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In situ acoustic target strength of anchovy kilka (*Clupeonella engrauliformis*) in the Caspian Sea (Iran)

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ABSTRACT

Understanding the factors that influence the target strength (TS) of fish is important for calculating accurate estimates of fish biomass and abundance using acoustic-based stock assessment techniques. The purpose of this study was to derive a robust TS model for anchovy kilka (*Clupeonella engrauliformis*), an important commercial-targeted fish species, based on its biological and morphological characteristics (length, weight, female maturity status, condition factor, depth of fish occupancy), and season. *In situ* measurements of TS were collected in the southern Caspian Sea during winter (February-March) and spring (May) 1997 using a Simrad EK500 echosounder operating a 38-kHz split-beam transducer. The results showed high variability in the mean TS estimates of anchovy kilka, despite a relatively small range in the sizes of fish encountered across the study site (range in mean fish lengths = 3.2 cm). A multiple linear regression analysis showed that the mean TS of anchovy kilka was significantly ($P < 0.05$) correlated with indices of female maturity status and depth of fish occupancy, but not size ($P > 0.05$), suggesting that biological characteristics other than size were important drivers of this variation. Our estimated TS model for anchovy kilka conformed to the equation: $TS = 20\ \log L - 0.096\,(\%MF) - 6.04\ \log\left(\frac{Z}{10} + 1\right) - 65.9$ when the percentage of maturing females (*MF*, %) and the depth of fish occupancy (Z, m) were included in the analysis. These results help to improve the accuracy of acoustically-derived estimates of anchovy kilka abundance and biomass during routine stock assessments, which is important for robust resource management strategies in the Caspian Sea region.

1. Introduction

Anchovy kilka (*Clupeonella engrauliformis*; hereafter AK) is a small pelagic fish species which is limited to the central and southern Caspian Sea. This species, along with the common kilka (*Clupeonella cultriventris caspia*) and bigeye kilka (*Clupeonella grimmi*), is considered to be an important component of the Caspian Sea ecosystem, comprising an important dietary component of several large predatory fish, particularly sturgeon species (*Huso huso*), and the Caspian seal (*Pusa caspica*) (Leppäkoski et al., 2009). It is also an important target species for local commercial fisheries in the region.

The total commercial catches of kilka by all five Caspian-bordering countries peaked at their highest level in the history of the fishery (423,000 t) in 1970, but since that time, there has been a general decline in the yearly landings, with catches since 2002 being below 100,000 t y^{-1} (Fazli, 2011). From the beginning of Iranian kilka fishery in the 1970s to 1990, annual catches were less than 4000–10,000 t. The period between 1991 and 1999 saw a marked increase in fishing effort for kilka species by the Iranian fishing fleet, with commercial catches rising from 13,000 t to a maximum level of 95,000 t, which represented ~34% of the total catch for these species in the Caspian Sea during this time. In subsequent years, however, the kilka catches by Iran decreased sharply to levels as low as 25,483 t in 2009 (Fazli, 2011).

Of the kilka species targeted by this fishery, AK contributed approximately 70–85% of the total catch in the Caspian Sea between the 1970s and 2005 (Mamedov, 2006). In 2005, the total catch for AK was reported to be around 54 300 t (Daskalov and Mamedov, 2007), of which, the Iranian fishery contributed approximately 8% (Fazli, 2011).

In contrast, the catches of common kilka have increased by more than 85% of the total catch in recent years (Fazli, 2011; Kanatyev and Huseynov, 2014), which constituted a marked shift in species

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selection by the fishery since the 1970s, when common kilka typically comprised just 1% of the total catches. A converse shift in landings occurred between the 1970s and early 2000s for big-eye kilka, with catches of this species decreasing from ~20 to <2% of the total kilka catch over this period (Prikhodko, 1975; Mamedov, 2006).

This sudden change in amount of kilka landings and species composition was partly related to an invasion by the comb jelly *Mnemiopsis leidyi* in the Caspian Sea in 1999 that is thought to have caused changes in the prey field composition of the main kilka species and altered their predator/prey dynamics (Ivanov et al., 2000).

This event had a profound impact on the Caspian Sea AK population, in particular, with mean catches of this species decreasing from 323 500 t in 1965–1990 to 67 200 t in 2001–2005 (Daskalov and Mamedov, 2007).

Maintaining sustainable fisheries and effective ecosystem management requires accurate information about the population dynamics, abundance, and spatio-temporal patterns in the distribution of the main commercially-targeted fish species. To date, biomass estimation, and therefore stock assessments, of the kilka species are based solely on fishery-landings data, and more robust fisheries independent data at the appropriate spatial and temporal scales are clearly required to improve the management of this important commercial resource. Underwater acoustics are used commonly for monitoring fish stocks of many commercially-targeted species around the world, providing important fisheries independent information for routine stock assessment and management purposes (Simmonds and MacLennan, 2005). Such acoustic surveys were first conducted for three commercially-targeted kilka species in the Iranian waters of the Caspian Sea between 1995 and 1997, but surveys have since been limited in this region due to financial and logistical issues. Recent declines in landings and marked changes in species catch composition in the Caspian Sea kilka fishery have highlighted the need for new acoustic surveys in the region in order to monitor these fish stocks more effectively and improve assessment and management strategies of this important economic resource. However, re-evaluation of previous acoustic survey design, methodology and assessment protocols are required before such a new monitoring strategy can be reinstated routinely in this fishery.

One of the major problems that needs to be addressed in order to facilitate robust estimates of abundance and biomass using acoustic methods is the determination of an appropriate target strength (TS) model for the main fish species in the Caspian Sea. This is a measure of the reflection coefficient of an ensonified organism that is used to scale measurements of acoustic backscatter to actual quantities of biomass and abundance. Also, understanding the factors that may affect TS is an essential prerequisite for improving the accuracy of acoustically-derived fish biomass from acoustic techniques. At present, these problems remain unresolved for three species kilka of the Caspian Sea, primarily due to a lack of *in situ* measurements.

Target strength relationships are largely dependent upon acoustic frequency, target orientation, body size, and particularly the presence/absence of a gas-bearing swimbladder, which can account for around 90% of the reflected echo from a fish possessing such an organ (Foote, 1980; McClatchie et al., 1996). It has long been known that TS correlates positively with the logarithm of fish length/weight. However, it has been reported that the effect of gonad condition and sexual dimorphism may be more important than length in determining the TS of fish during the main reproductive period (Ona, 1990; Ona et al., 2001; Jørgensen, 2004). As the gonads grow, there is a gradual compression of a gas-bearing swimbladder, which may increase or decrease the effective dorsal area of the swimbladder depending on species. The main aim of this study was to determinate an appropriate TS relationship for AK using data obtained from our baseline acoustic survey conducted in 1997, and evaluate variations in the TS of AK in relation to fish biological characteristics (length, weight, percentage of maturing females, and the condition factor, fish depth), and season. As this species possess a gas-bearing swimbladder, we examine the possibility that female maturity status influences TS in kilka species, and test the hypothesis that this factor is more important than length in predicting TS. We also investigate the effects fish depth and season on kilka TS.

Table 1
Simrad EK500 echosounder parameters and settings for anchovy kilka TS measurements.

Echosounder parameter	value	Unit
Frequency	38	kHz
Transducer model	Simrad split-beam ES38	
Pulse duration	1.0	ms
Maximum power	2000	W
Bandwidth	3.8	kHz
Beam width – 3 dB power	7.2	degree
Absorption coefficient	4	dB km^{-1}
Angle sensitivity	21.9	
Pulse interval	auto-calibration	S
TS threshold	−70	dB
TS transducer gain	26.6	dB
SV transducer gain	26.9	dB
TS of sphere	−33.6	dB
Alongship offset angle	0.15	degree
Athwartship offset angle	−0.02	degree

2. Materials and methods

2.1. Survey design

In this study, we used *in situ* TS measurements of AK collected in Iranian waters of the Caspian Sea on board RV "Guilan" during winter (February–March) and spring (May) 1997 (Fig. 1). During these surveys, the study area was sampled using a series of parallel (in deep waters) or zigzag (in shallow waters) transects depending upon the underlying bathymetry.

2.2. Data collection

A Simrad EK500 echosounder operating a 38 kHz split-beam transducer (type ES38) was running continuously during surveys, so that acoustic data were available at the location of each net trawl station. The system was set to single-target detection mode to collect single-target measurements of AK between 6 and 300 m, although most measurements of AK TS were obtained from the upper regions of the water column (above 60 m). The echosounder was calibrated using a standard copper sphere at the start of each cruise (Foote et al., 1987; Anon., 1990). The Echosounder operational settings used during the surveys are detailed in Table 1.

Fish were collected by midwater trawl nets deployed concurrent with *in situ* target strength measurements to verify species compositions and to provide AK length frequency distributions. The trawl net had a mouth height of ~24 m during trawling and had a-mesh size of 250 mm in the forward sections and 8 mm at the cod-end. Trawling speed was ~2.5 knots (1.3 m/s), with haul durations varying between 50 and 120 min, depending on the density of fish captured.

A random sub-sample of about 3 kg of fish was taken from each net haul to identify the species composition. In each sample, AK specimens were separated from the remaining catch and a random sub-sample of about 200 fish was then selected for determining length, weight, condition factor, and sex ratios. Sex maturity stage was also recorded for each specimen in this sub-