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Local Spatial Heterogeneity in Blue Whiting Length Structure

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Abstract: We have used "MultiSampler", a multiple opening-closing device that allows obtaining several samples from a single trawl haul, during the trawl-acoustic survey targeting blue whiting (*Micromesistius poutassou*) on their spawning areas west of the British Isles in spring 2005 and 2006. Typically, two consecutive samples were obtained with the vessel towing at same direction and at similar depth all the time, as if when fishing without the multisampler. Typically, cod-end was opened for 10-20 minutes for each sample. During standard survey operation without the multisampler, total towing time would have been similar but only one sample could have been obtained. Multiple samples taken within a distance of just 1–2 nautical miles reveal substantial variation in mean length of blue whiting in the samples originating from the same haul. Within-haul, between-sample variability is not much less than between haul variation, and may even be larger. Our findings highlight that spatial heterogeneity can be combated (1) by taking more trawl samples and (2) by keeping tow duration sufficiently long. The first option is preferable because it allows estimating uncertainty, whereas long tows hide small-scale variability.

Keywords: spatial heterogeneity, sampling design, trawl surveys

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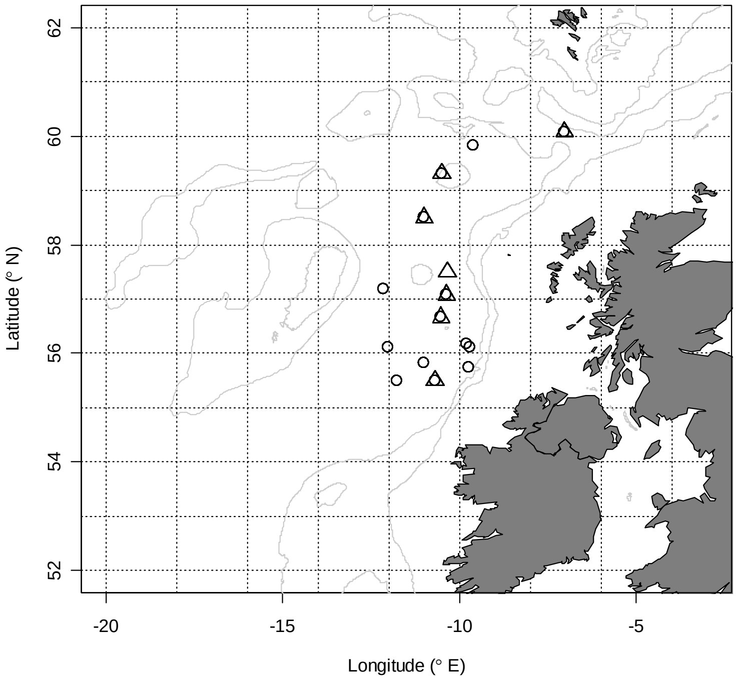
Introduction

There is no doubt about fish populations being spatially heterogeneous, but at which spatial scales the heterogeneity becomes prominent? Standard fisheries surveys are not designed to reveal fine-scale population structure of oceanic fish: trawling is expensive in terms of survey time, and therefore it is comparatively rare that more than one sample is obtained from any given location. However, with "MultiSampler" (Engås *et al.*, 1997), a multiple opening-closing device that allows obtaining several samples from a single trawl haul, the situation is quite different. While this device seems to have been primarily used to study vertical structuring of pelagic fish, it can equally well be used to assess horizontal structuring. In this paper we report on results of using the MultiSampler on blue whiting spawning stock surveys, revealing significant spatial heterogeneity already at the smallest spatial scale studied.

Materials and methods

We use data from blue whiting spawning stock surveys in 2005 and 2006 with R/V G.O. Sars (Figure 1, Appendix 1). This is an annual survey conducted west of the British Isles in March–April when blue whiting aggregate for spawning along the shelf edge and the Rockall bank. The survey is a trawl-acoustic survey where trawl samples are used to estimate age and length structure while the main information source for abundance estimation is acoustics.

Figure 1. Sampling stations in 2005–2006. Circles are stations where two subsamples with at least 50 blue whiting each were obtained. Triangles show the stations where three subsamples with at least 39 blue whiting each were obtained. Depth contours are for 200 m and 1000 m.



Samples were obtained with Åkra trawls, medium sized pelagic trawls with graded meshes. The trawl used in 2005 had a 486 m circumference, while in 2006 a slightly larger version of the trawl was used (circumference 586 m). The trawl was equipped with a MultiSampler (Engås *et al.*, 1997) that enabled opening and closing up to three cod-ends at command from the vessel. The details of survey operations are given in the survey reports (Heino *et al.* 2005, 2006). The sampling strategy was similar as without MultiSampler: we aimed at obtaining at least one trawl haul from every survey stratum (1° latitude, 2° longitude) with significant acoustic registrations of blue whiting. The trawl was used to target the main aggregations of blue whiting in depths of 370–560 metres. However, the normal haul was approximately evenly split in two or three subsamples, each representing towing time of 10–20 minutes, without significantly increasing total duration of a haul. The first subsample, or the subsample with the largest catch if there was a large difference, was taken as the main sample where all individual measurements were taken (age, length (down to nearest ½ cm), weight (g), sex etc.) from 50 individuals, while only length and weight were measured from blue whiting in the other samples. Up to 100 individuals were measured for length and weight, whenever available.

We use mixed linear models to analyse the data. All analyses were performed with lme4 package in R 2.4.1 (R Development Core Team, 2006). We denote the length (in cm) of individual k in subsample j at station i in year y with l_{yijk}. We consider three alternative models where sampling year is always treated as a fixed year effect and station as a random effect; treatment of subsample differs between the models:

Model	Formula	Explanation
m1	$l_{yijk}=\mu_y+e_j+\eta_i+\varepsilon_{yijk}$	• μ_y is a fixed year effect, and e_i a fixed subsample effect • η_i and ε_{yijk}, are random effects (zero mean but different variation) for station and the residuals error, respectively
m2	$l_{yijk}=\mu_y+e_i+\eta_{ij}+\varepsilon_{yijk}$	• μ_y is a fixed year effect • e_i, η_{ij} and ε_{yijk}, are random effects for station, subsample at station, and the residuals error, respectively

m3	$l_{yijk}=\mu_y+e_j+\eta_i+\tau_{ij}+\varepsilon_{yijk}$	• μ_y is a fixed year effect, and e_i a fixed subsample effect • η_i, τ_{ij} and ε_{yijk}, are random effects for station, subsample at station and the residuals error, respectively

Results

We first use subset of the data where two subsamples with at least 50 individuals in each are available. This subset contains in total 2503 individuals collected from 14 stations. The data are illustrated in Figure 2. The results of model fits can be summarized as follows:

Model	Df	AIC	BIC	logLik	Df	P
m1	4	11295.4	11318.7	-5643.7		
m2	4	11291.4	11314.7	-5641.7	0	
m3	5	11293.3	11322.4	-5641.6	1	0.7584

Models 1 and 2 have the same degrees of freedom and cannot be compared with ANOVA, but model 2 is seen to have lower AIC. Model 3 is more complex than model 2 but do not explain the data significantly better. We therefore choose model 2 to describe the data. This model yields the following estimates:

Random effects:	**Variance**	**Standard deviation**	
Subsample:Station	0.060	0.244	
Station	0.188	0.433	
Residual	5.230	2.287	
Fixed effects:	**Estimate**	**Standard error**	**t- value**
Intercept	26.8	0.176	153
Year	0.35	0.270	1.30

By far most of variability is occurring already between individuals within subsamples. Variance originating from between station variability in length is larger than that originating from variability between subsamples with stations, but the latter component is still substantial.

The second subset of the data contains stations with three subsamples with at least 39 individuals in each. This subset contains in total 2041 individuals collected from 7 stations. The data are again shown in Figure 2. The results of model fits can be summarized as follows:

Model	Df	AIC	BIC	logLik	Df	P
m1	4	9412.8	9435.3	-4702.4		
m2	5	9421.6	9449.7	-4705.8	1	1.0000
m3	6	9413.7	9447.4	-4700.8	1	0.0017

Based on an ANOVA comparing model 1 to models 2 and 3, it is seen that model 3 explain the data significantly better. We therefore choose model 3 to describe the second subset of data. This model yields the following estimates:

Random effects:	**Variance**	**Standard deviation**	
Subsample:Station	0.123	0.351	
Station	0.029	0.171	
Residual	5.789	2.401	
Fixed effects:	**Estimate**	**Standard error**	**t- value**
Intercept	26.7	0.189	142
Year	-0.009	0.256	-0.03
Subsample #2	-0.032	0.232	-0.14
Subsample #3	0.352	0.230	1.53

Variability between subsamples within stations is actually substantially larger than that between stations in this subset! There is no systematic difference in mean length between the first and second subsample, but there is an indication that individuals in the third subsample are larger than those in the first one.

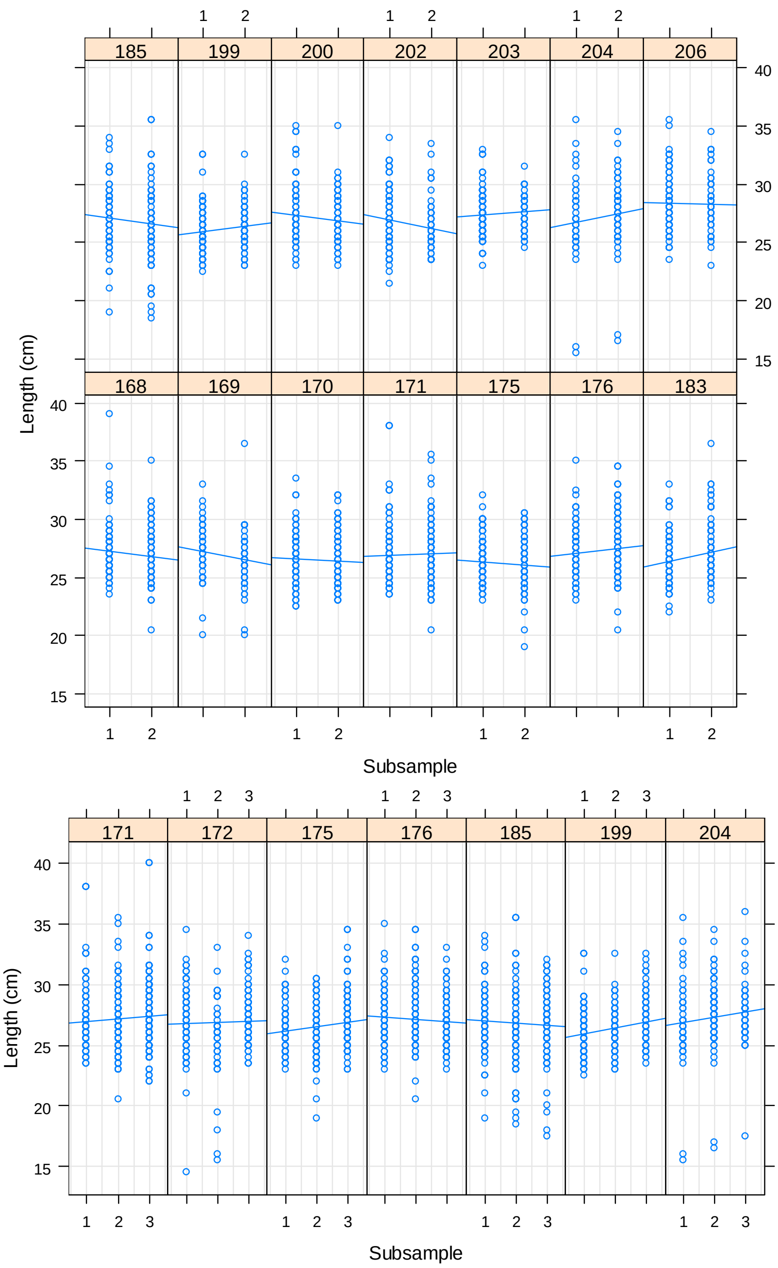


Figure 2. Illustration of the trawl data with two (top) and three subsamples (bottom) per station. Stations 171–185 are from 2005 survey, and stations 199–204 are from 2006 survey.

Conclusions

Our results suggest that there is substantial spatial heterogeneity in blue whiting length structure at spatial scale of about 1 nautical mile and even below. Depending on whether stations with two or three subsamples were used (respectively 14 and 7 stations), conclusions differ regarding how much variability there is between subsamples. Nevertheless, in both cases, variability between subsamples is remarkably large, given that it represents spatial scale of about 1 nm, while variability between stations represent spatial scales from tens to hundreds of nautical miles.

There is no systematic difference in mean length between the first and the second codend, but there is an indication that fish in the third codend were on average slightly larger than in the first two codends. This suggests that large fish might be able to swim ahead the trawl longer than small ones before getting exhausted and being captured by the trawl, and effect that is often postulated for fish that are active swimmers. This is a possible mechanism explaining why there was so much within station variability when stations with three subsamples were included but not when two subsamples were included.

Our findings highlight spatial heterogeneity of blue whiting at local scales, although differences were rather modest. Uncertainty resulting from spatial heterogeneity can be combated (1) by taking more trawl samples and (2) by keeping tow duration sufficiently long. The first option is always preferable because it allows estimating uncertainty. Increasing numbers of tows often requires cutting towing time. However, our results warn against cutting tows too short, unless duration can be compensated by more sampling (in mid-water trawling, effective fishing time is often less than half of the total duration of a single trawl operation). At present, it is not possible to say where optimal balance lies, but we hope to solve this issue soon.

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Appendix 1. Station data with numbers measured and mean length and weight per subsample.

Year	Month	Day	Station	Sub-sample	Lat. (°)	Lon. (°)	Duration (min)	Distance (nm)	Fishing depth Min (m)	Fishing depth Max (m)	Catch (kg)	Catch (num.)	Measured (num.)	Weight (g)	Length (cm)
2005	3	21	168	1	55.74	-9.75	10	0.7			150	1686	100	89.0	27.2
2005	3	21	168	2	55.74	-9.73	13	0.8			120	1383	100	86.8	26.8
2005	3	22	169	1	55.83	-11.00	14	0.7	500	470	4.7	50	50	93.3	27.2
2005	3	22	169	2	55.82	-10.99	17	0.7	480	430	4.5	53	53	85.1	26.5
2005	3	22	170	1	56.18	-9.80	11	0.6	490	475	70	852	100	82.2	26.6
2005	3	22	170	2	56.18	-9.79	10	0.6	475	450	80	960	100	83.3	26.4
2005	3	23	171	1	57.08	-10.36	12	0.5	500	480	30	332	100	90.4	26.9
2005	3	23	171	2	57.08	-10.38	12	0.6	510	490	30	313	100	95.8	27.1
2005	3	23	171	3	57.08	-10.40	12	0.5	520	490	300	2870	100	107.6	27.4
2005	3	24	172	1	57.50	-10.34	10	0.6	520		17	183	100	92.8	27.0
2005	3	24	172	2	57.50	-10.32	12	0.7	500		3.2	39	39	81.2	25.5
2005	3	24	172	3	57.51	-10.30	10	0.7	480		30	342	100	87.7	27.2
2005	3	26	175	1	58.50	-10.99	8	0.4	520	500	50	583	100	85.7	26.4
2005	3	26	175	2	58.50	-11.01	9	0.5	520	500	30	358	100	83.9	26.1
2005	3	26	175	3	58.50	-11.03	8	0.4	520	500	150	1670	100	89.8	27.2
2005	3	30	176	1	59.32	-10.50	13	0.8	520	485	75	720	100	104.1	27.1
2005	3	30	176	2	59.33	-10.49	13	0.9	500		30	273	96	110.0	27.5
2005	3	30	176	3	59.35	-10.46	11	0.7	455	445	20	221	100	90.6	26.7
2005	4	5	183	1	59.83	-9.61	16	0.9	520	480	130	1347	100	96.5	26.3
2005	4	5	183	2	59.83	-9.64	16	0.8	470	460	200	1885	100	106.1	27.2
2005	4	8	185	1	60.08	-7.03	21	1.2	400	380	70	762	100	91.9	27.1
2005	4	8	185	2	60.08	-6.98	20	1.1	400	370	50	566	100	88.3	26.6
2005	4	8	185	3	60.07	-6.95	20	1.1	400	370	35	395	100	88.7	26.7
2006	3	22	199	1	55.49	-10.69	21	1.1	560	540	8.7	104	104	84.0	26.0
2006	3	22	199	2	55.49	-10.66	20	1.1	540	520	21	251	100	81.6	26.4
2006	3	22	199	3	55.49	-10.62	21	1.2	560	540	150	1718	100	87.3	27.0

2006	3	23	200	1	55.50	-11.78	30	2	530	510	13	141	100	94.1	27.4
2006	3	23	200	2	55.50	-11.72	32	2.1	540	520	15	163	100	89.0	26.9
2006	3	24	202	1	56.10	-12.02	10	0.5	550	520	378	3364	100	112.3	27.0
2006	3	24	202	2	56.10	-12.00	18	1	560	540	31	312	50	100.8	26.3
2006	3	25	203	1	56.11	-9.72	11	0.6	500	490	150	1564	100	95.9	27.3
2006	3	25	203	2	56.11	-9.74	20	1.1			13	134	50	100.9	27.6
2006	3	25	204	1	56.67	-10.52	14	0.8	515	503	35	344	50	101.9	26.7
2006	3	25	204	2	56.66	-10.50	14	0.8	503	500	45	438	100	102.7	27.5
2006	3	25	204	3	56.66	-10.47	16	0.9	495	477	45	442	50	101.8	27.6
2006	3	27	206	1	57.18	-12.15	5	0.2	520	510	280	2338	100	119.8	28.4
2006	3	27	206	2	57.18	-12.16	2	0.1	520	510	200	1617	50	123.7	28.3