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Does the seasonal variation in fat content of blue whiting affect the acoustic conversion factor (TS)?

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Abstract

Blue whiting is a physoclist gadoid distributed in the Northeast Atlantic. The catches in recent years have ranged between 1-1.7 mill tonnes. The stock is currently being assessed from VPA and acoustic surveys in the spawning season. The latter usually yielding estimates twice the size of the former. Acoustic estimates in late summer in the Norwegian Sea in the early 80's, however, yielded lower acoustic estimates compared to those obtained during the spawning season the same year. The total fat content of blue whiting varies significantly during the year. Being at a minimum in April/Mai after spawning and at a maximum in August at the height of the feeding season. The gas filled swim bladder represents most of the acoustic back scattering energy (echo) and any changes in the volume of the swim bladder would affect the echo. If it is assumed that blue whiting is at neutral buoyancy in seawater, then changes in fat content, which has a lower specific density than seawater, may affect the amount of gas needed to attain neutral buoyancy. By simple modelling of the swimbladder we find an inverse relationship between the acoustic target strength and fat content, and seasonal variations in fat content of 7% might lead to a bias of up to 12% in acoustic biomass estimates, if they were compared between the low-fat and high-fat period. New in situ target strength measurements of blue whiting are asked for, also covering the natural variation in fat content of the fish.

Keywords: acoustic conversion; bias; assessment; condition factor; fat content; specific density; swimbladder; target strength (TS)

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Introduction

Blue whiting (*Micromesistius poutassou*) is a physoclist gadoid species that is widely distributed in the Northeast Atlantic, practically occurring in the whole area during some phase of its lifespan. Blue whiting undertake large north-south migrations during the year. The main spawning area is off the Porcupine Bank area west of the British Isles. After spawning in March and April they migrate northwards. It passes the Faroes on its way north into the Norwegian Sea in May-June on either side of the Faroes guided by the strength of the currents around the isles (Hansen & Jákupsstovu, 1992). The catches in recent years have increased from around 600,000 tonnes in the 80's to above 1 million tonnes in recent years with a maximum of 1.7 mill tonnes in 2001. The fish is mainly distributed in the 250-500 m layer, and in recent years the distribution of blue whiting has widened west- and northwards.

The blue whiting stock is currently assessed by two main methods, the analytical Virtual Population Analysis (VPA) and hydro acoustic surveys in the spawning season. In addition other surveys are also used in the process (ICES, 2001). The estimates of the spawning stock biomass (SSB) of blue whiting from acoustic surveys west of the British isles have been nearly twice as high as the VPA estimates, and in 2002 the acoustic estimate was nearly four times the VPA estimate (ICES, 2002). Acoustic estimates in late summer in the Norwegian Sea during the early 80's, however, yielded lower acoustic estimates compared to those obtained during the spawning season the same year (ICES, 1986). Even if one of the estimates (the acoustic estimate) is considered an index of the temporal development, there is a substantial temporal inconsistency in the fluctuations of the stock estimates from both methods (ICES, 2002).

The condition of the blue whiting varies with season and maturity. Prior to spawning the fat is converted to gonads, and after spawning the condition is very low with low fat content. During the early post-spawning migration when the condition is still low, blue whiting looks skinny and slender, but it rapidly puts on weight on its way north passing the Faroes and entering the Norwegian Sea. During summer and autumn the fish feed heavily on euphausiids and to a lesser amount on amphipods (personal observations). The fat content increases mainly as an increasing liver and the fish is building an energy storage reserve for the winter and next spawning.

In a gadoid fish the gas filled swimbladder represents 90 to 95% of the acoustic area back scattering energy (echo) (Foote, 1987) and any changes in the volume of the swim bladder would affect the echo of that fish. Assuming that blue whiting is at equilibrium buoyancy in seawater, then any changes in fat content, which has a lower specific gravity than seawater, would affect the specific gravity of the fish and hence the amount of gas needed to attain neutral buoyancy. Thus the TS should vary inversely with fat content of the fish.

There are other factors that may cause unexpected fluctuations in the acoustic estimate, such as varying seasonal developmental stages in the gonads and their effect on the TS (Ona, 1990; Ona *et al.*, 2001). This will however not be considered here.

In this paper we focus only on the possibility of a seasonal variation in the TS due to seasonal variation in fat content of the fish and do not address the possibility of an error in the absolute level of the TS.

Model

To investigate possible differences in TS we use a model with some simple assumptions. Since we only seek a relative measure, i.e. the difference between the low-fat TS and high-fat TS, we are not concerned with absolute value of the TS for blue whiting in this exercise.

Since we only consider relative measures, an average length (L) of the blue whiting is used in the model, representing an average of fish caught by the Faroese commercial vessels in 2001. The length of the swimbladder (h) is considered proportional to L, i.e. $h = aL+b$, leading to a fixed average length of the swimbladder in the analysis.

The shape of the swimbladder is approximated as a cylinder with volume $V = \pi r^2 h$, where h is length of the cylinder (swimbladder).

The volume of swimbladder required for neutral buoyancy in sea water is calculated from $V = (1/\rho_{sw} - 1/\rho_f)W$, where W is weight of the fish, ρ_f is the specific gravity of the fish and ρ_{sw} is the specific gravity of sea water (Alexander, 1966). This figure is usually presented as percentage volume ($100V/W$), i.e. the volume of the swimbladder in percentages of body weight (or body volume).

Since the length of the swimbladder h is fixed in the model, it is only the radius r that changes with changing V.

The area backscattering σ (m^2) of the fish is proportional to the projected area A of the swimbladder (MacLennon & Simmonds, 1992), and in the case of a cylinder shaped swimbladder, $A = 2rh$. Since the length of the swimbladder is constant, σ is proportional to the radius of the cylinder, r, and any changes in r will therefore be reflected in a proportional change in σ.

The target strength (TS) is the logarithmic expression of the area backscattering of a fish, $TS = 10Log_{10}(\sigma/4\pi)$. This is the measure used in literature to express the reflective properties of fish in traditional acoustic assessments (MacLennon & Simmonds, 1992).

Therefore, the difference between the low-fat TS and the high-fat TS gives the maximum difference in TS caused by changes in fat content of the fish.

Materials

The data on seasonal fat content (fish oil) analysis of blue whiting were obtained from samples throughout 2001 at Havsbrún fishmeal factory in Fuglafjørð, Faroe Islands. In total 151 samples spread throughout the year were analysed at Havsbrún. Each sample consisted of 100 kg of fish taken from each landing of blue whiting in 2001.

The samples were extracted with Petroleum ether with reference to standard Soxhlet Extraction Method.

A regression of swimbladder length (*h*) on fish length (*L*) was obtained from a sample of 50 blue whiting measured at our laboratory. The sample was obtained from a Faroese commercial factory trawler "Næraberg" fishing west of the British Isles in March 2002.

Results

The fat content in blue whiting is at a minimum in April/May (just above 2%) after spawning, where most of the resources have been used for gonad development (Fig. 1). The fish rapidly gain fat after spawning and reaches a maximum fat content in August (nearly 9%), which remains high in the remainder of the year (Fig. 1).

An average fish length of 27 cm was used in the model. The regression of swimbladder length (*h*) on fish length (*L*) resulted in the following relationship: $h = 0.477L - 2.48$ ($r^2 = 0.85$, n= 50, Fig. 2). A photograph of the length of the swimbladder in a 27.5 cm blue whiting is shown in Fig. 3, and a transversal view in Fig. 4.

The range of variation of fat content (%) in the material is roughly from 2-9% (Fig. 1); hence we investigate possible differences in TS with fat content from 1-10% fat, in steps of 1% (Table 1). The average specific density of fish fat (ρ_f) from the samples analysed at the fishmeal factory was 0.91 gcm^{-3}, and this figure is used in the analysis. The specific density of non-fat (ρ_{nf}, i.e. the rest of the fish when the oil had been extracted) was set to 1.081 gcm^{-3} (Harden Jones & Scholes, 1985). The specific density of sea water (ρ_{sw}) is 1.026 gcm^{-3} (Alexander, 1974).

Table 1. Range of fat content (1-10%), specific density of blue whiting (fat, non-fat, and combined), difference in density from that of seawater, volume (%), radius and projected area of swimbladder. The traditional TS (dB) is shown in the last row (see the Model section above for a description of the model and our assumptions).

	Density	Fat %									
Variables	ρ	1	2	3	4	5	6	7	8	9	10
Fat	0.91	0.009	0.018	0.027	0.036	0.046	0.055	0.064	0.073	0.082	0.091
Non-fat (rest of the fish)	1.081	1.069	1.058	1.048	1.037	1.026	1.015	1.004	0.994	0.983	0.972
Fish		1.078	1.077	1.075	1.073	1.072	1.07	1.068	1.066	1.065	1.063
Seawater	1.026										
Difference from seawater		0.052	0.051	0.049	0.047	0.046	0.044	0.042	0.04	0.039	0.037
V(swimbladder vol)/*W* (%)		4.727	4.581	4.434	4.287	4.139	3.99	3.842	3.692	3.543	3.393
Radius of swimbladder (*r*) (cm)		0.38	0.374	0.368	0.362	0.356	0.349	0.343	0.336	0.329	0.322
Projected area, cylinder $A=2rh$, $A \propto \sigma$ (backscattering) ($10^{-4}m^2$)		7.912	7.789	7.663	7.534	7.403	7.269	7.133	6.993	6.849	6.703
TS= 10 Log($\sigma/4\pi$) (dB)		-42.01	-42.08	-42.15	-42.22	-42.3	-42.38	-42.46	-42.55	-42.64	-42.73

The results show that the low-fat (2%) TS is –42.08 dB and the high-fat (9%) TS is -42.64 dB in this model (Table 1), which gives a maximum seasonal difference in TS of 0.58 dB, corresponding to a maximum difference (in linear values) of about 12% in biomass estimates obtained from a low-fat and a high-fat period, respectively.

Discussion

Blue whiting belong to those fish species with low and constant fat content in the fish tissue, at most about 1 %. However, the fat content, mainly in the liver, varies from 2 to 9% during the year. Such a variation in fat content would lead to a seasonal variation in TS of 12% in the worst case. Our figure corresponds to the expectation of Alexander (1974) where he predicted that since the fats are only little less dense than seawater it takes a lot of fat to make a small difference in the total density of the fish. Ona (2001) found a weak negative correlation between fat content and swimbladder volume per unit body weight in herring, however, the relationship was not statistically significant due to a large within-group variability in each seasonal sample. Reynisson (1993) related the fat content of Icelandic herring and TS, and found that the TS is lowered by about 0.2 dB for each 1% increase in fat content of the fish. However, in our case the approximate reduction in TS by each 1% increase in fat content was only about 0.08 dB.

A variation in TS of less than 12% must be considered a relatively small bias when we compare with the differences in the biomass estimates from the acoustic method and the VPA (ICES, 2002).

Since the fish is mainly skin and bone just after spawning (personal observations) and the specific density of bone is around 2.0 gcm^{-3} (Alexander, 1974), we anticipate that a closer analysis of the fish, where we make separate analyses of fat, flesh, bone and scales and their contribution to the whole fish, would yield a higher specific gravity of early post spawning fish than the figure we use in our study and thus a larger differences in TS. We further expect the fish to have lost (used) some of its flesh in addition to the fat as input to the gonad development and as an energy reserve immediately after spawning.

A word of caution should be given her. Any changes in the specific density of the non-fat part of the fish (Table 1) in the model would change the magnitude of the difference between the low and high-fat TS.

The answer to our initial question (in the title) must be as follows: Yes, we suggest that the target strength of blue whiting varies seasonally due to changes in fat content and the condition of the fish, leading to a potential bias in the stock estimates from the acoustics. However, based on the present material and model assumptions the bias in the TS is less than 12%.

New experiments for determining the TS of blue whiting are urgently needed to enable more realistic stock estimates from the acoustic method (ICES, 2002). These should take account of the developmental stages of the gonads (Ona, 1990; Ona *et al.*, 2001), the condition of the fish, and they should also cover the natural variation in fat content of the fish.

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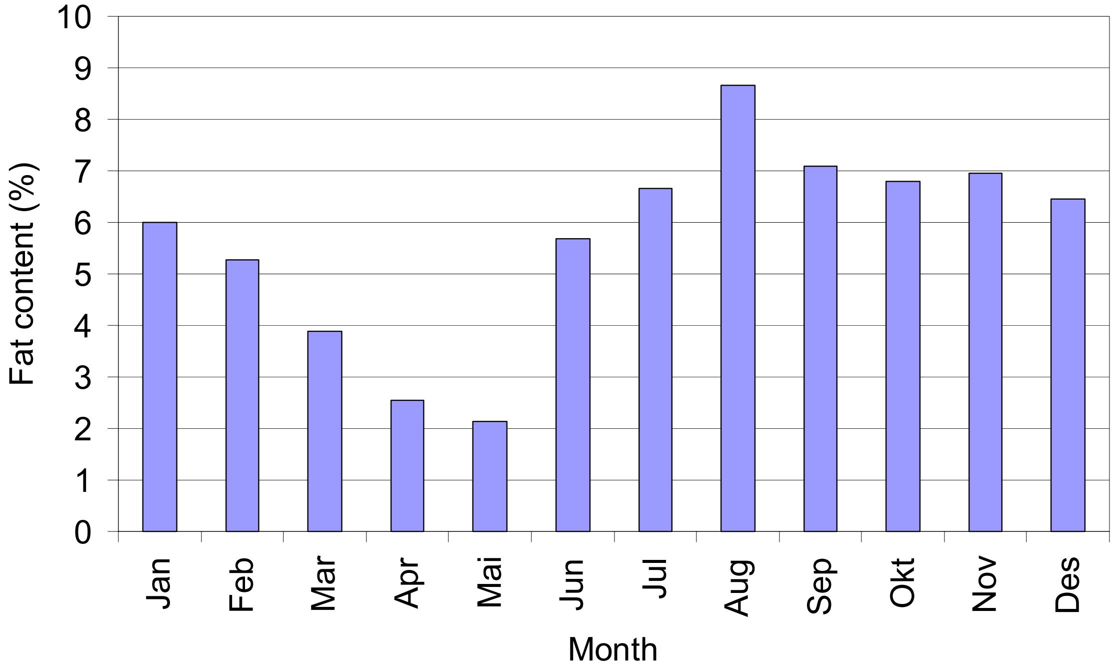

Fig. 1. Fat content (%) in blue whiting by month from the Faroese commercial landings during 2001. The fish was sampled by Gudny Vang at Havsbrún fishmeal factory in Fuglafjørð.

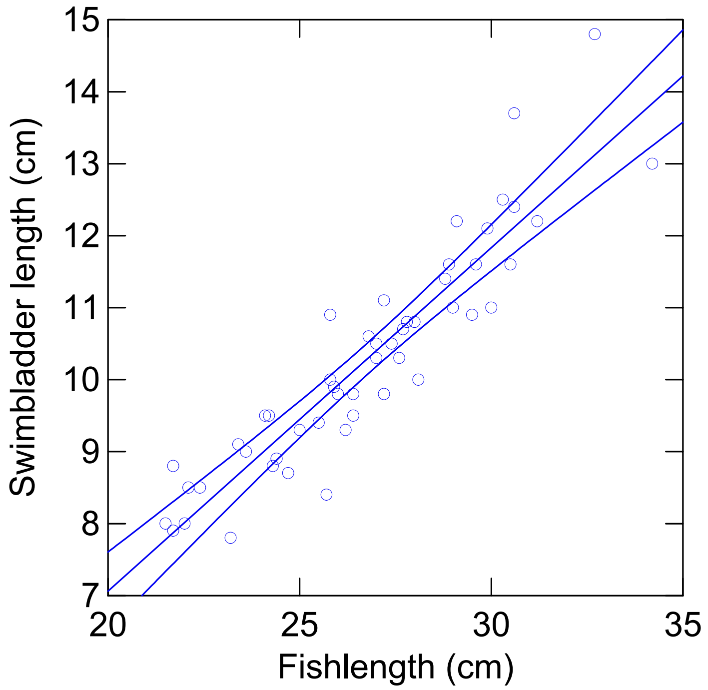

Fig. 2. Length of swimbladder (*h*) as a function of fish length (*L*) of blue whiting. The fish were sampled west of the British Isles in March 2002. A regression (h= 0.477L - 2.48, r^2= 0.85, n= 50) with 95% confidence interval on the line is indicated.

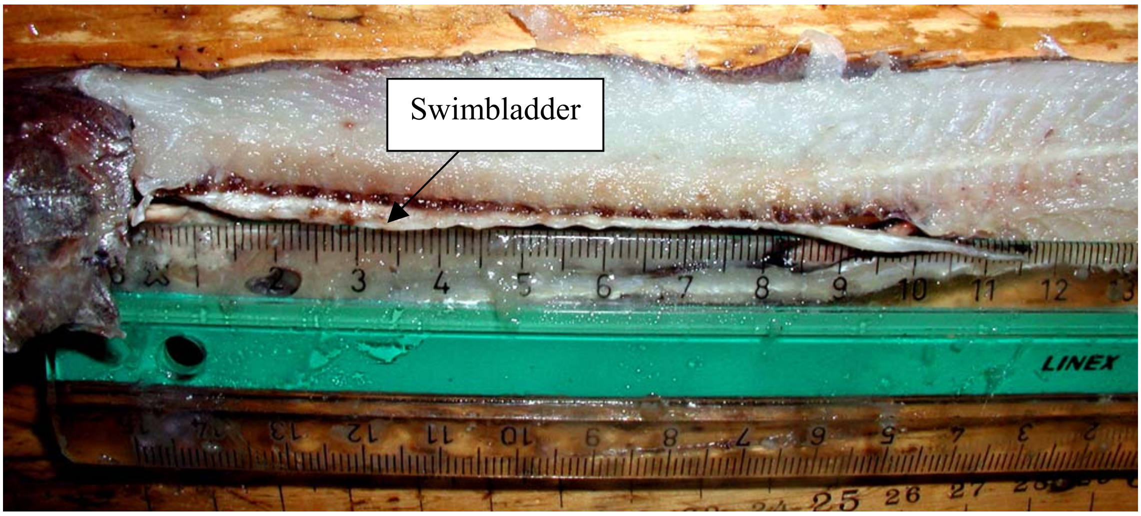

Fig. 3. Photograph of a 27.5 cm blue whiting cut open to show the swimbladder (deflated). The length of the swimbladder is 11.5 cm.

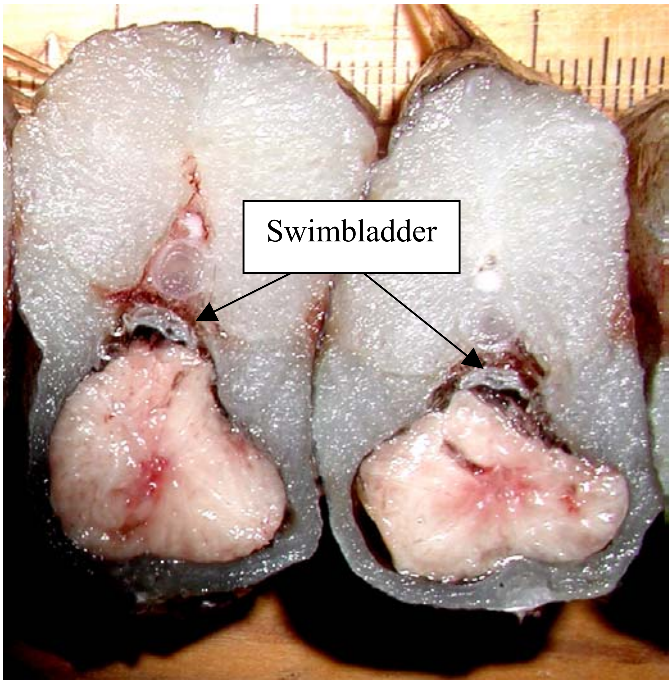

Fig. 4. Photograph of a 27.5 cm blue whiting cut transversally between the first and second dorsal fin to show the deflated swimbladder located dorsally in the body cavity below the vertebrae and above the well developed liver.