

Significance of Physiological and Biochemical Approaches for Black Sea Fishery Investigations

G. E. SHULMAN¹ V. N. NIKOLSKY¹ T. V. YUNEVA¹ A. M. SHCHEPKINA¹ L. BAT^{2*} A. KIDEYS³

¹ Institute of the Biology of Southern Seas, 2 Nakhimov av., 99011, Sevastopol, Ukraine

² Sinop University Fisheries Faculty Department of Hydrobiology, 57000 Sinop, Turkey

³ Middle East Technical University, Institute of Marine Sciences, Erdemli, Turkey

* Corresponding Author
e-mail: leventbat@gmail.com

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Abstract

Physiological and biochemical methods are important tools for solving certain fishery problems, such as observed trends of fish distribution and migrations; estimation of productivity of commercial species; indicators and monitoring of stock condition and separating populations. In the review, major results of related long-term studies are presented.

Key words: Anchovy, Sprat, distribution, migrations, productivity, indication, monitoring, stock condition.

INTRODUCTION

Physiological and biochemical investigations connected directly or indirectly with Black Sea fishery problems began in the mid-1950s and intensified during the following years [1-8]. They concerned: 1) characteristics of wintering migrations of fish and management of fishery; 2) estimation of production of commercial species and their significance in ecosystem trophodynamics; 3) indication and monitoring of fish stocks. Genetic research aided by biochemical markers enabled determination of population structure and distribution of commercial species [9-11]. We summarize here the main results of these studies.

Characteristics of Wintering Fish Migrations

These investigations were initially concerned with *Engraulis encrasicolus maeoticus* (Pusanov, 1926), (Azov Sea anchovy) and *E.e. ponticus* (Aleksandrov, 1927) (Black Sea anchovy). These fishes undertake long migrations within the Azov-Black Sea basin. It was shown that the most important physiological factor which determines the degree to which the Azov Sea anchovy are prepared for the wintering migration to the Black Sea is the level of energy (fat deposits) accumulated during summer and autumn feeding. This store is vital for fish survival in winter when food consumption either ceases or decreases (so named "endogenous" feeding, Figure 1). Populations which have accumulated a significant level of fat (i.e. over 20% of body weight) carry out migrations through the Kerch Strait with great intensity in dense schools. Migration of those schools with lower fat content (15–17%) takes place slowly and poorly. Finally, fish which do not accumulate the lower "limit" fat content (14%) generally fail to migrate, remaining in the Sea of Azov to die due to the temperature decrease in December. The most important ecological factor which triggers migration is the water temperature in the Sea of Azov (which significantly drops in autumn). There exists a close interaction between physiological and environmental factors (Figure 2). Migrations of fish with high fat content begin when the seawater temperature drops to levels within the upper limit values; while in fish with low fat content, migration

is initiated when seawater temperatures are at the lower limit values. These observations were first made in the 1950–1960s and used as a standard method for forecasting the onset and characteristics of wintering migrations of Azov anchovy which was then utilized in fish stock management [12-15].

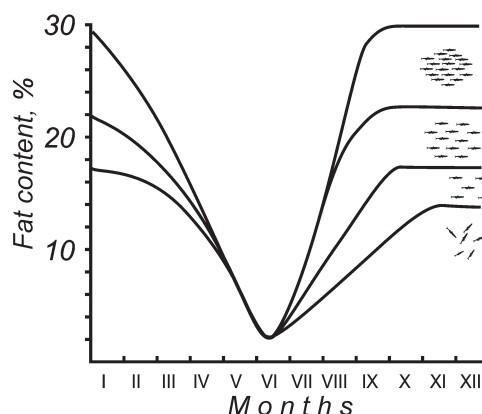


Figure 1. Relation between fat content and character of wintering migration of Azov anchovy.

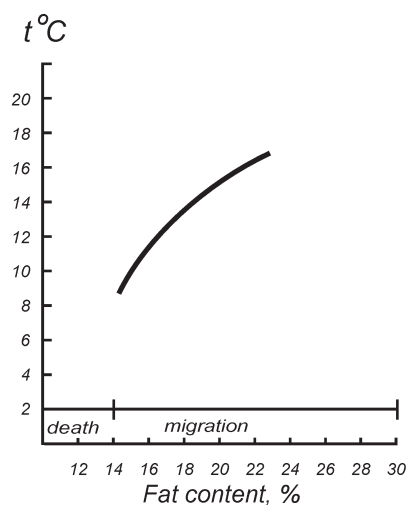


Figure 2. Relation between fat content in Azov anchovy and temperature of its wintering migration.

Unfortunately, the crisis of fishery science in Ukraine that clashed with economical difficulties halted the estimation of fat content in Azov anchovy in the pre-migratory period. This led to repeated failure in predicting the stock condition of this fish with substantial financial damages ensuing. Physical properties of wintering migrating populations of the Black Sea anchovy turned out similar to those of the Azov anchovy with the single difference that the fat content of the first subspecies was less than in the second one [16-17] (Figure 3).

Another significant commercial species, the Black Sea sprat *Spratus sprattus phalericus* (Risso, 1827) does not carry out extensive migrations in contrast to anchovy. However, accumulated fat stores are significant for this fish as they form dense schools which can be caught more easily. This is obviously also significant for fishery management [4].

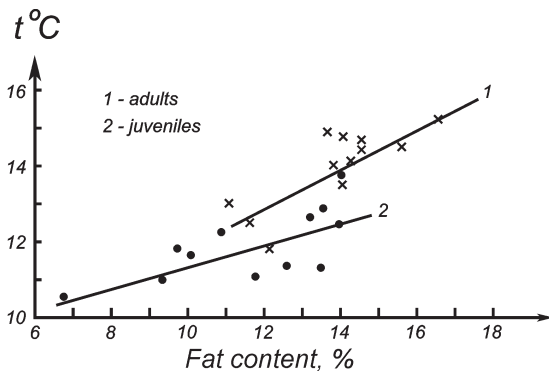


Figure 3. Relation between fat content of Black Sea anchovy and water temperature during winter migration [17].

Significance of Commercial Species in Trophodynamics of the Black Sea Ecosystem

At first consideration, this problem appears purely scientific. However, characterization of trophodynamic structure of ecosystems is also significant in fishery management. After calculation of the mass and/or energy balance in most important commercial fishes of the Black Sea pelagics (anchovy, sprat and horse mackerel *Trachurus mediterraneus ponticus* Aleev, 1956) [3,5] we defined annual production of these species (Table 1). Total consumption of zooplankton by these species was also approximated which was unexpectedly low (6–10 % only). Similar values were also obtained by Sorokin [18]. At the same time, the annual production of major food competitors of small pelagics (medusa *Aurelia aurita* (Linnaeus, 1758),

chaetognata *Parasagitta setosa* (Muller, 1847), and during the last two decade the alien ctenophore *Mnemiopsis leidyi* (Agassiz, 1860) are two–three fold higher. Hence, the consumption of zooplankton by these competitors is also several fold higher than by the main pelagic fishes. What practical conclusion can be made from this? In order to understand the processes determining the condition of pelagic fish species it is essential to study not only fish but to embrace other aspects related with their direct food competitors which affect trophic relationships in the ecosystem. Unfortunately this is ignored too often with negative consequences for fishery management [19].

Indication and Monitoring of Commercial Stock Condition

We previously emphasized that characteristics determining fish population condition besides their abundance and biomass data, age-size structure, behavior and distribution are necessary for estimation of fish food supply/ nutrition condition as just food is the most important “channel” of interaction with environment [5,7]. Level of energy (fat) stores accumulated by pelagic fishes during feeding period is a good indicator of this condition (degree of wellbeing/ health). Such long-term investigations have been carried out on the Black Sea sprat and anchovy. These are very significant not only for estimation of the condition of commercial stocks but also to understand characteristics of the entire pelagic ecosystem. Sprat is a cold tolerant species whilst anchovy is warm tolerant. They feed (and accumulate fat) at different times of year: sprat in springtime and at the onset of summer; anchovy meanwhile feed towards the end of summer and in autumn (Figure 4). So knowledge of fat levels accumulated by populations of each species allows us to estimate ecosystem throughout the year. The most complete data set (from 1960 till 2006) on the monitoring of fat content levels was obtained for sprat (Figure 5). Earlier, we revealed a positive relationship between these data and phytoplankton biomass in the Black Sea [7-8]. In contrast, a relationship between sprat fat content and biomass of fodder zooplankton is absent. This is due to consumption of a significant quantity of zooplankton by higher trophic levels. But a negative relation is revealed between sprat fat content and surface water temperatures in the Black Sea (Figure 6). This was shown to be especially strong over the last few years when following a high increase in the water temperature the sprat fat content dramatically decreased.

Table 1. Annual total production (P_y) and consumption (C_y) of zooplankton production

Consumers	P_y , gram	C_y , %	Years	Authors
Anchovy <i>E. e. ponticus</i>	$30.9 \cdot 10^{10}$		1948–1975	
Sprat <i>S. s. phalericus</i>	$21.0 \cdot 10^{10}$	6–10%	1960–1975	[3]
Horse mackerel <i>T. m. ponticus</i>	$2.6 \cdot 10^{10}$		1976–1975	
<i>A. aurita</i>	$(12–100) \cdot 10^{13}$	to 60%	1960–1988	[18, 20-23] [24]
<i>M. leidyi</i>	$(50–500) \cdot 10^{13}$	to 25%	1990–2005	Anninsky (per. com.)
<i>P. setosa</i>	$31.7 \cdot 10^{13}$	to 25%	1960–1969	[21]

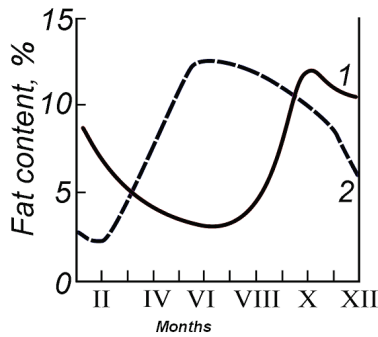


Figure 4. Seasonal dynamics of fat content in anchovy (1) and sprat (2).

Obviously, this is a result of the decrease in the rate of forming primary production due to a reduction in water turbulence while the surface water temperature acted as an indicator of turbulence [8,18]. Generally, it was shown that important processes occurred in the Black Sea pelagic system approximately every 10 years: these were associated with water temperature fluctuations, phytoplankton biomass and fat content in sprat (Table 2). Based on these deductions, a principle for the prediction of sprat fat content in forthcoming years was established. As predictors, the forecasting model included annual surface water temperature and sprat fat contents

of previous [25]. The model is unable to accurately predict certain situations when extraordinary anomalies are observed. However, this model is sufficient in predicting the tendency for changes in sprat condition.

Table 2. Decadal changes in the analyzed indicators for the period 1960–2005

Indicators	Decades				Beginning of the XXI century
	1960s	1970s	1980s	1990s	
Surface water temperature	High	Low	Low	Increasing	High
Phytoplankton biomass	Decreasing	Increasing	High	High	Low
Sprat fat content	Decreasing	Increasing	High	High	Low

It is interesting to reveal the different influence of climatic (water temperature), biological (food competition) and anthropogenic (pollution and eutrophication mainly via rivers) factors on sprat food supply/nutritional condition estimated by

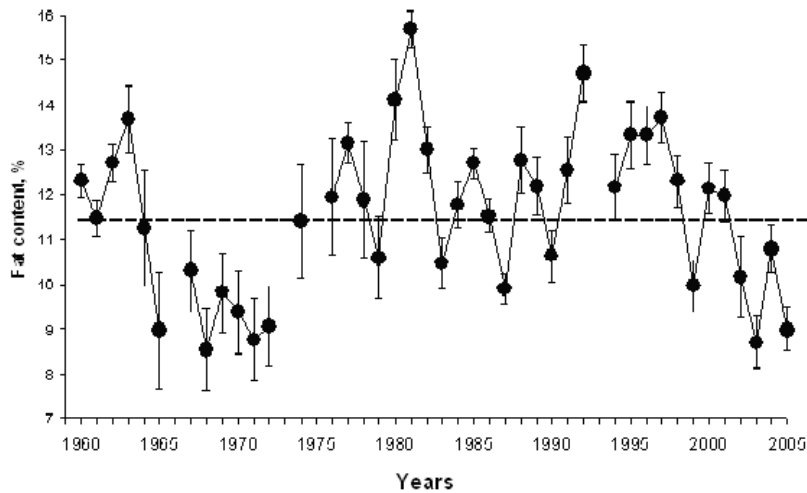


Figure 5. Long-term dynamics of sprat fat content from 1960 to 2005.

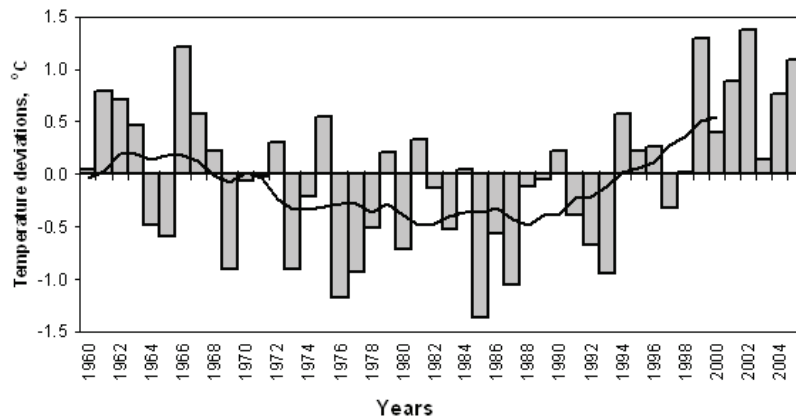


Figure 6. Long-term deviations in annual surface water temperatures in the Black Sea off South Crimea (1960–2005) mean (bars); solid line indicates data smoothed with the 11-year filter.

body fat content. We pertained to achieve this with the help of the produced scheme (Figure 7). The climatic influence in the 1970s was intensified by the so called “green revolution”, when a sharply strengthened nutrient inflow to the Black Sea was seen due to intensive agriculture [26]. On the contrary, in the 1980s a sharp abundance explosion of the medusa *A. aurita* followed by the small pelagic fishes (mainly sprat and anchovy) and finally the alien ctenophore *M. leidyi* led to large fluctuations in the fat content of sprat populations (nicknamed “rolling boat”). Evidently these explosions were sustained by high phytoplankton concentrations. As for the alien ctenophore its mass development in the Black Sea perhaps was also caused by an increase of ecosystem “immunity” due to high level of eutrophication coupled with the warming event in the 1980s.

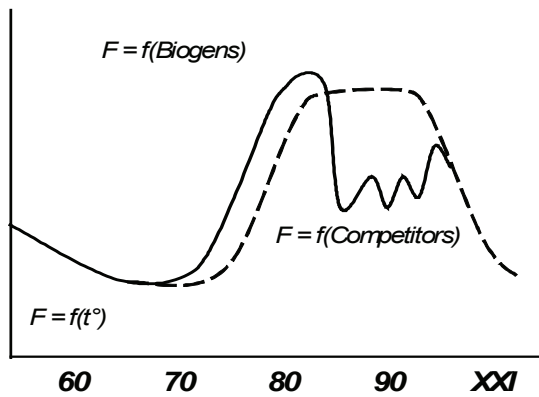


Figure 7. Scheme of long-term dynamics of sprat fat content: observed pattern (solid line) and probable trend caused by global climatic factors (dashed line).

Generally, dynamics of the Black Sea food supply estimated by changes in the body fat content is rather similar to changes in stock (biomass and landings) of many small pelagic fish species from other marine basins of the Mediterranean, Atlantic and even the Pacific (Table 3). This shows the global nature of climatic processes throughout the World’s Oceans that cause mega-scale variability in processes governing the condition of many species of small pelagic fishes. Many literature data concerning the condition of other significant components of ecosystems show the same [27,28].

Table 3. List of species whose catch value correlate with levels of Black Sea sprat fatness

Species	Region	Reference
anchovy <i>E. e. mediterraneus</i>	all regions of Mediterranean	[29]
anchovy <i>E. meridionalis</i>	Binguel current	[30]
anchovy <i>E. capensis</i>	South Africa	[31]
anchovy <i>E. mordax</i>	California	[30]
herring <i>Clupea harengus harengus</i>	the Iceland Sea	[32]
capelin <i>Mallotus vilosus vilosus</i>	the Iceland Sea and Barents Sea	[33]
sardine <i>Sardina sagax melanostica</i>	the Japan Sea	[30]

Unfortunately such estimations of Black Sea anchovy food supply are less systematic than for sprat. But for anchovy it is still possible to draw significant conclusions (Figure 8). Fat content levels for anchovy populations in autumn 2005 were less than average values for previous decades (data for 1990s are absent). This may show that the warm tolerant anchovy, in spite of the high temperature, is also negatively affected by climate change due to inhibition of primary production like the cold tolerant sprat. If global warming will continue, it may have negative consequences for food supply/nutrition condition of Black Sea pelagic fishes and therefore on their stock abundance and catches. Since 2005, the monitoring of fat content in anchovy populations has been undertaken as for sprat.

All these data demonstrate the importance of fat content level as an ideal indicator of the condition of small pelagic fish, and such information could be utilized in the stock management studies in the Black Sea.

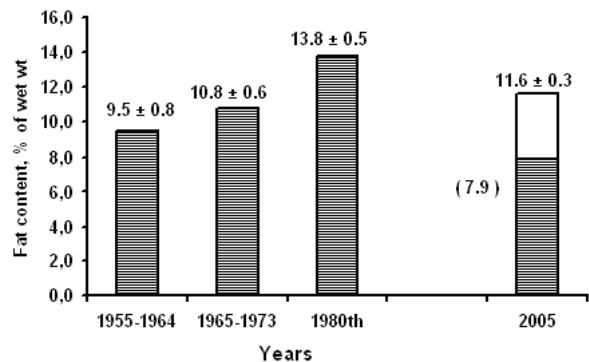


Figure 8. Fat content of anchovy at the end of the 2005s feeding period compared to long-term data [2,5-6].

The final problem which renders large significance in Black Sea fishery investigations is biochemical features of population genetic structure. Studies began in the 1960s [34-37], developed then in Bulgaria and achieved some very interesting results [10-11,38]. Initially, the story of the large horse mackerel was interpreted. This fish appeared suddenly in the Black Sea in the mid 1940s and produced a giant abundance explosion in the 1950s. At that time its annual catch reached 10–15 thousand tons. Since the beginning of the 1960s this fish disappeared from catches completely. It was shown that large horse mackerel (individual fish length exceed 50 cm) had been a heterosis hybrid between small Black Sea horse mackerel *T. m. ponticus* (length 15-20 cm) and larger Mediterranean species *Tr. m. mediterraneus* (Steindachner, 1868) (length 25-30 cm) (Figure 9). This mass hybridization probably occurred in wartorn 1940s, when fishery was absent and the Mediterranean subspecies may have extended its area reaching the Black Sea. This hypothesis conforms with data of morpho–statistic analysis [39]. The Bulgarian authors (referred to above) also studied the genetic structure of the Black Sea and Azov Sea anchovy in comparison with anchovies of the Mediterranean and other regions of the World’s Oceans. Unexpected data were obtained by these authors at the end of autumn 2005. It was showed (personal information) that in catches at the Turkish coast (Sinop region) a number of the Azov anchovy had been found together with the Black

Sea anchovy (!). This affects previous knowledge about distribution and localization of both subspecies in the Black Sea.

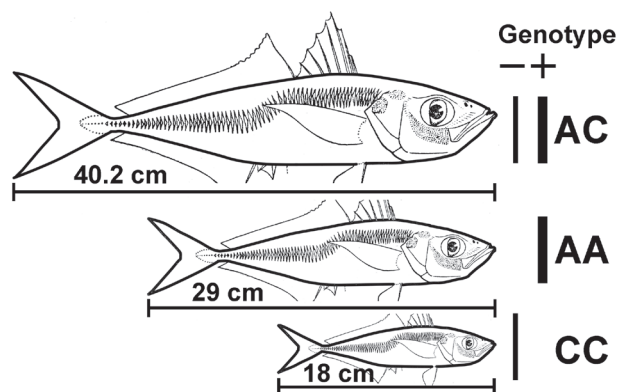


Figure 9. Three forms of horse-mackerel *Trachurus mediterraneanus*: large (genotype AC), *T. m. mediterraneanus* (AA), and *T. m. ponticus* (CC) after Dobrovolov, [11].

This review shows that many problems of the Black Sea fishery cannot be addressed without physiological and biochemical approaches. This relates: 1) short-term prediction of time and character of wintering migrations of Azov Sea and Black Sea anchovies; 2) long-term prediction fishery perspectives; 3) consideration about probable transformation of biota (including ichthyofauna) in shelf (first of all coastal) zone; 4) estimation of condition (degree of wellbeing) of commercial stocks; 5) influence on this condition by climatic and regional biological and anthropogenic factors; 6) determination of population structure, distribution and localization of commercial stocks.

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