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PLASTICITY OF DIGESTIVE SYSTEM OF WADERS (CHARADRII) AS MIGRANTS (PECULIARITIES OF FAT ACCUMULATION AND THE SOURCE OF ESSENTIAL POLYUNSATURATED FATTY ACIDS DURING MIGRATORY STOPS IN THE AZOV-BLACK SEA REGION)

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Plasticity of Digestive System of Waders (Charadrii) as Migrants (Peculiarities of Fat Accumulation and the Source of Essential Polyunsaturated Fatty Acids During Migratory Stops in the Azov-Black Sea Region). Lykova, I. O., Kovtun, M. F., Kharchenko, L. P., Kratenko, R. I. — The plasticity of the digestive system (DS) of birds allows them to use a wide range of feeds, which is especially important for migratory birds. Some fatty acids (FAs) included in the spectrum of polyunsaturated FAs (PUFAs) are not synthesized in the bird organism, and are supplied only with food. They determine the level of unsaturation of lipids, and are essential for the organism. Among other important functions of these FAs are energy: they affect the energy metabolism of muscle cells. This is what determines the demands of migratory birds to the fodder base of migration stops. The largest number of general lipids among investigated species of invertebrates living in the Azov-Black Sea region ponds is found in the organisms *N. zonata, A. salina, H. diversicolor, I. baltica* (4.6–4.0%). The highest content of PUFAs was revealed to be present in the lipids of mollusks *H. acuta* and *Th. astrachanicus*: 32.87–35.73 % of the total amount of FAs. The content of PUFAs in the organism of *Chironomis* depends on the degree of water salinity. The unsaturation coefficient of FAs (K_1) is revealed to be the highest in Mollusk lipids (*H. acuta* — 1.361; *Th. astrachanicus* — 1.610) and some Polychaeta. These types of invertebrates are the main source of intake of essential PUFAs by the organism of the waders at migratory stops in the Azov-Black Sea region.
Key words: Charadrii waders, distant and local migrants, migratory stops, fat accumulation, fatty acid composition of lipids, essential fatty acids.

Introduction

Migration, as a part of survival strategy, is inherent to many species of animals. The scales of different animals migrations vary significantly from local or intra-regional to transcontinental ones. If the former are caused mainly by the trophic factor and, in particular, by competition for energy sources, then the latter are historical, geological, genetic, ethological, climatic, and trophic. Among the land animals, the most prominent transcontinental migrants are the representatives of the Aves class and, in particular, some species of waders (Charadrii).

Migrations have long attracted the attention of specialists in various fields of science. As for birds, matters connected with their orientation during seasonal transcontinental migrations, energy consumption and energy supply of these multi-hour flights were of great interest.

For birds, during long flights, the main source of energy is fat reserves. Therefore, the success of distant migrations depends on the proper fat accumulation in the bird organism during the pre-migratory period and its renewal at migratory stops (Piersma et al., 2005; Yohannes et al., 2010). The energy of the flight of migratory birds has been sufficiently investigated (Blumental, Dolnik 1962; Gavrilov, 2012, etc.), and the energy properties of fats are described in biochemical literature (Lehninger, 1985).

According to some authors, body mass of waders during the period of a migration stop can grow by 40–80 % (Jehl, 1997; Khomenko, 2003; Atkenson, 2007). Our data prove the mass of the tundra waders species to get increased by 27.6–75.7 %, during their migration stop in the Azov-Black Sea region. This increase in their body weight occurs mainly due to fat accumulation, and only, to a small extent, due to the mass growth and morphometric indices of the intestine, stomach, and liver (Lykova, 2014).

The most optimal form of energy storage in the animal body is triacylglycerols (TAGs). They are synthesized in hepatocyte and adipocyte cytoplasm from glucose, ketoacids, amino acids, free fatty acids (FFAs), and accumulated in the adipose tissue of various organs. When oxidized to CO_2 and H_2O, TAGs release the highest amount of energy (9.3 kcal/1 g) compared with carbohydrates and proteins. TAGs physico-chemical properties are determined by the fatty acids (FAs), that are the part of their composition, and the main energy material for almost all tissues and organs (except for brain cells) are saturated FFAs (Lehninger, 1985).

The largest number of general lipids is deposited in the liver, thoracic muscle, abdominal and subcutaneous fat, which are a kind of fat "depot". Thus, during the period of migratory stops of waders in the Azov-Black Sea region, the content of total lipids in their liver increased by 1.3–4.5 times; in the chest muscles — by 2.7–3.85 times, in abdominal fat — by 1.6–2.4 times (Lykova, 2014; Kovtun et al., 2018).

The liver is not only the "depot" of general lipids, but also an organ where the process of synthesis of fatty acids occurs. Undoubtedly, the fatty acid composition (FAC) of liver lipids is represented by saturated, monoenic and polyeneic FAs. In turn, the spectrum of saturated FAs is represented by the meristic (C14:0), palmitic (C16:0) and stearic (C18:0) acids that are synthesized in the liver. The spectrum of monoenic FAs is represented by palmitoleic (C16:1), oleinic (C18:1), eicosenic (C20:1), erucic (C22:1) and tetracosenic (C24:1) acids. Monoenic FAs form the largest proportion of all unsaturated liver FAs, which are the part of liver lipids FAC, and are the main link of lipid synthesis (Kharchenko, Lykova, 2012).

In addition to monoenic FAs, polyunsaturated fatty acids also enter the chemical composition of the body, most of which are not synthesized in the animal organism, but are supplied by food (Kreps, 1981). Polyunsaturated fatty acids (PUFAs) determine the level of unsaturation of lipids and are essential for the body. PUFAs provide a number of important functions: structural (they are the main component of cell membranes); regulatory (synthesis of thromboxanes and prostaglandins); affect the energy cellular metabolism, acting through changes in membrane structures and systemic mechanisms of cells (Maillet, Weber, 2009); signal and transport.

The spectrum of saturated FAs in the lipids of abdominal fat, and, partly, in the chest muscles, is similar to the spectrum of saturated FAs in liver lipids (Kharchenko, Lykova, 2012). The main place of synthesis of saturated FAs is adipose tissue, where abdominal lipids are deposited. In the liver 10 % of FFAs is synthesized from their total amount in the body.

The mechanism of FFA oxidation in the muscles occurs in mitochondria and is a source of energy for muscle contraction. The endurance of muscle tissue during long-distance flights substantially depends on the FAC of muscle tissue lipids and the number of PUFAs that replenish the body of birds during the period of the migration stop (Weber, 2009; Kharchenko, Lykova, 2014).

Since the introduction of PUFAs into the body of birds is possible only with feed, this is what, according to some authors, determines the demands of migratory birds to the trophic base of migration stops (Maillet, Weber, 2006, 2009). This led us, within the framework of bird adaptations to distant migrations, to investigate the changes in fatty acid composition of lipids in tissues and organs of waders during migratory stops in the Azov-Black Sea region (Kovtun et al., 2018). The main objective of this work is to identify the supply sources of essential PUFAs in the organism of the experimental birds at the migration stops in the Azov-Black Sea region. For this purpose, FAC of lipids was studied in the organism of littoral invertebrates, which are the main feed of the investigated species of waders at migratory stops in the region.

Material and methods

The material for this work was collected during 2010–2015 in shared expeditionary trips with ornithologists of the Azov-Black Sea ornithological station to various wetlands of the Zaporizhzhya, Kherson and Crimea

regions, and hunting trips during the hunting season in this region (the coast of Central and Eastern Syvash, Molochniy and Utlyutskiy estuaries, Peremozhna River near the village of Bolotne Dzhankoi District, Great Utlyuk River, etc.). The contents of general lipids and their FAC in the liver, abdominal fat and thoracic muscles were studied in 6 species (table 1) of waders (*Tringa glareola* Linnaeus, 1758; *Philomachus pugnax* (Linnaeus, 1758); *Calidris minuta* (Leisler, 1812); *Calidris ferruginea* (Pontoppidan, 1763); *Calidris alpina* (Linnaeus, 1758); *Limicola falcinellus* (Pontoppidan, 1763)). These species use the feed base of the above-mentioned region for the renovation of energy reserves during migration stops.

In accordance with the objective of this study, it was necessary to investigate the sources of essential FAs in bird organism. For this purpose, we collected representatives of nine species of invertebrate animals, which are the dominant feed of the above species of waders during migratory stops in the Azov-Black Sea region. We determined the content of total lipids and their fatty acid composition in the organism of the invertebrates (*Nereis zonata* Malmgren, 1867; *Hediste diversicolor* (O. F. Müller, 1776); *Gammarus aequicauda* (Martynov, 1931); *Idotea balthica* (Pallas, 1772); *Artemia salina* (Linnaeus, 1758); *Chironomus salinarius* Kieffer, 1915; *Chironomus plumosus* (Linnaeus, 1758); *Theodoxus astrachanicus* Starobogatov in Starobogatov, Filchakov, Antonova & Pirogov, 1994; *Hydrobia acuta* (Draparnaud, 1805)).

Specimens of tissues (liver, pectoral muscle and abdominal fat) that were frozen in liquid nitrogen at t =– 195 °C were used to determine the content of total lipids and their fatty acid composition in birds (Folch et al., 1957). Samples of invertebrates for analysis were collected according to the standard method (Arsan et al., 2006) using a benthic glass with a grabber area of 0.015 m^2 in the coastal meadows at places of waders feeding (from 0 to 10 cm). The material was washed through a set of soil sieves with a minimum aperture size of 1.0 mm. The collected invertebrates belonging to the same species were washed, dried with filter paper and fixed in 90 % ethanol, and, until analysis, were stored at t = + 4 °C (Tkach et al., 2007).

Determination of the contents of general lipids and their fatty acid composition was performed by gas chromatography, using the gas chromatograph GC-14B of "SHIMADZY" company with a flame-ionizing detector, temperature programming and calculation of data on the integrator G-6. Experiments were conducted at the experimental laboratory of instrumental research at Ukrainian Research Institute of Oils and Fats (Kharkiv).

General lipids from tissues and organs of the waders and invertebrates were extracted with a mixture of chloroform and methanol in the ratio 2: 1 (Folch et al., 1957). Methyl esters of fatty acids were obtained by re-etherification method. Methyl esters of higher FAs, total lipids and fractions of unsaturated FAs were separated by gas-liquid chromatography (Rivis et al., 1997). The research was carried out on a capillary column DB-23 60m x 0.25 mm id, 0.25μm 122–2362 at a thermostat temperature of columns — from +175 °C to + 230 °C with a programmable temperature increase of 3 °C / min. Injector temperature was +240 °C, split system with split ratio was 1:70, detector furnace temperature was +250 °C, volume of sample was 1 ml of methyl ether solution. The experiments with waders tissues lipid contents were performed in triplicates, the determination of general lipids and their fatty acid composition in invertebrates were carried out in six fold measurements.

The obtained data, namely the content of total lipids (% in 10 g of wet matter) and contents in their FAs (% of the sum of FAs) in tissues and organs of birds with different fat contents degree and in the investigated invertebrates, were statistically processed using Excel and Statistica 8.0 programs using the Student's t-test (Lakin, 1990).

Results and discussion

Discussion of the sources of the introduction of essential PUFAs into the organism of experimental birds, we want to start with data on changes in the fatty acid composition of lipids in the tissues and organs of the sandpipers during migration stop to the Azov-Black Sea region. As already noted in the introductory part, during the migration stop, the body mass of the investigated birds increased by 27.6–75.7 % (Kovtun et al., 2018). The increase in body weight was mainly due to intense lipid accumulation in subcutaneous and abdominal fat, and, to a lesser extent, the accumulation of lipids in the muscles, as well as, due to the increase in digestive system organs mass. Thus, the increase in stomach mass was due to the thickening of muscular stomach walls; intestine — the increase in the linear parameters and the thickness of the walls; mass of digestive glands — by way of fat accumulation (Lykova, 2014).

We investigated the contents of general lipids and their FAC in the liver, abdominal fat and chest muscles of birds at the beginning of the migration stop and at the end of it. In all the birds examined, body weight and fat accumulation degree were determined according to Blumenthal & Dolnik (1962). Birds with minimum body mass index and low fat contents degree served as a standard for the status of birds at the beginning of the migration stop (Davidson, 1984). Birds with a maximum body weight and high fat contents degree served

as a standard for birds at the end of the migration stops. During the period of migration stop the weight of the experimental waders species organism was established to have increased by 1.3–1.7 times (table 1).

Samples of tissues and organs were selected from birds of one sex, since it is known that the composition of feeds of males and females may vary significantly (Chernichko, 2010), which may affect the rate of fat accumulation and the process of receiving essential PUFAs in the organism (Maillet, Weber, 2009).

In analyzing the obtained data we evaluated the changes in the contents of total lipids in experimental tissues and organs during the period of migration stop, as well as changes in the contents of polyunsaturated FAs in the fatty acid composition. The increase in the contents of general lipids characterizes the overall fat contents accumulation during migration stops, and changes in FAC of lipids in tissues and organs of the waders reflect the specificity of fat accumulation and depend on the intake of polyunsaturated FAs in the wader organism with food. Estimates of changes in FAC of lipids in tissues and organs of investigated birds can be evaluated by such indices as the unsaturation coefficient of lipids (K_1), which is expressed by ratio of PUFAs sum to saturated FAs sum (Σ PUFAs/Σ SFAs). The change in this ratio reflects the increase in the contents of polyunsaturated FAs in the lipid FAC. The increase in this index indicates the improvement in the permeability of cell membranes (Kreps, 1981), which accelerates the overall metabolism of birds in the premigratory period.

The properties of cell membranes are influenced not only by the contents of PUFAs, but also by the ratio of ω3 and ω6 PUFAs in the composition of phospholipids in cellular membranes (K_2). The melting point of the linoleic (ω6) acids is higher than that of the linolenic series (ω3), therefore, the ratio of ω3 FAs sum to ω6 FAs (Σω3 / Σω6) is an indicator of membrane lipids viscosity (Kreps, 1981; Tkach, 2007). The increase of this index indicates the decrease in the viscosity of membranes and the increase in the intensity of metabolic processes.

Taking into account the aforementioned, in the analysis of lipid FAC of investigated tissues and organs, we evaluated precisely changes in the unsaturation coefficient (K_1) and the ratio Σω3/Σω6 FAs (K_2).

Fatty acid composition of investigated wader species liver lipids. During the period of migration stop, the content of total lipids in the liver of the investigated waders significantly ($p < 0.1$) increased by 1.5–4.5 times (table 2). The process of fat accumulation in the liver resulted in a significant increase in the content of PUFAs by 3.6–6.5 %.

Table 1. Body mass minimal and maximal values (g) and fat contents degree of the studied waders

Species	L		H	
	Body mass (g)	Quantity of fat accumulation	Body mass (g)	Quantity of fat accumulation
Calidris alpina ♂	38.2–51.7 n = 7	~	56.8-63.6 n=8	X
Calidris ferruginea ♀	38.7–53.6 n = 12	~	68.0-75.3 n=14	X
Calidris minuta ♂	20.6–22.2 n = 5	~	27. 2-30.5 n=3	X
Limicola falcinellus ♂	31.5–34.3 n = 3	~	37.9-41.2 n=3	+
Tringa glareola ♀	41.6–55.3 n = 5	~	62.5-71.0 n=7	X
Philomachus pugnax ♂	174.0–196.5 n = 11	~	201.0-274.5 n=19	X

Note. L — birds with low fat contents degree; H — birds with high fat contents degree; "~" — small fat accumulation, "+" — average fat accumulation, "X" — big fat accumulation; n — number of the studies birds.

Table 2. Content of main fatty acids (% of the sum of fatty acids) in the liver total lipids of the studied waders, depending on birds fat contents degree

Fatty Acids	*Calidris alpine* ♂				*Calidris minuta* ♂				*Tringa glareola* ♀				*Philomachus pugnax* ♂			
	L		H		L		H		L		H		L		H	
	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m
Total lipids (% in 10 g of wet matter)	1.96	0.18	8.71	0.49 [a]	2.86	0.52	8.31	0.65 [b]	2,67	0,32	7.57	0.63 [b]	2.94	0.16	4.31	0.31 [c]
Saturated																
14:0 myristic	0.92	0.05	0.45	0.15	0.78	0.11	0.42	0.08	1.23	0.18	0.47	0.08	0.98	0.12	0.31	0.05
16:0 palmitic	25.53	1.74	21.73	0.89	24.82	0.78	25.26	0.52	26.85	1.15	21.91	0.43	26.77	0.82	23.80	1.07
18:0 stearic	14.15	0.34	10.98	0.87	16.62	0.25	10.66	0.38	20.18	0.35	19.02	0.52	23.24	0.46	18.03	0.49
Sum	**40.60**	**1.78**	**33.16**	**1.53**	**42.22**	**1.38**	**36.34**	**0.85**	**48.26**	**1.65**	**41.40**	**1.18**	**50.99**	**1.40**	**42.14**	**1.61**
Monoene																
16:1 palmitoleic	2.10	0.37	3.12	0.58	1.95	0.12	3.20	0.25	1.75	0.18	3.04	0.31	1.54	0.21	2.05	0.11
18:1 oleic	36.64	1.85	38.74	1.51	32.54	1.05	34.83	1.24	27.45	0.68	28.59	0.52	23.58	0.96	25.92	0.91
20:1 eicosenic	0.65	0.16	1.22	0.23	0.71	0.06	1.70	0.08	0.82	0.10	1.65	0.15	0.89	0.12	1.87	0.11
22:1 erucic	~		1.03	0.08	~		0.62	0.08	–		~		–		~	
24:1 tetracosenic	1.23	0.20	1.09	0.11	2.82	0.24	2.33	0.12	1.84	0.22	2.66	0.18	2.41	0.27	2.29	0.12
Sum	**40.62**	**1.09**	**45.20**	**1.12**	**38.02**	**0.64**	**42.68**	**1.05**	**31.86**	**0.85**	**35.94**	**0.82**	**28.42**	**1.56**	**32.13**	**1.25**
Polyene																
18:3ω3 linolenic	1.33	0.17	0.31	0.11	0.81	0.22	1.18	0.31	1.85	0.34	0.62	0.12	0.19	0.02	0.27	0.03
20:5ω3 eicosopentaenoic	0.62	0.04	1.67	0.13	0.61	0.15	0.73	0.08	0.57	0.08	2.61	0.34	0.50	0.03	0.92	0.05
22:6ω3 docosahexaenoic	~		1.56	0.23	0.35	0.05	2.03	0.18	0.45	0.05	1.92	0.22	0.58	0.05	2.14	0.25
Ω3 acid sum	1.95	0.15	3.54	0.29 [b]	1.77	0.25	3.94	0.24 [b]	2.87	0.21	5.15	0.38 [b]	1.27	0.08	3.33	0.15 [a]
18:2ω6 linoleic	4.75	0.41	7.43	0.52	4.28	0.22	5.01	0.25	6.07	0.42	6.85	0.26	6.94	0.35	8.70	0.28
20:4ω6 arachidonic	7.13	0.35	8.50	0.29	8.67	0.35	9.33	0.32	7.10	0.25	8.25	0.31	9.59	0.32	12.26	0.25
Ω6 acid sum	11.88	0.52	15.93	0.78 [b]	12.95	0.45	14.34	0.28	13.17	0.46	15.10	0.35 [c]	16.53	0.84	20.96	0.87 [c]
K_2 (Σ ω3/Σ ω6)	**0.164**	**0.002**	**0.222**	**0.006** [a]	**0.137**	**0.002**	**0.275**	**0.005** [a]	**0.218**	**0.004**	**0.341**	**0.006** [b]	**0.077**	**0.002**	**0.159**	**0.003** [b]
Sum	**13.63**	**0.86**	**19.47**	**1.09** [c]	**14.72**	**0.58**	**18.28**	**0.61** [c]	**16.04**	**0.64**	**20.25**	**0.82** [c]	**17.80**	**0.97**	**24.29**	**1.07** [b]
K_1(Σ polyene/Σ saturated)	**0.335**	**0.005**	**0.587**	**0.022** [a]	**0.349**	**0.011**	**0.503**	**0.018** [a]	**0.332**	**0.012**	**0.489**	**0.015** [b]	**0.349**	**0.009**	**0.576**	**0.011** [a]

Note. L — birds with low fat contents degree; H — birds with high fat contents degree; "–" — not found ; "~" — in trace amounts; [a] — $p < 0.01$ (according to t-Student test); [b] — $p < 0.05$ (according to t-Student test); [c] – $p < 0.1$ (according to t-Student test); *M — mean value; m — standard error.

The unsaturation coefficient (K_1) of liver lipid FAs of the investigated species of waders was significantly increased ($p < 0.05$) in 1.44–1.75 times. Thus, at the beginning of the migration stop, this index varies within the range of 0.335–0.349, and in the end — increases to 0.489–0.587 (table 2), which indicates an acceleration of the metabolic processes in liver cells at migration stops due to improved hepatocyte membrane permeability.

Investigation of PUFA spectrum of liver lipids (K_1) and ω3 and ω6 PUFAs ratio (K_2) showed that the ratio (Σω3 / Σω6) of linoleic and linolenic type FA changes with the general increase in the contents of PUFAs. In the process of fat storage, the ratio of Σω3/Σω6 (K_2) significantly increased ($p < 0.05$) by 1.35–2.1 times. Thus, at the beginning of the migration stop, this index varies within the range of 0.077–0.218, and in the end — increases to 0.159–0.334 (table 2), which may indicate the decrease in the membrane viscosity and the increase in the intensity of metabolic processes in the liver cells (Bogach et al., 1981, Kazimirko, Maltsev, 2004).

Fatty acid composition of abdominal fat lipids of investigated wader species. At the beginning of the migration stop, there was almost no abdominal fat in the studied waders. During the period of migration stop, the contents of total lipids in adipose tissue was significantly ($p < 0.05$) increased by 1.6–2.4 times and amounted to 61.2–78.2 % (table 3). The contents of PUFAs in lipids of abdominal fat in the process of fat accumulation was found to be increased by 6.74–9.87 %. FAs unsaturation coefficient (K_1) during the period of migration stop was significantly ($p < 0.01$) increased by 1.7–2.4 times. Thus, at the beginning of the migration stop, this index varies within the range of 0.204–0.256, and in the end — increases to 0.424–0.505 (table 3), which indicates the intense accumulation of PUFAs in the adipose tissue. The lipids of investigated wader species abdominal fat were established to have a high ω3 and ω6 PUFAs ratio (K_2). Thus, ω3 PUFAs were deposited in the adipose tissue, which entered the body of birds with food. The analysis of the ratio of Σω3/Σω6 PUFAs in waders with different fat contents degrees showed the significant ($p < 0.05$) increase of this index in 1.2–1.6 times in the process of fat accumulation. Thus, at the beginning of the migration stop, this index varies from 0.166 (in *P. pugnax*) to 1.625 (in *C. ferruginea*), and at the end - increases to 0.272 (in *P. pugnax*) — 1.855 (in *C. ferruginea*) (table 3). This indicates the reduction in the viscosity of the membranes and the increase in the intensity of the metabolic processes in the adipocytes of the investigated wader species.

The investigated *Calidris* species were found to have the ratio of Σω3/Σω6 PUFAs of abdominal fat lipids significantly ($p < 0.01$) higher (1.512–1.835) than that of other studied species of waders (0.166–0.768) (table 3). In our opinion, this was due to the trophic specialization of the investigated waders, and, possibly, their different migration strategies, i.e. a significant distance of continuous flight. The feeds of *Calidris* species were dominated by invertebrates, which are the main source of essential ω3 PUFAs. The lowest ratio of Σω3/Σω6 PUFAs is noted in *P. pugnax* (0.166–0.272), the feeds of which contain a large portion of plant components.

Fatty acid composition of thoracic muscle lipids of the investigated wader species. At the beginning of the migration stop, the contents of total lipids in the chest muscles of the studied waders was 2.5–3.2 %, at the end of the migration stop — increased to 8.3–10.1 % (table 4). Consequently, in the process of fat accumulation, the contents of lipids in wader chest muscles was significantly ($p < 0.01$) increased in 2.7–3.95 times. The contents of polyunsaturated FAs in the lipids of the thoracic muscles were found to be significantly ($p < 0.05$) increased by 7.94–17.45 %. FAs unsaturation coefficient (K_1) of the thoracic muscle lipids in all investigated waders during the period of migration stop significantly ($p < 0.05$) increased in the range of 1.7–3.3 times, which is the highest index among investigated tissues and organs of the waders. Thus, at the beginning of the migration stop, this index varies within the range of 0.262–0.451, and in the end — increases to 0.589–0.917 (table 4). The obtained results testify that in the process of fat accumulation in the wader organism at migratory stops, the contents of PUFAs in the endoplasmic fat and

Table 3. Contents of main fatty acids (% of the sum of fatty acids) in the abdominal fat total lipids of the studied waders, depending on birds fat contents degree

Fatty Acids	*Calidris alpine* ♂				*Calidris ferruginea* ♀				*Calidris minuta* ♂				*Limicola falcinellus* ♂				*Tringa glareola* ♀				*Philomachus pugnax* ♂			
	L		H		L		H		L		H		L		H		L		H		L		H	
	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m
Total lipids (% in 10 g of wet matter)	29.20	1.27	66.05	1.75[a]	33.56	2.14	72.31	2.26[a]	40.51	1.18	68.25	2.19[b]	38.25	1.52	61.18	1.04[b]	31.58	0.85	77.11	1.96[a]	36.45	2.07	78.22	2.99[a]
Saturated																								
14:0 myristic	1.72	0.06	4.91	0.22	2.84	0.12	3.16	0.15	0.95	0.08	1.54	0.06	1.85	0.12	2.12	0.15	2.05	0.08	2.81	0.18	0.76	0.08	0.93	0.16
16:0 palmitic	18.67	0.55	17.20	0.40	23.73	0.62	22.40	0.48	26.62	0.58	24.33	0.72	19.75	0.55	17.52	0.42	24.02	0.48	22.09	0.61	29.55	1.21	26.62	0.71
18:0 stearic	9.30	0.24	6.33	0.16	7.63	0.22	10.40	0.30	8.58	0.28	9.15	0.25	10.16	0.32	13.40	0.55	8.78	0.38	11.32	0.62	8.92	0.65	12.66	0.76
Sum	29.69	0.94	28.44	0.51	34.20	1.02	35.96	0.98	36.15	1.21	35.02	1.05	31.76	0.84	33.04	1.12	34.85	1.31	36.22	1.24	39.23	1.94	40.21	1.63
Monoene																								
16:1 palmi-toleic	16.75	0.93	24.24	0.82	12.44	0.74	12.44	0.45	13.19	0.52	13.75	0.78	5.14	0.24	6.05	0.31	12.38	0.38	13.75	0.62	4.19	0.24	4.83	0.42
18:1 oleic	38.26	0.91	18.72	0.75	39.63	1.06	30.41	0.83	38.28	0.75	26.25	0.85	47.25	1.24	32.28	0.62	39.32	0.58	27.41	0.45	45.05	1.19	34.63	0.53
20:1 eicosenic	0.55	0.02	1.14	0.06	0.64	0.02	0.96	0.05	0.75	0.06	0.69	0.04	2.33	0.12	1.62	0.09	1.28	0.11	0.72	0.08	0.72	0.04	0.62	0.05
22:1 erucic		-	0.51	0.02	0.26	0.02	0.53	0.03	~		0.48	0.02	0.59	0.02	0.72	0.04	–		~		–		~	
24:1 tetra-cosenic	0.71	0.06	1.08	0.06	0.15	0.01	1.25	0.05	0.62	0.04	1.05	0.06	0.59	0.02	1.22	0.06	0.52	0.04	0.87	0.10	~		0.36	0.12
Sum	**56.27**	**0.78**	**45.69**	**0.82**	**53.12**	**1.33**	**45.59**	**0.92**[b]	**52.84**	**1.48**	**42.22**	**1.07**	**55.90**	**1.65**	**41.89**	**1.28**	**53.50**	**1.17**	**42.75**	**0.87**	**49.96**	**1.47**	**40.44**	**1.12**
Polyene																								
18:3ω3 linolenic	1.56	0.05	1.18	0.06	1.41	0.06	1.85	0.10	0.82	0.06	1.48	0.08	~		0.95	0.04	0.72	0.08	1.21	0.07	0.59	0.03	0.99	0.05
20:5ω3 eicosopentaenoic	2.90	0.33	6.70	0.28	3.43	0.27	6.71	0.41	2.71	0.18	7.27	0.33	1.29	0.08	3.85	0.24	0.95	0.08	2.87	0.22	0.15	0.01	0.94	0.07
22:6ω3 docosahexaenoic	~		1.29	0.10	0.46	0.04	1.35	0.08	0.52	0.04	1.43	0.06	1.28	0.07	2.28	0.10	0.98	0.08	2.46	0.13	0.66	0.08	1.86	0.06
Ω3 acid sum	4.46	0.42	9.17	0.52[b]	5.30	0.32	9.91	0.47[b]	4.05	0.22	10.18	0.43[a]	2.57	0.18	7.08	0.25[a]	2.65	0.15	6.54	0.31[a]	1.41	0.07	3.79	0.15[a]
18:2ω6 linoleic	2.47	0.28	3.73	0.25	2.44	0.14	2.43	0.22	2.79	0.20	3.98	0.31	3.36	0.24	6.17	0.36	4.74	0.16	8.06	0.37	8.25	0.46	11.06	0.52
20:4ω6 arachidonic	0.68	0.08	1.45	0.14	0.82	0.06	2.91	0.11	0.54	0.05	2.75	0.12	0.63	0.08	3.05	0.18	0.55	0.06	2.68	0.15	0.25	0.04	2.88	0.10
Ω6 acid sum	3.15	0.21	5.18	0.28[b]	3.26	0.18	5.34	0.22[b]	3.33	0.24	6.73	0.28[b]	3.99	0.14	9.22	0.41[a]	5.29	0.25	10.74	0.37[a]	8.50	0.62	13.94	0.53[b]
K_2 (Σ ω3/Σ ω6)	**1.410**	**0.04**	**1.770**	**0.06**[a]	**1.625**	**0.03**	**1.855**	**0.05**[a]	**1.216**	**0.04**	**1.512**	**0.05**[b]	**0.644**	**0.01**	**0.768**	**0.01**[b]	**0.501**	**0.008**	**0.609**	**0.01**[b]	**0.166**	**0.003**	**0.272**	**0.005**[b]
Sum	**7.61**	**0.28**	**14.35**	**0.42**[a]	**8.56**	**0.25**	**15.25**	**0.38**[a]	**7.38**	**0.52**	**16.91**	**0.84**[b]	**6.56**	**0.31**	**16.30**	**0.75**[a]	**7.94**	**0.32**	**17.28**	**0.91**[a]	**9.90**	**0.49**	**17.73**	**1.02**[b]
K_1(Σ polyene/Σ saturated)	**0.256**	**0.013**	**0.505**	**0.015**[a]	**0.250**	**0.015**	**0.424**	**0.011**[a]	**0.204**	**0.008**	**0.483**	**0.012**[a]	**0.206**	**0.006**	**0.493**	**0.015**[a]	**0.228**	**0.011**	**0.477**	**0.018**[a]	**0.253**	**0.004**	**0.441**	**0.011**[a]

Note. L — birds with low fat contents degree; H — birds with high fat contents degree; "–" — not found ; "~" — in trace amounts; [a] — $p < 0.01$ (according to t-Student test); [b] — $p < 0.05$ (according to t-Student test); *M — mean value; m — standard error.

membranes of myofibrils significantly increase. The unsaturation (K_1) of thoracic muscle lipids of waders is somewhat higher than that of the liver or abdominal fat, which indicates the special value of PUFAs for the work of the chest muscles during the flight.

The ratio of ω3 and ω6 PUFA sums (K_2) of investigated wader thoracic muscle lipids during the period of migration stops significantly ($p < 0.01$) increased by 1.4–4.0 times. Thus, at the beginning of the migration stop, this index varies within 0.085-0.481, and in the end — rises to 0.298–0.778 (table 4), which indicates the increase in the endurance and readiness of muscle tissue for significant loads during further flights. The significant raise in the content of ω3 PUFAs was due to the increase in eucozopentaenic (C20:5) and docosahexaenoic (C22:6) FAs in FAC. These two predetermine a number of important functions in the muscles: increase permeability of membranes of myofibrils, participate in the formation of hormones, perform functions of the temperature stabilizer of lipid bilayers, which is one of the main methods of rapid reaction of the organism to any changes in the temperature of the environment (Bogach et al., 1981; Kazimirko, Maltsev, 2004). For migratory birds, this feature is of great importance, as they may fall from one climatic zone to another within a few hours of flight, and changes in the structure of membranes of myofibrils contribute to increased endurance of birds during migration (Maillet, Weber, 2006, 2009; Weber, 2009).

Fatty acid composition of lipids in the organism of littoral invertebrates. In connection with the great importance of essential PUFAs in the life of birds and, especially in stressful situations, which may happen at all stages of migration, it was necessary to identify the sources of receiving these acids by the organism of waders. Essential PUFAs enter the body only with food, therefore the contents of general lipids and their FAC were investigated in 9 species of littoral invertebrates, which are the main feeding objects of the waders at the migration stop.

The composition of FA phytoplankton organisms is directly dependent on environmental conditions. When the water temperature decreases, the degree of FA unsaturation increases. The lack of nitrogen, phosphorus or silicon, as a rule, increases the contents of saturated FAs, and the amount of unsaturated ones decreases. The composition of FAs is also influenced by light and salinity (Sushchyk, 2008; Zhukova, 2009). Accordingly, all these factors also affect the transfer of fatty acids along the food chain: phytoplankton - invertebrates — waders.

Based on the foregoing, for a comparative analysis, samples of invertebrate animals were collected, which are the main forage of waders at migration stops in the Azov-Black Sea region. The samples were collected in reservoirs with different salinities in places of mass accumulations of waders, in the same period of the year (May–June), at the same ambient temperature (+ 25-27 ^{0}C) (table 5).

According to the investigation results on the contents of general lipids in the organism of the invertebrates species, the most amount of lipids were found to be contained in *N. zonata* — 4.6 %, a relatively high level of lipids was also observed in *A. salina* — 4.4 %, *H. diversicolor* — 4.0 %, *I. balthica* — 4.0 %. Relatively low content of lipids was noted in *Ch. plumosus* — 1.5 % and *Ch. salinarius* — 1.8 % (table 6). Consequently, Polychaeta and *Artemia*, as a source of fats, are the most productive for waders.

Analysis of FAC of the studied invertebrate species showed the contents of PUFAs to go significantly higher ($p < 0.01$) in the lipids of mollusks *H. acuta* and *Th. astrachanicus* — 32.87–35.73 % of the total amount of FAs, which is 2.0–2.7 times higher than the content of PUFAs in other investigated species of invertebrates (table 6).

A comparative analysis of the contents of PUFAs in closely related species of chironomuses living in ponds with different salinity of water showed significant differences ($p < 0.05$) with respect to the contents of these FAs. So *Ch. plumosus*, which lives in low-saline water (3–5 ‰) has the contents of polyene FAs 1.5 times higher than *Ch. salinarius*, which lives in ponds with high salinity of water (86.8 ‰). Salinity of water in ponds affects

Table 4. Content of main fatty acids (% of the sum of fatty acids) in the thorax muscles total lipids of the studied waders, depending on birds fat contents degree

Fatty Acids	*Calidris alpine* ♂				*Calidris ferruginea* ♀				*Calidris minuta* ♂				*Limicola falcinellus* ♂				*Tringa glareola* ♀				*Philomachus pugnax* ♂			
	L		H		L		H		L		H		L		H		L		H		L		H	
	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m
Total lipids (% in 10 g of wet matter)	2.73	0.24	9.71	0.34[a]	2.55	0.28	10.07	0.65[a]	3.12	0.14	9.29	0.38[a]	2.68	0.28	8.35	0.41[a]	2.92	0.18	10.09	0.52[a]	3.19	0.18	8.57	0.49[a]
Saturated																								
14:0 myristic	0.89	0.06	3.23	0.25	2.40	0.22	0.88	0.09	1.48	0.08	0.95	0.06	2.76	0.18	1.68	0.11	0.92	0.05	1.65	0.11	0.96	0.06	0.43	0.13
16:0 palmitic	20.62	0.62	17.13	0.71	24.27	1.69	16.01	1.14	27.82	1.35	20.78	0.74	27.18	0.58	25.10	0.65	25.15	1.12	19.52	0.80	28.38	1.94	19.55	0.99
18:0 stearic	12.31	0.76	9.81	0.58	7.39	0.58	13.26	0.70	11.40	0.61	12.44	0.45	10.58	0.47	4.51	0.28	12.80	0.36	10.35	0.51	12.26	0.34	13.98	0.81
Sum	**33.82**	**0.84**	**30.17**	**1.23**	**34.06**	**1.08**	**30.15**	0.92	40.70	1.26	34.71	1.11	40.52	1.73	31.29	0.88	38.87	1.32	31.52	0.68	41.60	2.28	33.96	1.93
Monoene																								
16:1 palmitoleic	11.13	0.61	17.54	0.92	11.40	0.41	8.60	0.22	10.55	0.38	9.18	0.32	12.48	0.40	15.60	0.54	7.12	0.35	5.78	0.23	4.61	0.36	3.11	0.38
18:1 oleic	34.43	1.31	21.63	1.04	38.10	1.50	32.11	1.33	35.48	1.08	29.17	0.95	32.93	1.36	18.76	0.54	37.45	1.06	27.28	0.58	40.21	0.85	29.78	1.51
20:1 eicosenic	0.23	0.02	0.74	0.06	~		0.33	0.02	0.36	0.02	0.72	0.05	~		0.35	0.04	0.50	0.05	0.32	0.02	0.62	0.06	0.22	0.03
22:1 erucic	1.95	0.12	2.32	0.23	0.88	0.09	1.52	0.12	~		1.08	0.08	-		0.92	0.08	0.38	0.02	1.48	0.13	-		~	
24:1 tetracosenic	0.82	0.08	1.44	0.15	~		0.70	0.05	0.73	0.05	1.54	0.12	0.62	0.06	3.18	0.20	0.42	0.05	1.12	0.11	0.23	0.02	1.09	0.13
Sum	**48.56**	**1.13**	**43.67**	**1.36**	**50.38**	**1.41**	**43.26**	**1.25**	**47.12**	**1.83**	**41.69**	**1.28**	**46.03**	**1.22**	**38.81**	0.93	45.87	1.05	35.98	0.74	45.67	1.29	34.20	2.05
Polyene																								
18:3ω3 linolenic	0.29	0.02	0.96	0.06	1.03	0.05	1.74	0.12	0.34	0.02	0.86	0.05	0.25	0.02	1.12	0.10	0.85	0.08	1.13	0.11	0.72	0.07	0.79	0.10
20:5ω3 eicosopen-taenoic	3.45	0.28	6.82	0.25	1.88	0.12	5.46	0.20	0.68	0.04	5.18	0.30	1.58	0.12	9.65	0.28	1.25	0.10	3.18	0.15	0.20	0.02	1.18	0.03
22:6ω3 docosa-hexaenoic	1.06	0.11	1.51	0.08	1.14	0.10	1.58	0.08	1.15	0.10	2.38	0.12	~		1.78	0.15	1.23	0.08	2.93	0.10	~		4.57	0.23
Ω3 acid sum	4.80	0.16	9.29	0.27[a]	4.05	0.21	8.78	0.25[a]	2.18	0.12	8.42	0.28[a]	1.83	0.15	12.55	0.30[a]	3.33	0.12	7.24	0.28[a]	0.92	0.10	6.54	0.19[a]
18:2ω6 linoleic	5.15	0.11	5.82	0.12	5.90	0.24	5.53	0.20	6.27	0.22	6.79	0.18	5.10	0.21	5.56	0.18	7.64	0.31	9.21	0.28	10.45	0.48	12.43	0.51
20:4ω6 arachidonic	5.31	0.15	8.09	0.22	2.52	0.12	7.61	0.27	2.23	0.11	5.24	0.15	4.32	0.21	10.57	0.34	1.08	0.10	8.27	0.23	0.26	0.05	9.50	0.27
Ω6 acid sum	10.46	0.36	13.91	0.24[b]	8.42	0.22	13.14	0.35[a]	8.50	0.21	12.03	0.27[a]	9.42	0.30	16.13	0.44[a]	8.72	0.35	17.48	0.40	10.71	0.52	21.93	0.78[a]
K_2 (Σ ω3/Σ ω6)	**0.458**	**0.006**	**0.668**	**0.02**[b]	**0.481**	**0.011**	**0.668**	**0.018**[a]	**0.256**	**0.008**	**0.699**	**0.025**[a]	**0.194**	**0.005**	**0.778**	**0.028**[a]	**0.381**	**0.011**	**0.414**	**0.012**[b]	**0.085**	**0.002**	**0.298**	**0.006**[a]
Sum	**15.26**	**0.50**	**23.20**	**0.77**[b]	**12.47**	**0.34**	**21.92**	**0.78**[a]	**10.68**	**0.41**	**20.45**	**0.74**[a]	**11.25**	**0.52**	**28.70**	**1.02**[a]	**12.05**	**0.51**	**24.72**	**0.64**[a]	**11.63**	**0.96**	**28.47**	**1.29**[a]
K_1(Σ polyene/ Σ saturated)	0.451	0.005	0.769	**0.028**[a]	**0.366**	**0.010**	**0.727**	**0.021**[a]	**0.262**	**0.008**	**0.589**	**0.018**[a]	**0.277**	**0.006**	**0.917**	**0.031**[a]	**0.310**	**0.009**	**0.784**	**0.032**[a]	**0.279**	**0.005**	**0.838**	**0.022**[a]

Note. L — birds with low fat contents degree; H — birds with high fat contents degree;"–" — not found ; "~" — in trace amounts; [a] — $p < 0.01$ (according to t-Student test); [b] — $p < 0.05$ (according to t-Student test); *M — mean value; m — standard error.

Table 5. Species composition of the studied aquatic invertebrates and characteristics of collection sites

Class	Insecta		Malacostraca		Branchiopoda	Gastropoda		Polychaeta	
Species	*Chironomus salinarius*	*Chironomus plumosus*	*Gamarus aequicauda*	*Idotea balthica*	*Artemia salina*	*Theodoxcus astrachanicus*	*Hydrobia acuta*	*Nereis zonata*	*Hediste diversicolor*
Collection date	17.05. 2013	15.05. 2013	16.05. 2013	16.05. 2013	04.06. 2012	05.06. 2012	17.05. 2013	16.05. 2013	05.06. 2012
Collection site	Molochnyi estuary. Radionovka vil.	Artificial flooding. Ryumshino vil. Jankoy Dist.	Jankoy outflow. Eastern Syvash	Jankoy outflow. Eastern Syvash	Utlyuk estuary. Akimovskyi Distr.	Utlyuk estuary. Akimovskyi Distr.	Molochnyi estuary. Radionovka vil.	Jankoy outflow. Eastern Syvash	Utlyuk estuary. Akimovskyi Distr.
Water salinity (‰)	86.8	3–5	21.2	21.2	50-60	50–60	86.8	21.2	50–60

the qualitative composition of phytoplankton, and, accordingly, and the contents of PUFAs in invertebrates (Sushchyk, 2008; Zhukova, 2009). Thus, the feeding of waders with the same species of invertebrates, but in territories with different hydrological regime regarding the salinity of water, has a different effect on the rate of fat accumulation and the delivery of polyunsaturated acids to the organism of birds.

The unsaturation coefficient (K_1) of invertebrate investigated species is found to be significantly higher ($p < 0.05$) in the lipids of molluscs (*H. acuta* — 1.361, *Th. astrachanicus* — 1.610), high degree of unsaturation of FAs is noted in the lipids of Polychaeta (*N. zonata* — 0.816, *H. diversicolor* — 0.872) and *A. salina* — 0.849 (table 6). These types of invertebrates are the main source of inflow of essential PUFAs to the organism.

The ratio of ω3 and ω6 PUFA sums (K_2) in the lipids of investigated invertebrates is established to be significantly higher ($p < 0.01$) in *A. salina* (table 6), that is, *Artemia* is the most effective source of ω3 PUFAs, especially eicosapentaenoic (C20:5) FA, for waders.

In the lipids of different types of littoral invertebrates, the ratio of ω3 and ω6 PUFA sums (K_2) can vary significantly depending on the influence of a number of factors, in particular the spectrum of nutrition, temperature and water salinity. Thus, in closely related species of chironomuses, a significant difference ($p < 0.05$) of the K_2 coefficient was established, which in *Ch. plumosus* was 2 times higher than in *Ch. salinarius* (table 6).

The results of the research on ω6 PUFA contents in the lipids of the studied invertebrates showed the best source of FA linoleic type for waders to be molluscs *H. acuta* and *Th. astrachanicus*, and Polychaeta *N. zonata* and *H. diversicolor*. The largest amount of arachidonic (C20:4) FA is contained in the lipids of *Th. astrachanicus* — 10.53 %, which is 11–16 times higher than its content in the lipids of the chironomuses (0.66–0.96 %). The contents of linoleic (C18:2) FA is the highest ($p < 0.05$) in the lipids of *H. diversicolor* — 9.24 % of the amount of FFAs (table 6).

In general, the analysis of the spectrum of polyene FAs in the lipids of the investigated invertebrates and the ratio of linoleic and linolenic acids may indicate the content of these acids in the aquatic invertebrate lipids to be dependent on their food spectrum and

Table 6. Content of main fatty acids (% of the sum of fatty acids) in total lipids of the studied invertebrates

Fatty Acids	*Chironomus salinarius*		*Chironomus plumosus*		*Gammarus aequicauda*		*Idotea balthica*		*Artemia salina*		*Theodoxus astrachanicus*		*Hydrobia acuta*		*Nereis zonata*		*Hediste diversicolor*	
	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m	M	m
Total lipids (% in 10 g of wet matter)	1.8	0.18	1.5	0.16	3.0	0.12	4.0	0.21	4.4	0.18	3.6	0.16	3.1	0.16	4.6	0.12	4.0	0.18
Saturated																		
14:0 myristic	9.64	0.96	8.55	0.37	4.93	0.32	0.99	0.08	2.89	0.27	1.85	0.22	1.15	0.12	0.97	0.14	0.91	0.18
15:0 pentadecanoic	1.16	0.13	1.85	0.19	0.85	0.04	0.41	0.05	-		0.44	0.05	0.35	0.02	-		-	
16:0 palmitic	20.00	2.40	21.24	0.54	18.13	1.37	19.27	1.53	17.72	1.85	14.67	1.38	16.23	1.72	25.07	2.08	22.37	1.68
17:0 margarinic	2.98	0.35	3.55	0.22	2.64	0.21	1.78	0.12	2.37	0.31	1.46	0.26	2.10	0.25	0.94	0.18	4.90	0.37
18:0 stearic	3.69	0.59	4.16	0.51	6.71	0.42	8.84	0.75	5.38	0.60	3.75	0.42	4.31	0.35	5.80	0.57	2.17	0.35
Sum	**37.47**	**2.57**	**39.35**	**2.36**	**33.26**	**1.65**	**31.29**	**1.95**	**28.36**	**1.76**	**22.17**	0.84	24.14	1.52	32.78	2.75	30.35	1.85
Monoene																		
16:1 palmitoleic	24.46	1.19	21.21	1.61	24.75	1.54	7.28	0.68	12.34	0.85	4.79	0.55	5.22	0.45	5.31	0.78	5.50	0.57
18:1 oleic	17.70	1.02	11.56	0.58	19.97	1.28	43.11	2.10	31.18	1.65	13.33	0.86	18.56	1.68	31.23	2.55	28.14	1.48
20:1 eicosenic	0.83	0.12	0.41	0.08	1.10	0.15	0.53	0.08	1.09	0.22	10.55	1.12	8.37	0.85	0.92	0.15	1.83	0.44
22:1 erucic	-		-		~		0.73	0.21	~		2.77	0.31	1.32	0.08	~		0.91	0.18
24:1 tetracosenic	-		-		1.53	0.18	1.55	0.30	1.08	0.31	1.51	0.15	1.56	0.15	1.15	0.18	1.85	0.18
Sum	**43.02**	**1.81**	**33.18**	**1.24**	**47.35**	**2.84**	**53.20**	**1.25**	**45.69**	**2.15**	**32.95**	**1.91**	**35.03**	**1.77**	**38.61**	3.12	38.23	2.15
Polyene																		
18:3ω3 linolenic	0.83	0.15[a]	8.87	0.67[a]	0.93	0.11	0.61	0.08[a]	2.17	0.34	6.93	0.75	4.97	0.75	2.52	0.22	3.88	0.28
20:5ω3 eicosopentaenoic	5.74	0.39	4.79	0.22	7.58	0.66	2.44	0.25	13.18	0.92[a]	8.21	0.72	9.85	0.82	11.15	1.25	9.23	0.85
22:6ω3 docosahexaenoic	~		~		1.70	0.35	1.80	0.25	2.26	0.20	2.62	0.18	2.41	0.15	1.75	0.45	2.06	0.12

Table 6. Continued

Ω3 acid sum	6.57	0.35[a]	13.66	0.95	10.21	0.83	4.85	0.78	17.61	1.18	17.76	0.98[a]	17.23	1.32	15.42	1.33	15.17	0.95
18:2ω6 linoleic	7.58	0.72	7.90	0.61	3.85	0.32	4.47	0.35	3.13	0.21	7.44	0.55	8.12	0.75	8.65	0.78	9.24	0.87[b]
20:4ω6 arachidonic	0.96	0.08[a]	0.66	0.07	1.42	0.21	4.06	0.45	3.35	0.45	10.53	0.75[a]	7.52	0.82	2.70	0.25	2.07	0.18
Ω6 acid sum	8.54	0.66	8.56	0.82	5.27	0.38[a]	8.53	0.87	6.48	0.76	17.97	1.24[a]	16.54	1.11	11.35	1.42	11.31	1.16
K_2 (Σ ω3/Σ ω6)	0.769	**0.05**[b]	**1.59**	**0.09**[b]	**1.94**	**0.11**	**0.568**	**0.05**	**2.72**	**0.32**[a]	**0.988**	**0.12**	**1.041**	**0.15**	**1.36**	**0.22**	**1.34**	**0.25**
Sum	**15.11**	**1.07**[b]	**22.22**	**1.15**[b]	**15.48**	**0.85**	**13.38**	**0.82**	**24.09**	**1.74**	**35.73**	**1.52**[a]	**32.87**	**1.72**[a]	**26.77**	**1.82**	**26.48**	**1.75**
K_1(Σ polyene/Σ saturated)	**0.403**	**0.05**	**0.565**	**0.07**	**0.465**	**0.05**	**0.427**	**0.06**	**0.849**	**0.11**	**1.610**	**0.18**[b]	**1.361**	**0.21**	**0.816**	**0.08**	**0.872**	**0.10**

Note. "–" — not found; "~" — in trace amounts; [a] — $p < 0.01$ (according to t-Student test); [b] — $p < 0.05$ (according to t-Student test); M — mean value; m — standard error.

environmental conditions. The shallow waters of the Azov-Black Sea region are noted to have different hydro-ecological characteristics and a large supply of phytoplankton. This explains the mass character of the investigated invertebrate species in certain feeding fields and their use as the main feeding objects by many species of waders.

Conclusions

As already mentioned, the plasticity of the organs of the digestive system of birds is an integral part of the adaptive strategy of migratory birds and, in particular, allows the use of various feed resources and the restoration of energy reserves at migratory stops with different ecological conditions.

The main food for waders at migratory stops in the Azov-Black Sea region is littoral invertebrates, fatty acid composition of which depends directly on the composition of the phytoplankton, which they feed on and the environment. First of all — the water temperature and its salinity. These two factors also affect the transfer of FAs along the trophic chain: phytoplankton → litoral invertebrates → waders. It is the plasticity of the digestive system that allows birds to regulate quantitative food and FFAs intake in their organism.

The performed research has shown Mollusca, Polychaeta and *Artemia salina* are the most important feed for waders. The mollusks contain the largest number of polyene FAs, especially C20:4 arachidonic. Polychaeta also contain a high level of polyene FAs, which serve as a source of both linoleic acid and linoleic acid for birds. The large contents of eicosapentaenoic and docosahexaenoic acids in *Artemia salina* and the masses of this species on the fodder fields contribute to the fact that waders, in a short period, can replenish their organism with the necessary amount of these PUFAs.

The concern of biologists is focused on a tendency of alterations in the hydrological regime of many ponds at the Azov-Black Sea region, which has emerged in recent decades (Ilin et al., 2009). Anthropogenic influence and climate change lead to shallowing and raising the salinity of water ponds, or their complete drying, which, in turn, affects the species composition of the littoral invertebrates and under-

mines the feeding base of migratory birds. One of the factors that helps birds adapt to these changes is the plasticity of their digestive system.

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