, when 1+ parr were most abundant and few 0+ fish were present, the average length of 1+ parr was 104mm. These differences suggest that growth was inhibited by competition from other fish and that the size of the effect varies with density.

As a consequence, when body size is incorporated into the assessment, Figure 20b shows that the variation in all the measurements is reduced suggesting that biomass density captures more of the site's functionality than numerical density alone. In particular, total biomass density is rather similar among years suggesting that the maximum capacity of Lythmore to support fish of all age-classes ismore-or-less fixed at around 10 or 11 g.m^{-2}.

Conclusions

There are at least four factors that appear to affect the numbers and/ or size of fish of any age class at any site in any year. These are the adequacy of recruitment, the physical quality of the habitat, the site's altitude and its competitive environment. It must also be recognised that the survey sites are open-ended and fish of different ages and/ or sizes can move into or out of them at will.

It appears that the capacity of any site for holding fish biomass has a ceiling that is ultimately limited by the site's fixed characteristics - altitude and physical habitat quality. Due to variations in the other factors - recruitment and competition - it seems that the total biomass density at a site like Lythmore can be reached in a multiplicity of different ways involving different combinations fish number, body size and age-class. This means that numerical density values for 0+ or for 1+ parr cannot be properly evaluated on their own; the values need to be viewed in the context formed by all the other fish that are present.

Furthermore, the September surveys provide only a snapshot of a dynamic process that probably evolves continuously over the full year. The picture is likely to be especially fluid in the period after May when emigrating smolts abandon stream habitat for the sea and the new year-class of 0+ fish emerges to compete for the vacated space. The September surveys post-date this phase by several months.

Site assessments.

Table 6 suggests that spawning in the Caithness rivers was generally sufficient to establish strong year-classes of 0+ in the majority the sites in most of the rivers. The Barrock Mill site on the River Wester was a notable exception. Elsewhere, however, local shortfalls in 0+ recruitment tended to become resolved by the 1+ parr stage, probably due to on-going recruitment from the wider stream area. Thus, for example, weak 0+ year-classes at The Clow, Strathcoull and Coille Braigh in 2013 were followed by strong year-classes of 1+ parr in 2014.

Table 8 shows density values for 0+ fish and 1+ parr relative to the maximum predicted for altitude. Although this is probably the most telling summary of the headline values, it does not disclose any of the mechanisms involved. Thus, any shortfall in density from the predicted maximum for altitude could be attributed to any, or all, of the other factors – recruitment, habitat quality and competition. Indeed, having now considered the effects of competition in some detail, it can be seen that part of the proposed effect of altitude on 0+

and 1+ parr numbers may, in fact, be due to competition from the large, older parr that tend to be a particular feature of high altitude sites.

As regards smolt production, the numerical density of 1+ parr (as per Table 3) represents the simplest option for assessing most sites. This is because in Caithness conditions most of the 1+ parr will become smolts the following spring and because some of the variations in fish mortality rate and/ or movement into and out of sites that evidently smooth the distribution of fish between the 0+ and 1+ parr stages have already had their effect by September. Even so, for any particular site, 1+ parr production in one year is not a particularly accurate guide to likely production in another – as Figure 19 shows.

In addition, any over-emphasis on numbers risks neglecting the question of quality. For example, in 2015, the 1+ parr at Bilbster had an average length of 112mm while those at Dalganachan had reached only 85mm. The disparity in body weight is much greater since these values for body length correspond to body weights of around 16g and 7g, respectively. Within sites, the values differed between years and, considering Dalganachan again, the mean body length of 1+ fish reached 95mm (ca. 10g) in 2013. All these values are for September and by smolting time the fish will be larger. However, if the disparities in body size are maintained through to smolting they may well prove large enough to cause differences in survival rate for fish leaving different sites or leaving the same site in different years.

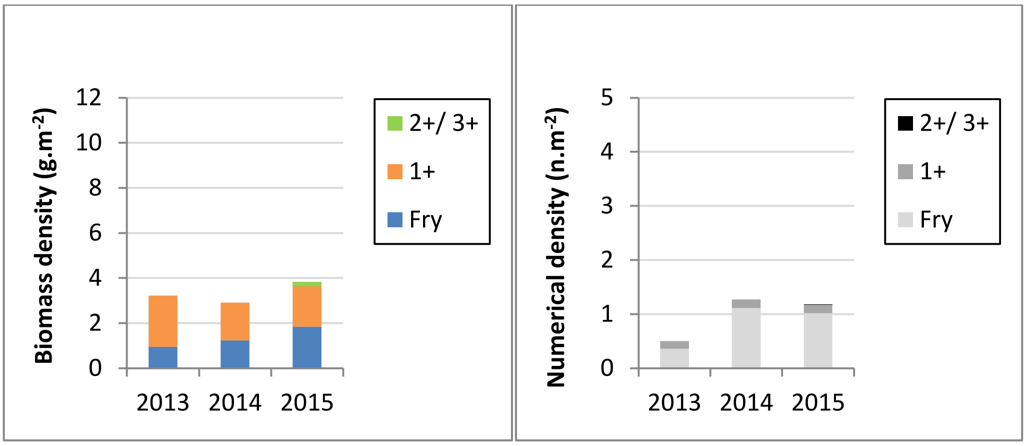
A more ambitious target for fishery managers is to assess the status of sites in relation to their functionality - their capacity to support all the competing age classes over the span of years between hatch and emigration. Biomass density appears to constitute the best measure for doing this – as Figure 19 also shows. Repeat data over a series of years is required to assess inter-annual variation within sites. Once this is in place, each site can be used as its own internal reference standard, with constant up-dating as more survey data becomes available. Total biomass density can be broken down to consider the separate contributions of the year classes and combined with numerical density values to provide a fuller picture. This approach targets an understanding how sites function, how they relate to one another and how they perform each year in relation to their potential. If this can be understood, then evident weaknesses can be pin-pointed and considered for management.

From a practical point of view, the main weakness in the biomass approach is that the number of older parr present in any survey sites is generally low, making accurate estimation of their density, and therefore their biomass density, problematic. In the case of biomass density, the difficulty is also compounded by the large quantal contributions sometimes made by a very few, very large fish (see Appendix 1).

With this caveat, the biomass density values for each of the Caithness sites have been used as a basis for the assessments listed below (Figures 21.1 – 21.26). The values for numerical density are also shown for comparison. The commentaries for each site draw on numerical density and length data when these seem informative. Site altitude is specified. The vertical axes of the sets of graphs have been set to the same maximum at each site in order to aid comparison.

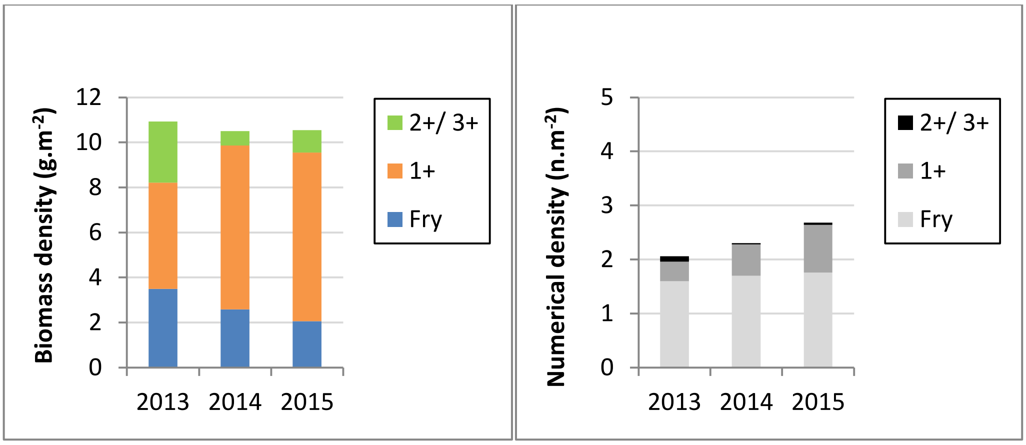
Forss Water

21.1 Cnoc-glas – 110m



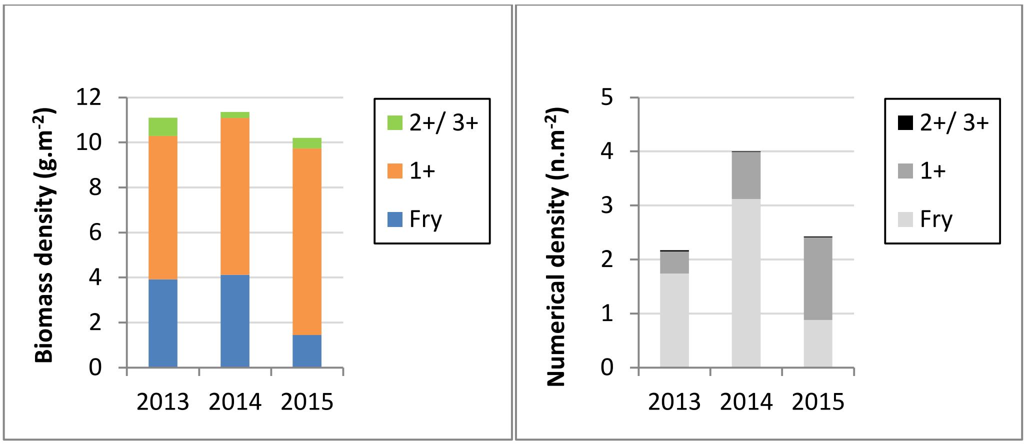
Cnoc glas is the highest altitude site on the Forss. 0+ and 1+ parr predominated. Total biomass densities were more similar between years than the contributions of the individual year-classes. The maximum value was 3.8 g.m^{-2}. This is one of the lower values for the Caithness sites. 0+ were notably small in 2014 and notably few in 2013.The numerical densities of 1+ parr were similar among years. Production of smolts is probably therefore uniform and somewhere near capacity.

21.2 Shurrey – 89m



Shurrery is one of the most productive sites in Caithness. The maximum biomass density for salmon of all ages combined was 10.9 g.m^{-2}. Values were similarly high in all years. Total biomass densities were more similar than the contributions made by the individual year-classes. The 0+ were notably large in 2013 and the 1+ parr were notably small in 2015 for reasons that are not clear. The site is functioning consistently well and probably near its maximum capacity to produce smolts.

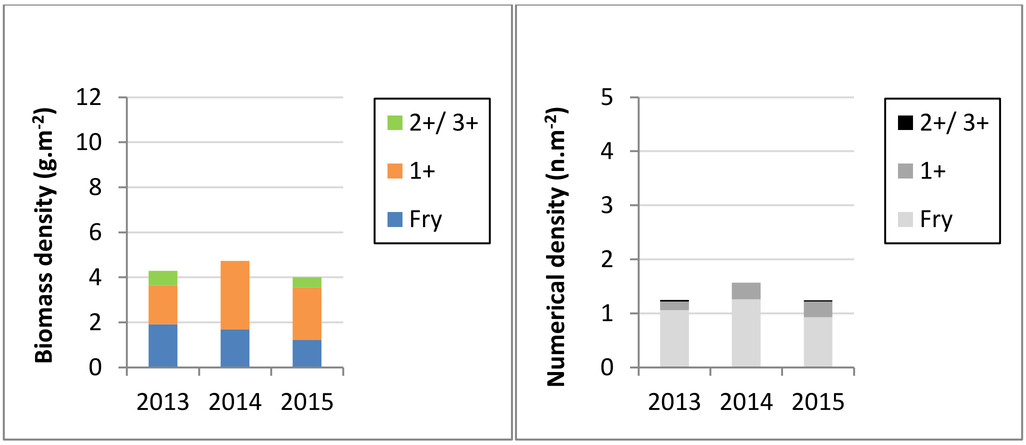
21.3 Lythmore – 24m



Lythmore is also extremely productive. The maximum biomass density for salmon of all ages was 11.4 g.m^{-2}; values were similarly high in all years. Again, total biomass densities were more similar than the contributions made by the individual year-classes. 0+ were notably large in 2013 and the 1+ were notably small in 2014. Lythmore, like Shurrery 13km upstream, is functioning consistently well and probably near to its maximum capacity to produce smolts.

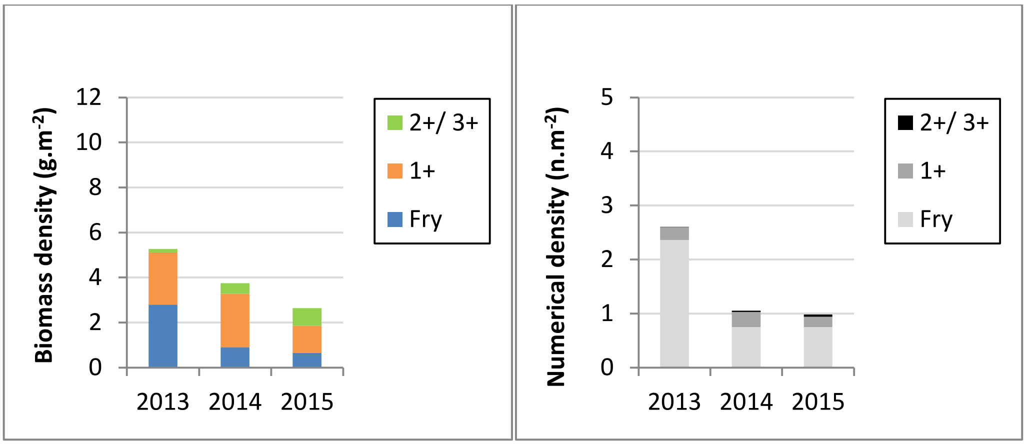
Thurso River

21.4 Rumsdale – 159m



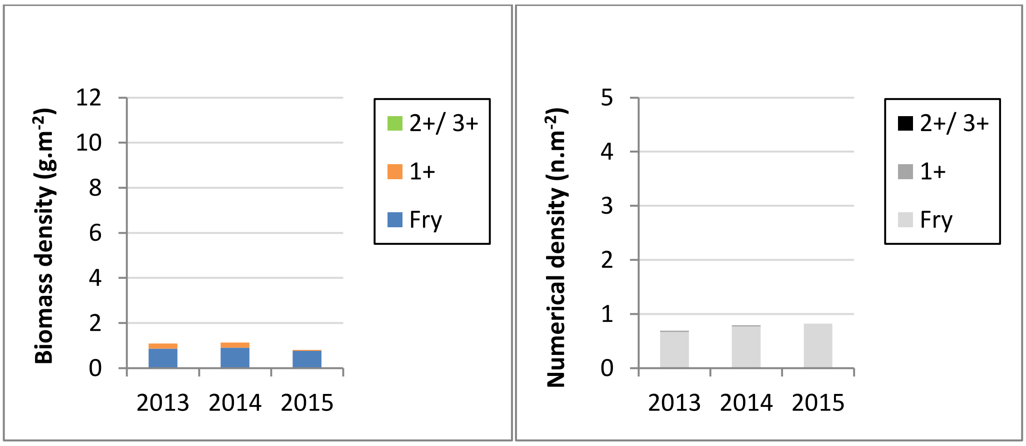
Rumsdale is the highest of the Thurso sites. The maximum value for biomass density was 4.7 g.m^{-2}. Values were rather similar in all years. Again, total biomass densities were more similar than the contributions made by the individual year-classes. The values achieved at Rumsdale were similar to those achieved at sites of similar altitude - for example, at Braemore or Cnoc glas. Rumsdale functions consistently and probably near its maximum capacity to produce smolts.

21.5 Dalganachan - 147m



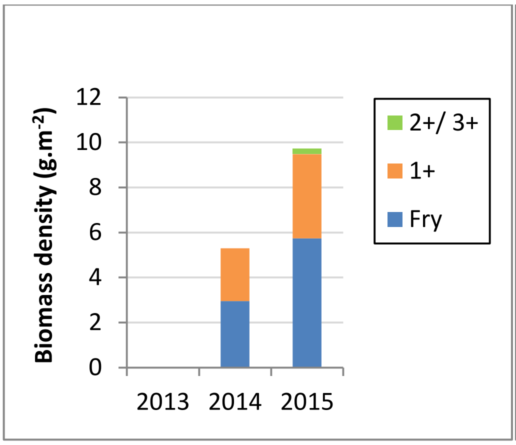
The highest biomass density achieved at Dalganachan was 5.3 $g.m^{-2}$ in 2013 when 0+ numbers were highest. The lowest level was 2.6 $g.m^{-2}$ when both the 0+ and the 1+ parr were relatively small. Despite this, the numerical densities of 1+ fish were rather similar in all years. The biomass densities of parr of all ages were more similar still because larger older parr were present in years when 1+ parr were fewer. The site is complex but smolt output is probably robust and near maximal.

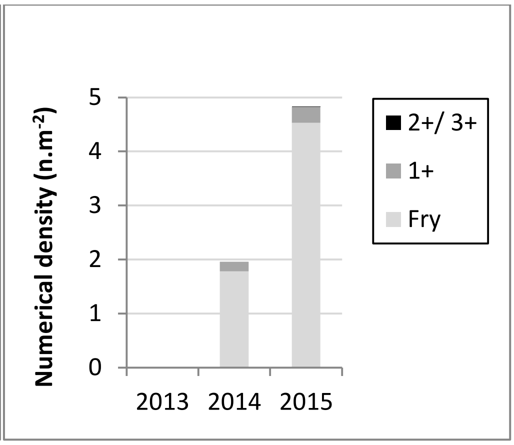
21.6 Dalnagleton – 124m



Dalnagleton is the most unproductive of the survey sites. 0+ are present at modest numerical density; the maximum value observed was 0.82.m^{-2} in 2015. The 0+ are also small and parr are very scarce. The low productivity of the site and, especially the scarcity of parr, are caused by the stream substrate being uniformly composed of fine gravels, lacking the complexity imparted by larger stones or rocks. In this respect, the site is typical of the lower reaches of the upper Thurso near to Loch More.

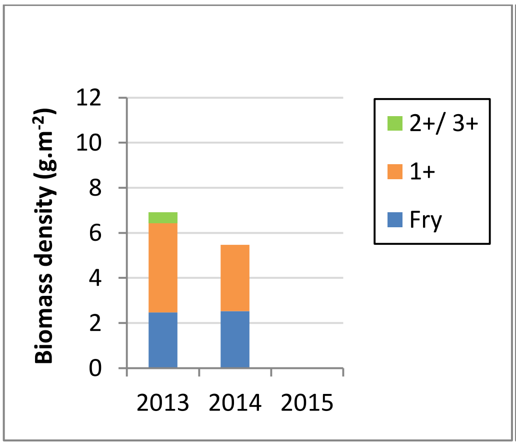
21.7 The Fanks – 91m

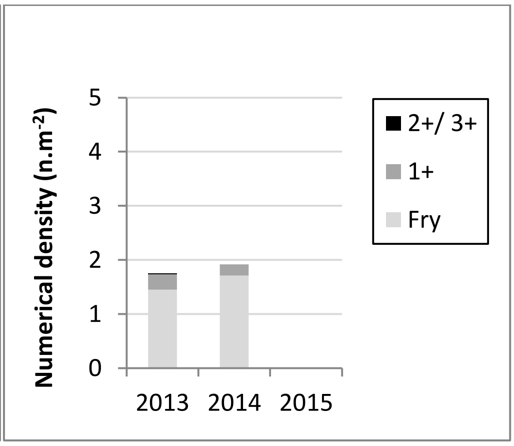




The Fanks is located on a side channel. It was surveyed in two years as a possible, more accessible alternative to the nearby site on the main river-stem at Smerrary. The parr are consistently large. The site was very productive in 2015 at 9.7 g.m^{-2}, mostly due to the exceptionally high density of 0+ (4.5.m^{-2}). 0+ density in 2014 was 1.8.m^{-2}. The 0+ were larger in 2014 than in 2015. Conditions in the side channel may vary annually due to changes in river level and this may be reflected in the variability observed. Smerrary, therefore, may be the more representative site.

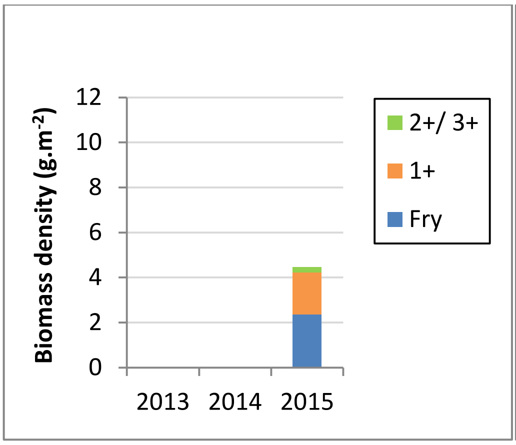
21.8 Smerrary – 86m

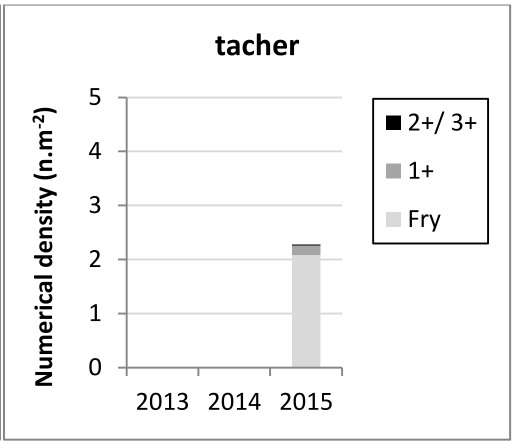




Smerrary is a main-stem site near The Fanks. In 2014, both sites were surveyed and the size, density and biomass density values were all very similar. 0+ and parr densities were similar at Smerrary in 2013 and in 2014. The biomass density was 6.9 g.m^{-2} in 2013 and 5.5 g.m^{-2} in 2014. Smerrary functions consistently and probably somewhere near its full capacity. It is probably superior to The Fanks as a monitoring site.

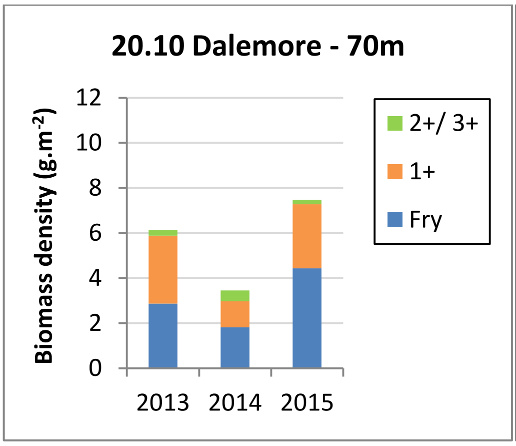
21.9 Tacher – 80m

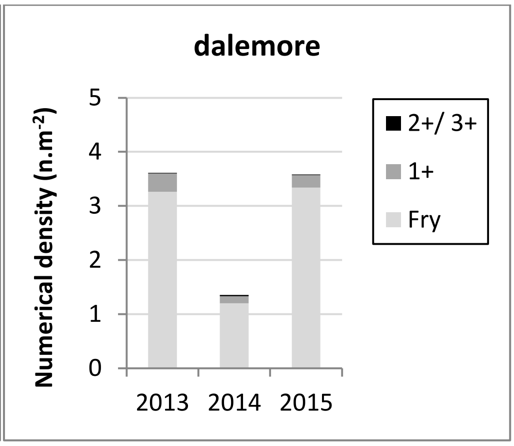




The site at Tacher was surveyed only in 2015. The site is on the Little River about 4.5 km upstream of its confluence with the main river. Tacher supports a high density (2.09.m^{-2}) of relatively small 0+ (50mm average) and a modest density of 1+ parr of near-average size. The biomass density was 4.5 g.m^{-2}. This value is marginally higher than the median value for all the Caithness sites in 2015. Further surveys would be required to rate the site with greater confidence.

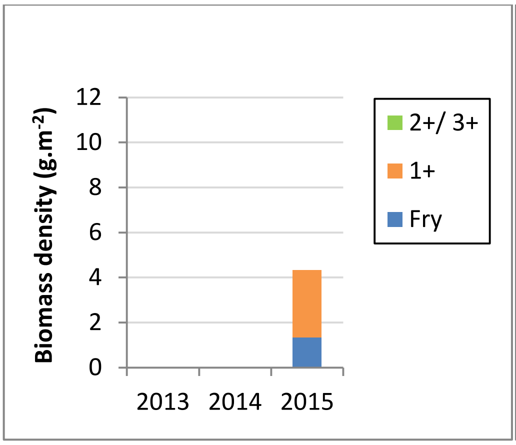
21.10 Dalemore – 70m

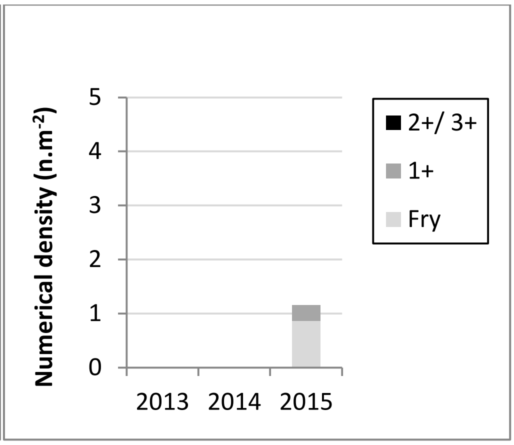




Dalemore lies on a side channel. In 2013 and in 2015 it held 0+ at densities of more than 3.m^{-2}. The 0+ were very small in 2013. The site also supports modest densities of 1+ parr that vary greatly in length among years for reasons that are unclear. In 2015 the highest biomass density value was observed at 7.5 g.m^{-2}. Dalemore is relatively variable among years perhaps because, like The Fanks, the side channel may be susceptible to inter-annual variation in river flow.

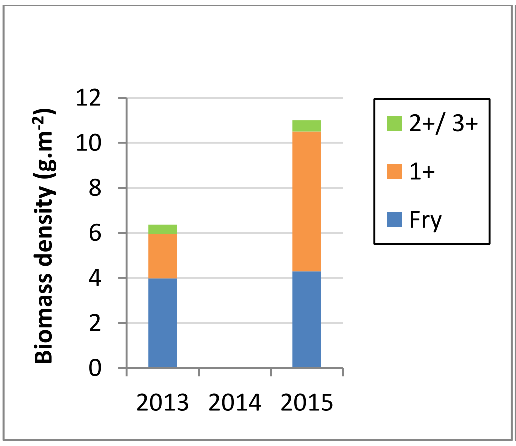
21.11 Inshag – 68m

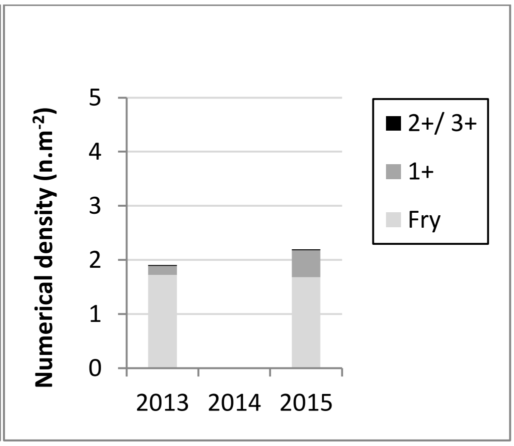




Like Tacher, the Inshag site is located on the Little River. Inshag is about 300m above the Little River's confluence with the main river. The site was surveyed only in 2015, when the biomass density was very similar to the value at Tacher at 4.3 $g.m^{-2}$. However, the proportional contribution of 0+ to biomass was much less at Inshag than at Tacher and the contribution of 1+ parr to total biomass density was much greater. Further survey work would be required to assess Inshag more thoroughly.

21.12 Hoy – 23m

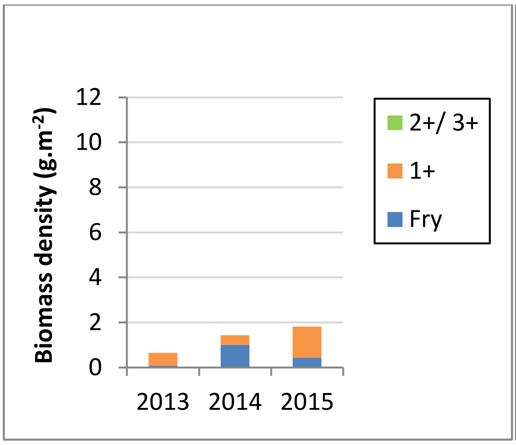


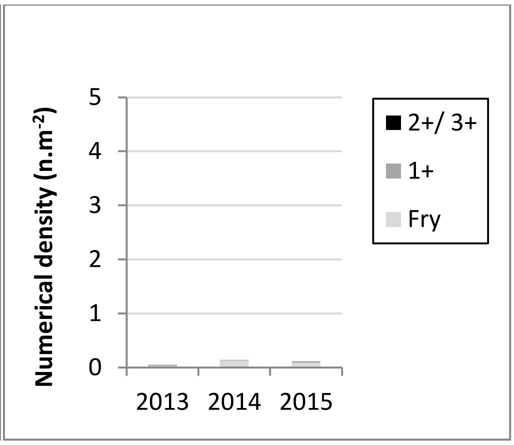


Hoy is a main-river site and the lowest altitude site on the Thurso. The site was surveyed in 2013 and 2015. 1+ Parr were few in 2013 ($0.17.m^{-2}$) but abundant in 2015 ($0.50.m^{-2}$); 0+ were abundant in both years. Body length was similar in both years for both 0+ and 1+ parr. Biomass density was 11.0 $g.m^{-2}$ in 2015. This is among the highest values observed during the surveys. Hoy probably functioned near full-capacity in 2015 but the scarcity of 1+ parr in 2013 is unexplained.

River Wester

21.13 Barrock Mill – 11m

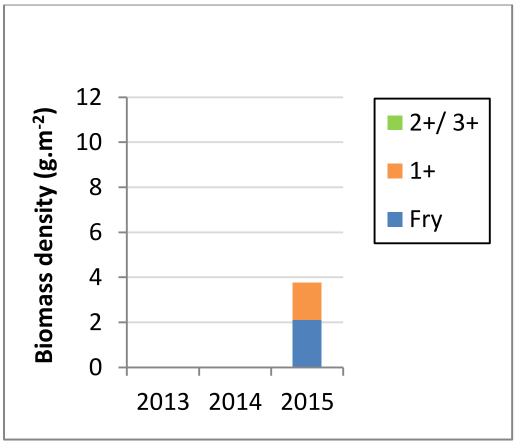


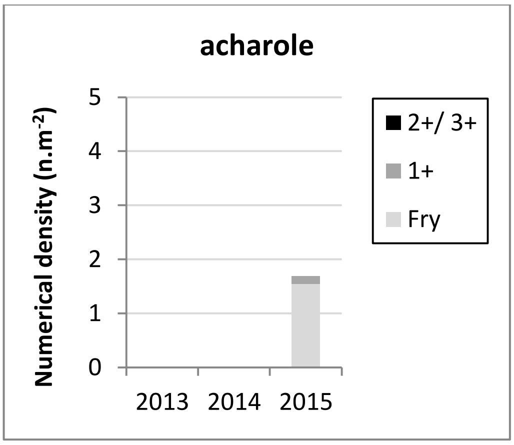


Barrock Mill is the only site on the River Wester. Despite its low altitude, the site supports very low densities of both 0+ and 1+ parr. The habitat appears to be of excellent quality and fish of both age-classes are exceptionally large, suggesting that the site could readily support greater numbers. The site evidently suffers consistently low recruitment of 0+ and this limits the abundance of 1+ fish later on. The maximum observed biomass density was only 1.8 $g.m^{-2}$.

Wick River

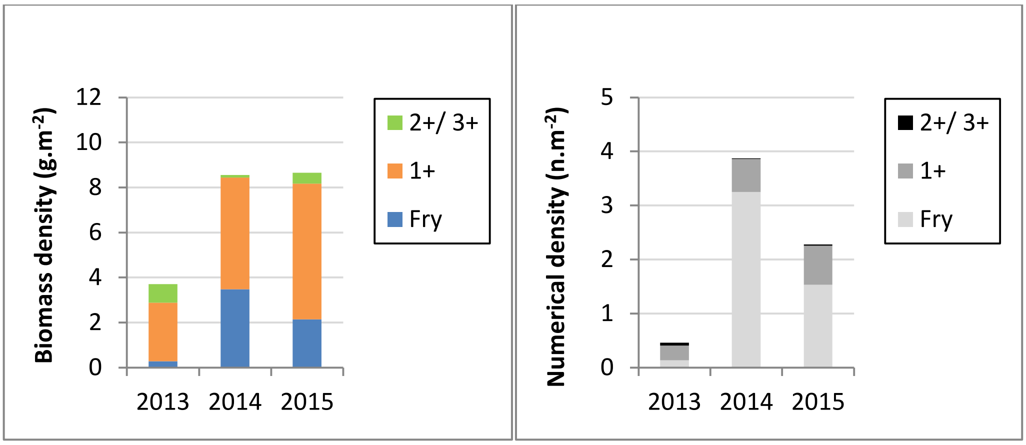
21.14 Acharole – 56m





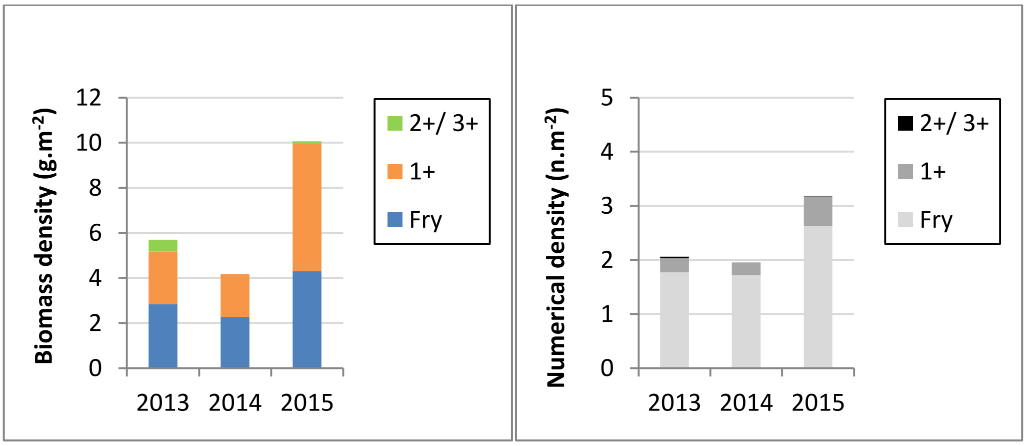
Acharole is the highest site in the Wick River catchment. It was surveyed only once, in 2015. The density of 0+ was very similar to the density of 0+ at The Clow (3.5 km downstream) the same year but the density of 1+ fish was much lower. The 0+ were of equivalent size at both sites but the 1+ parr were much larger at Acharole. The biomass density at Acharole was 3.8 $g.m^{-2}$ in the single year of survey. More survey work would be required to provide a more rigorous assessment.

21.15 The Clow - 36m



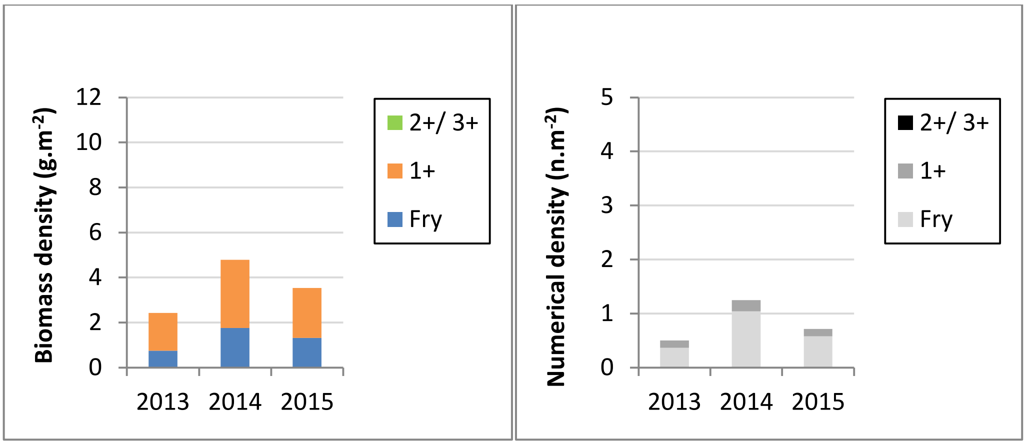
Biomass density was very high at The Clow in 2014 and 2015, being greater than 8 g.m^{-2} in both years. However, the equivalent value was only 3.7 in 2013 due to poor 0+ recruitment; the few 0+ in 2013 were relatively large. The shortfall in 0+ recruitment was evidently rectified later on by recruitment from the wider vicinity because the density of 1+ fish had become very high (0.61.m^{2}) by 2014. Lack of 0+ was not a consistent feature of the site since 0+ densities reached 3.3.m^{2} and 1.5.m^{2} in 2014 and 2015, respectively.

21.16 Sheriff’s – 33m



Productivity at Sheriff’s is potentially very high; the biomass density value in 2015 was 10.1 g.m^{-2}. However, production was much lower in 2013 and 2014. This was mostly due to low parr densities but 0+ densities were lower, too. Levels of 0+ in 2014 did not constrain 1+ biomass density in 2015 but similar levels in 2013 were insufficient to support full recruitment of 1+ parr in 2014. This suggests that 0+ recruitment in 2013 was sub-optimal over the wider vicinity of the site.

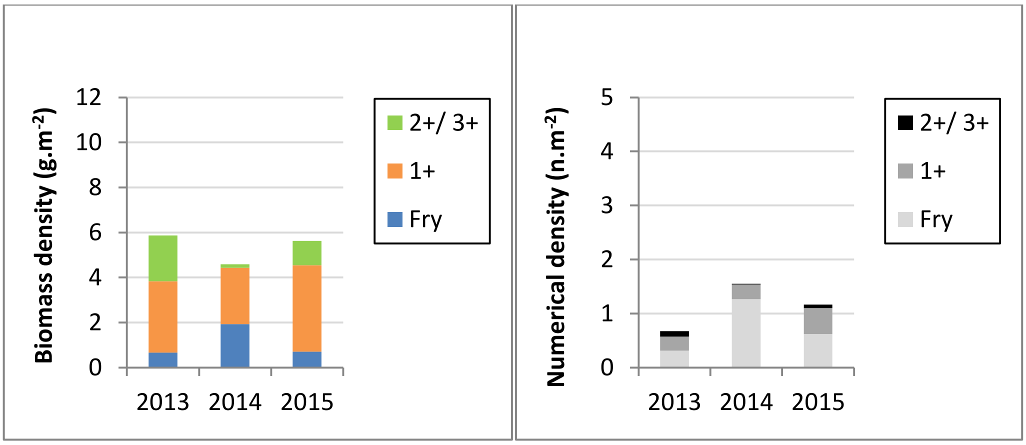
21.17 Bilbster – 9m



It should be noted that the wetted area of the Bilbster site is highly variable. The maximum biomass density observed was 4.8 g.m^{-2}. This is less than expected from a low altitude site of its type. 0+ recruitment is consistently lower than might be anticipated (0.36 – 1.04.m^{-2}) and this may feed through to limit 1+ densities to the relatively modest values observed (0.13 – 0.21.m^{-2}). This suggests low levels of 0+ recruitment caused by patchy spawning in the wider vicinity of the site.

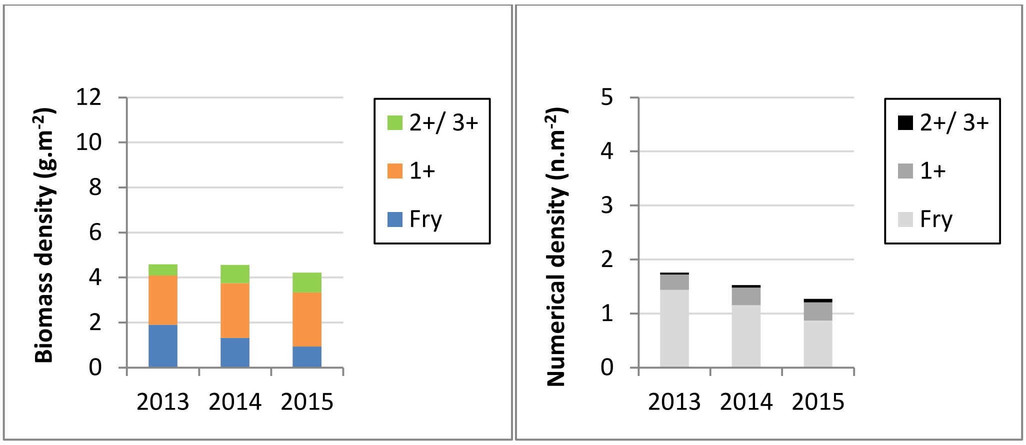
Dunbeath Water

21.18 Achnaclyth – 120m



Dunbeath Water is a high energy spate river and a relatively hostile environment for salmon. Yet, Achnaclyth supported a total biomass density of almost 6 g.m^{-2} in both 2013 and 2015; levels in 2014 were only slightly lower. Recruitment of 0+ is variable and relatively low but parr biomass values are relatively high (2.7-5.2 g.m^{-2}), especially when the substantial contribution sometimes made by older parr is considered. The 0+ were inexplicably small in 2015 and the 1+ parr were inexplicably large in 2013.

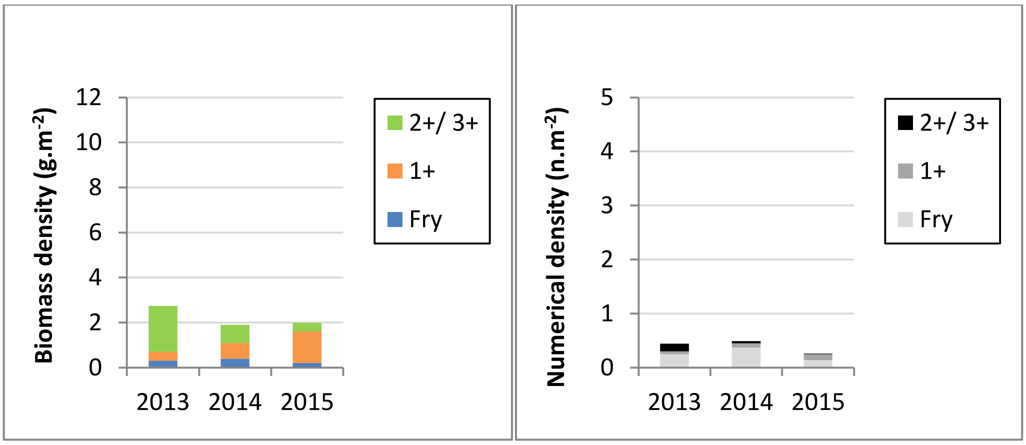
21.19 Culvid – 97m



Culvid consistently supports salmon at biomass densities in excess of 4 $g.m^{-2}$. The maximum biomass density was 4.6 $g.m^{-2}$ in both 2013 and 2014. 0+ recruitment is consistently around 1.m^{-2} and 1+ parr densities are about 0.3.m^{-2}. Some older parr are present. Culvid is therefore somewhat similar to Achnaclyth, which lies 2.5km upstream. Both sites support moderate/ good fish populations and both are probably operating near full capacity. Both sites are trickle stocked with 0+ each year.

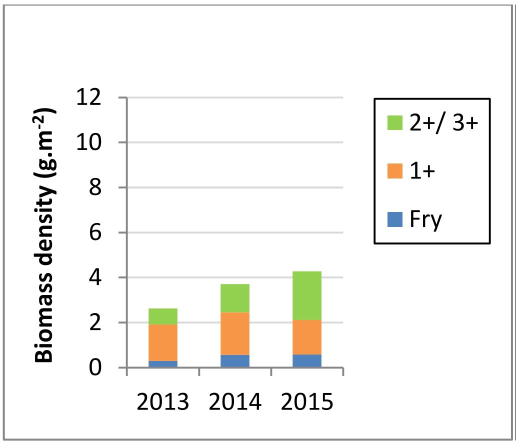
Berriedale Water

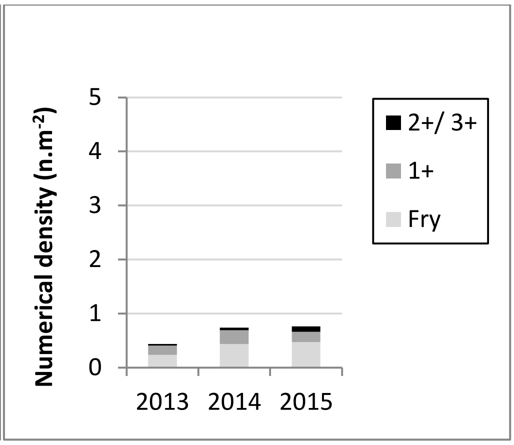
21.20 Gobernuisgach



At 250m, Gobernuisgach is the highest survey site in Caithness. It consistently supports a biomass density of about 2 $g.m^{-2}$ and the maximum value was observed in 2013 at 2.7 $g.m^{-2}$ when older parr were most numerous. 0+ recruitment is relatively low and parr densities are modest, with a relatively large contribution being made by the older parr. Parr size is variable; the 1+ parr were much larger in 2015 when older parr were many fewer. The site is probably therefore operating near its maximum capacity to support pre-smolts.

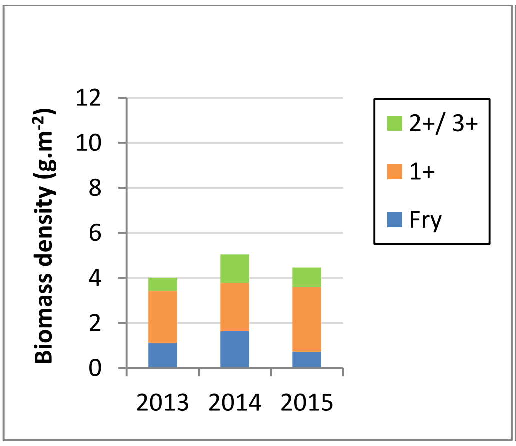
21.21 Corrichoich - 200m

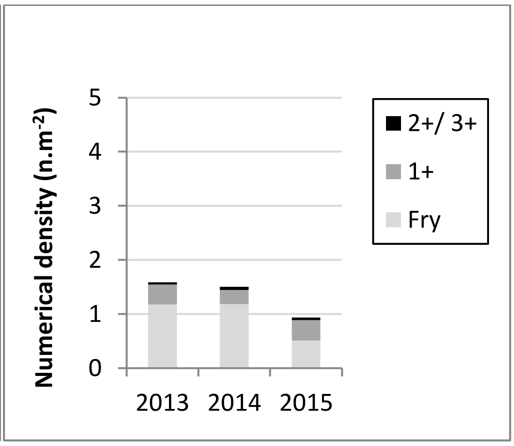




As for Gobernuisgach, 6km upstream, productivity at Corrichoich is likely to be constrained by high altitude. In addition, the physical habitat is uniformly harsh comprising a plain channel studded with boulders. Unsurprisingly, 0+ recruitment is consistently low and both 0+ and 1+ parr are consistently small. Despite this, the highest biomass density value was 4.3 $g.m^{-2}$ (2015); the lowest value was 2.6 (2013). Older parr contribute substantially to total biomass. As for Gobernuisgach, Corrichoich is probably operating near its maximum capacity to produce smolts.

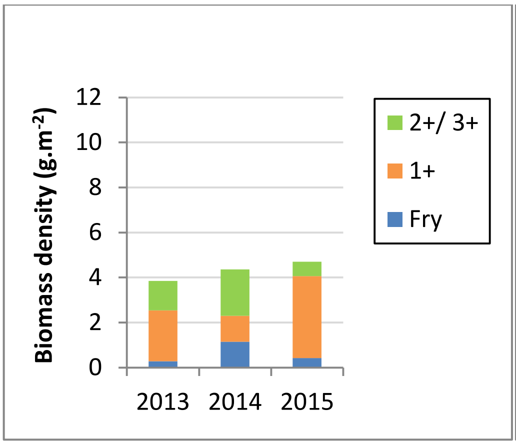
21.22 Braemore – 156m

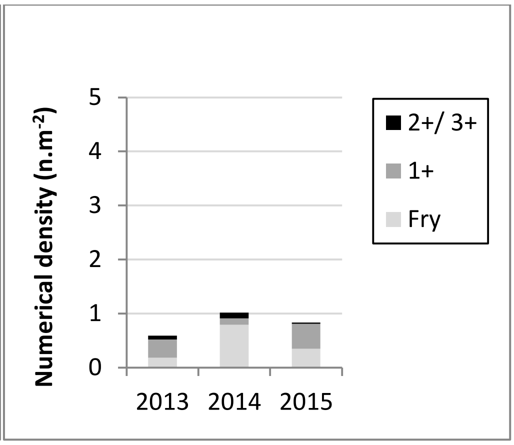




Braemore is also a high altitude site but relatively benign in comprising a balanced mixture of substrate types. 0+ recruitment is moderate and variable (0.5 -1.2.m^{-2}). The density of 1+ parr was between 0 .26 and 0.38.m^{-2}. The sizes of the fish and variation in size were unremarkable. Biomass density was at its maximum value in 2014 at 5.0 $g.m^{-2}$; the lowest value observed was 4.0 $g.m^{-2}$ (2013). Braemore operates consistently and probably near its maximal capacity.

21.23 Strathcoull – 38m

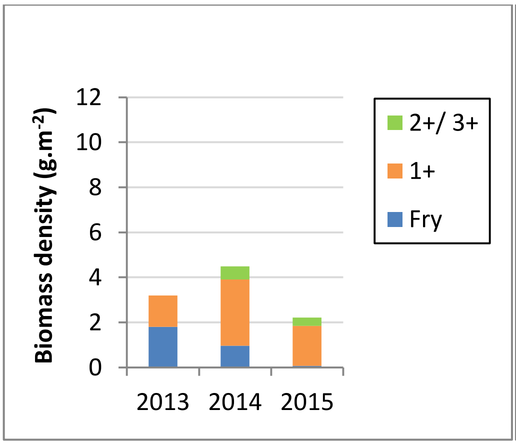


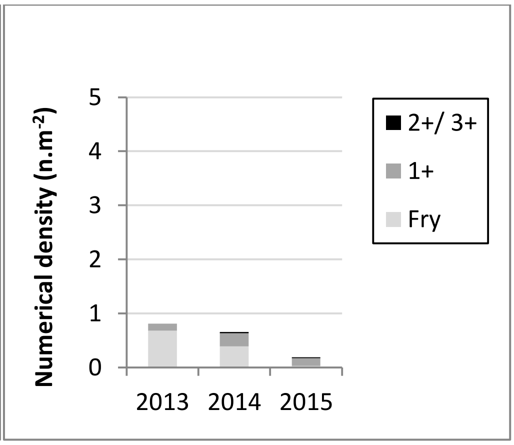


Although Strathcoull lies at relatively low altitude, it is a high gradient, high energy site and the habitat is dominated by boulders. 0+ recruitment is irregular and often low. Older parr make a substantial contribution to the total fish biomass. The maximum biomass density was observed in 2015 at 4.7 $g.m^{-2}$ and the lowest value was 3.8. Despite its unpromising physical characteristics, Strathcoull appears to function relatively consistently and probably near its maximum capacity.

Langwell Water

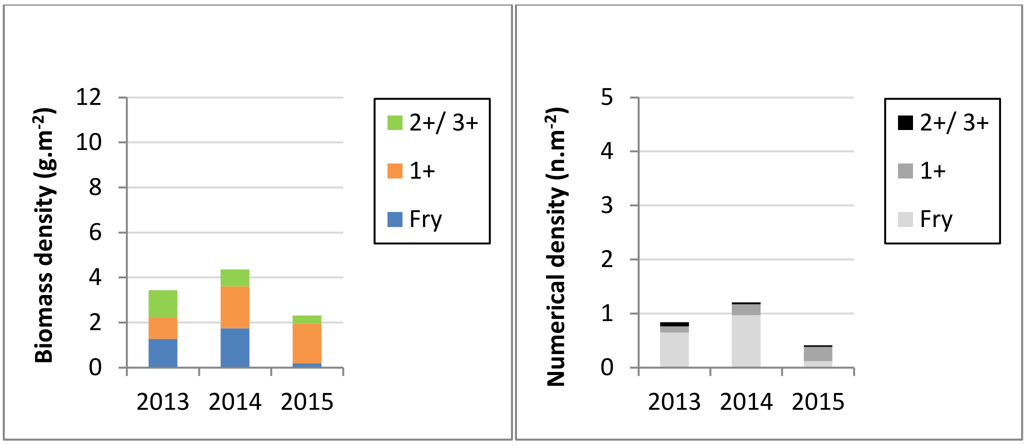
21.24 Wag – 188m





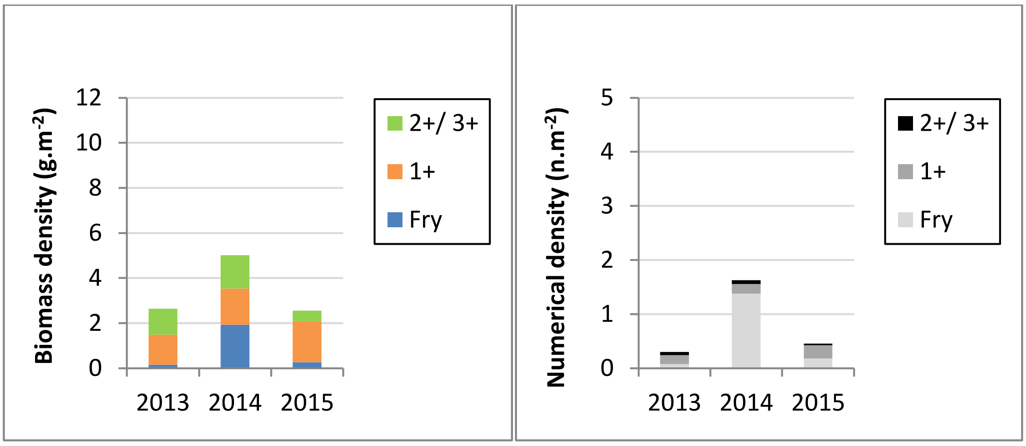
Wag is the highest altitude site on the Langwell but its physical characteristics are relatively benign. Biomass density is potentially quite high since the maximum level was observed was 4.5 $g.m^{-2}$ (2014). 0+ recruitment is variable, however, and 0+ density was very low in 2015 (0.03.m^{-2}). As a result, biomass density was also lowest, at 2.2 $g.m^{-2}$ in 2015. Wag therefore performed inconsistently. The seeming shortfall in 0+ recruitment in 2015 is noteworthy and should be followed up.

21.25 Aultibea – 125m



Aultibea lies 5km downstream of Wag and patterns of biomass density are generally similar. 0+ recruitment is irregular and, as for Wag, 0+ density was very low in 2015 (0.12.m^{-2}). Densities of 1+ parr are modest (0.11-0.26.m^{-2}) and older parr contribute substantially to the total biomass density. The greatest value for biomass density was observed in 2014 (4.4 g.m^{-2}). The lowest value was for 2015 (2.3 g.m^{-2}) when 0+ recruitment was low. Again, this shortfall should be further investigated.

21.26 Coille Braigh



Although Coille Braigh is only 6.5km from the sea it still lies at 93m. Due to its high-energy nature, the site habitat is dominated by boulders. Unsurprisingly, 0+ recruitment is irregular and levels were very low in both 2013 and 2015 (0.18 and 0.08.m^{-2}, respectively). The maximum biomass density (5.0 g.m^{-2}) was observed in 2014 but, like Aultibea and Wag further upstream, inter-annual variation is high. The low level of 0+ recruitment in 2015 may be part of a river-wide pattern.

Summary.

The Caithness rivers appeared to be in good heart over the period of the survey, with the exception only of the River Wester.

Median values for 0+ density were relatively high (0.68 - 1.17.m^{-2}), particularly in 2014. Total biomass density values at many sites were often rather similar among years. The maximum values achieved (ca. 11 g.m^{-2}) are in line with the maximum values reported from elsewhere in the species' range. The majority of the survey sites were probably, therefore, fully charged, or nearly so, with a balanced mixture of age-classes. The remaining sites performed less consistently - near to capacity to produce biomass in some years but not in others. Any shortfalls in total biomass density were mostly the result of local variations in 0+ biomass density.

0+ recruitment was consistently inadequate only at Barrock Mill on the River Wester where parr density was limited by low 0+ density in every year. Elsewhere, any local shortfalls in numerical or biomass density at the 0+ stage tended to become resolved by the 1+ parr stage, presumably due to net movement in the intervening year from areas of high density to areas of low density.

In 2015, 0+ recruitment appeared to be unusually low at all three survey sites on the River Langwell. It is recommended that these sites should be re-examined in 2016 to establish whether production of 1+ parr will be constrained in these circumstances or whether recruitment from the wider vicinity of the sites will still be a sufficient buffer.

Acknowledgements. The Crown Estate co-funded the surveys of 2013 and 2014 and its generous contribution is acknowledged. The sustained effort of the Board's field team ensured that the survey data obtained were of the high quality necessary to support the analyses contained in this report.

Appendix 1.

Primary data for parr more than 1+ years of age.

Site	Observed number			Mean estimated body weight (g)		
	2013	**2014**	**2015**	**2013**	**2014**	**2015**
Cnoc-glas	0	0	1	-	-	34.2
Shurrery	9	2	4	27.0	28.5	22.4
Lythmore	4	2	3	36.7	22.9	28.2
Rumsdale	5	0	4	22.5	-	19.4
Dalganachan	1	3	6	22.9	22.8	18.7
Dalnagleton	0	0	0	-	-	-
The Fanks	-	0	1	-	-	31.1
Smerrary	2	0	-	33.4	-	-
Tacher	-	-	1	-	-	29.6
Dalemore	3	6	2	20.5	20.9	20.9
Inshag	-	-	0	-	-	-
Hoy	2	-	2	32.0	-	28.2
Barrock Mill	0	0	0	-	-	-
Acharole	-	-	0	-	-	-
The Clow	8	1	4	16.1	15.4	19.4
Sheriff's	5	0	1	17.4	-	15.0
Bilbster	0	1	0	-	22.9	-
Achnaclyth	13	1	8	19.8	17.7	17.0
Culvid	8	10	13	13.4	16.4	14.5
Gobernuisgach	18	5	2	14.8	21.2	25.8
Corrichoich	4	7	12	23.5	23.9	22.3
Braemore	7	11	8	14.8	19.4	19.1
Strathcoull	8	12	3	17.6	19.1	23.5
Wag	8	5	4	21.7	24.3	19.8
Aultibea	18	9	7	16.0	19.9	12.5
Coille Braigh	10	11	4	18.7	21.4	17.5