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ANCHOVIES OF THE SEA OF AZOV AND THE BLACK SEA: REGULARITIES OF WINTERING MIGRATIONS (BRIEF REVIEW)

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Close relation between internal (level of fat stores) and external (temperature fall) impulses of wintering migration of Azov and Black Sea anchovies *Engraulis encrasicolus maeoticus* and *E. e. ponticus* ("dosage principle") was revealed. Schools with high fatness begin migration at more high temperature than that ones with low fatness. Intensity of migration also correlates with level of fatness. Regularities obtained may be used for study of wintering migration of other truly marine fishes.

Key words: Anchovy, migrations, fat, temperature

Выявлено тесное взаимодействие между эндогенным (уровень жировых запасов) и экзогенным (температурный перепад) факторами зимовальных миграций азовского и черноморского анчоуса (хамсы) *Engraulis encrasicolus maeoticus* и *E. e. ponticus*, названное автором "принципом дозировки". Скопления с высокой жирностью начинают миграцию при более высоких температурах, чем с низкой жирностью. Роль жировых запасов в формировании зимовальных миграций показана также и на других вида морских рыб.

Ключевые слова: анчоус, миграции, жир, температура

Against background of impressing achievements in study of physiological ecology of anadrom and semianadrom fishes migrations [2, 3, 11—15, 18—21, 27, 28, 31, 36, 38, 39, 44, 60, 70—72] results of similar investigations of wintering migrations of truly marine fishes seem more than unassuming. It has several reasons. First of all truly marine fishes living in less variable environment change the character of their metabolism for adaptations to new conditions is not so considerable. Besides this it is more difficult to organize constant observations and catch of these fishes than that ones which move from river to sea and back. At last, it is not easy always to distinguish the wintering migration in true type. For instance, cold water Black Sea sprat *Sprattus sprattus phalericus* in winter months not only feeds intensively but spawns too [16, 37, 54, 55]. Wintering migration may not be taken for feeding migration. Regular fish wintering is characterized by cessation or in the last resort by strong decreasing of feeding. Energy expenditures for food obtaining at low temperature often do not compensate their

income to organism. Energy balance becomes negative and for its support fish must transfer to endogenous feeding [55]. Difficulties in study of physiological ecology of fish wintering migrations brought about that for present time "hydrological approach" prevails and migration regularities reduce exclusively or mostly to changes of temperature environment ignoring metabolic rhythms of populations during annual life cycle.

All this induced us to return for problem of regularities of physiological ecology of fish wintering migrations and to consider it at the example of two subspecies of European anchovy – Azov *Engraulis encrasicolus maeoticus* and Black sea *E. encrasicolus ponticus.* We earlier twice have generalized from materials obtained on these subspecies [55, 56]. However new aspects of researches and new data not included into previous reviews do the present report, as I think, useful.

Results and discussion. Azov and Black Sea subspecies of European anchovy are perfect objects for study of regularities of wintering migration (fig. 1).

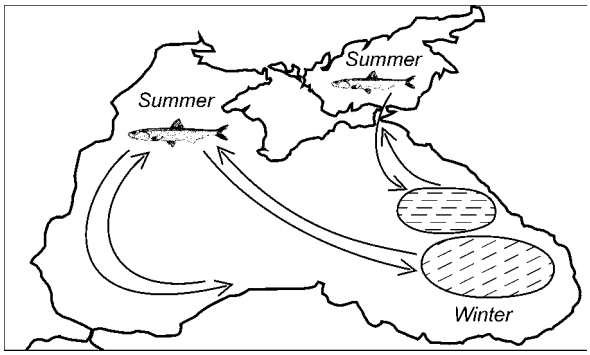

Fig. 1. Migrations of Azov and Black Sea anchovies
Рис. 1. Миграции азовского и черноморского анчоуса

These fishes are delicious products of great consumer demand a long ago as ancient times of Greece and Rome. Presently time they form the basis of fishery for many countries of region (Turkey, Russia, Georgia, Ukraine). All fishing of both subspecies is based on two periods of their annual cycle – wintering migration and wintering. Undoubtedly just this reason was that both these periods for long time attracted attention of researchers. Briefly cardinal stages of these investigations are presented in Table 1.

Table. Stages of wintering migrations of Azov and Black Sea Anchovies investigations
Таблица. Этапы исследования зимовальных миграций азовского и черноморского анчоуса

Research Subject	Cardinal Results	Authors
1	2	3
Temperature effect on the start of Azov anchovy wintering migration	Temperature fall till 9 – 12°C forces Azov anchovy to start migration to the Black Sea for wintering	[33]
Forming of internal (endogenous) stimulus of Azov anchovy for wintering migration	Fat stores accumulated by Azov anchovy in summer-autumn feeding period are migrating stimulus without any connections with external factors. Condition factor is indicator of degree of readiness for wintering migration	[25]

Table (cont.)

1	2	3
Unity of internal and external (exogenous) factors forcing migration of Azov anchovy	As level of fat stores (endogenous factor) so temperature fall till 9 – 12°C (exogenous factor) in combination are necessary for start of migration. Creation the promises of scientific prediction of wintering migration	[68]
Character of relationship between internal and external factors in forming migrating impulse of Azov anchovy	Minimal fatness which adult anchovy must have for start of migration is 14%. However migration may begin not necessarily at temperature fall till 9–12°C but also in another ranges (15–16°, 16 –17°C etc).	[52—55]
Elaboration scientific principles of terms and character of its migration	There is close relation between the level of accumulated fat stores and perception of external temperature impulse (“dosage principle”). Fatness determinates intensity of migration too. Prediction of terms and character of migration must base on the data of fatness and hydrometeorological forecast	
Applied realization of prediction. Analyses of difference terms of exit of juvenile and adult anchovy from Sea of Azov. Behavior at the wintering area	Successful prediction of terms and character of migration of adult (industrial) anchovy. External impulse for start of migration for juvenile is not so much temperature fall as food supply (provision) In winter area more fatted anchovy forms more dense schools, localize deeper and are not so mobile as less fatted fish.	[63]
Specific feature of wintering migration of Black Sea anchovy	The same regularities are confirmed which were obtained on Azov anchovy with amendment to another quantitative parameters	[6]
Closer definition of prediction methods of wintering migration of Azov anchovy	Successful prediction (without any failure) during 70s	[8, 29]
Quantitative characteristics of Black Sea anchovy wintering migration	Relation between fat store level of Black Sea anchovy (adult and juvenile) and terms of approach to Caucasus region was derived.	[5]
Critical situations	It was shown how low food supply of Azov anchovy occurred at the end of 80s – start of 90s caused to disastrous consequences (disturbance of wintering migration and mass death of fish).	[61, 67]
Employment of principles of research of wintering migrations of Azov and Black sea anchovies for analogous investigations of another species	Reveal of regularities of wintering migrations for fishes of the Caspian Sea (kilka) and Far East region – Japanese Sea and Sea of Okhotsk, the Northern-West part of Pacific (sardine, saury, wall-eye pollack, spiny-rayed flounder)	[10, 46, 47, 57, 58, 65, 66]
Generalization of materials obtained	Analyses of ecologo-physiological regularities of wintering migrations and wintering of fish as constituent periods of annual cycle	[56]

Adduced retrospective needs several explanations.

1) Fat accumulated during premigration feeding is the most important endogenous factor, which prepares anchovy populations for wintering migration. Fat stores which consist of neutral lipids (triacyl glycerols) are the cardinal energy sources provided: locomotion activity of fish during migration, endogenous feeding in winter area, the start of differentiation of generative tissue in early spring and, at last, start part of spring prespawning migration. As to energy expenditure for migration there is direct analogy with birds of passage [7, 22] for which as well as for fishes the cardinal biological significance of prespawning feeding is fat accumulation.

Naturally, this accumulation is provided by the complex processes of neuro-endocrine regulation (Fig. 2), but they are still not completely studied.

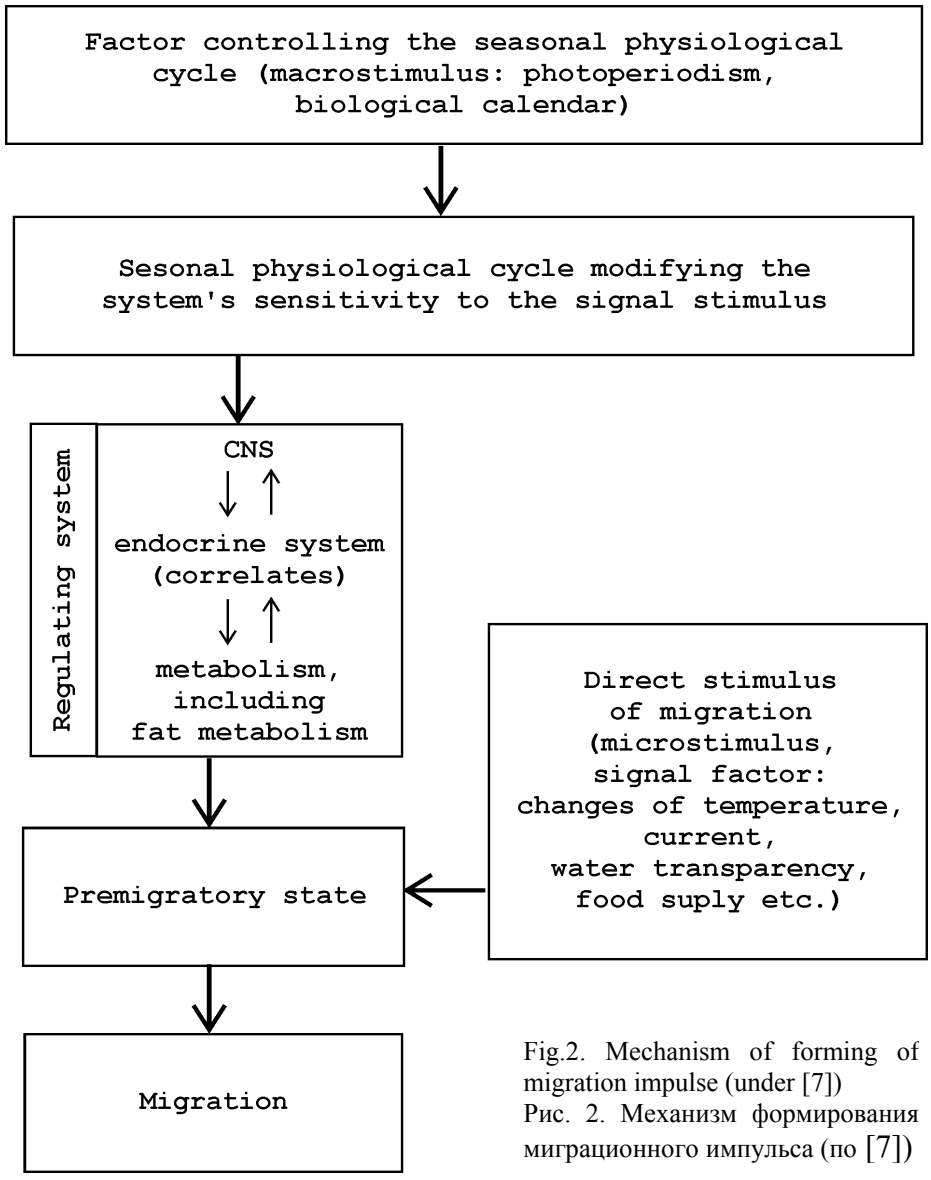

Fig.2. Mechanism of forming of migration impulse (under [7])
Рис. 2. Механизм формирования миграционного импульса (по [7])

It is known that lipid metabolism in fish is regulated by interaction of pituitary hormones somatotropin and prolactin [18, 26, 30, 48, 49, 64].

Apparently the achievement of definite level of energy (fat) stores effecting on neuro-endocrine system just forms capacity for perception of external signal (trigger) of migration impulse. The necessity of achievement of definite level of fat stores for start of wintering migration is comfired on many fish species: Atlanto-Scandinavian herring *Clupea harengus harengus* from the Greenland, Norwegian and Barents Seas [34, 35, 40, 51, 59]; Baltic herring *Clupea harengus membras* [23, 24], blue whiting *Micromesistius poutassou* and capelin *Mallotus villosus villosus* from the Norwegian and Barents Seas [40], Atlantic cod *Gadus morhua morhua* from the Barents Sea [45]; Pacific whiting *Merluccius productus* [62] and saury *Cololabis saira* [10, 41]; Japanese sardine *Sardinops sagax melanosticta* [57]; Caspian kilka *Clupeonella engrauliformes* [47]; anchovies from Chesapeake Bay *Anchoa michelli* [69], Argentine and Uruguay continental shelf [1, 4].

2) There is close relation between level of accumulated fat stores in fish and character of wintering migration, first of all, of its intensity. Fat accumulated conduces to form dense schools due to advantage of shoaling reflex under feeding one [32]. Consequently anchovy stocks with high fat content carry out wintering migration more intensively than that ones with less fat stores.

Last stocks "trickle" through Kerch Strait as small thinned out schools (Fig. 3).

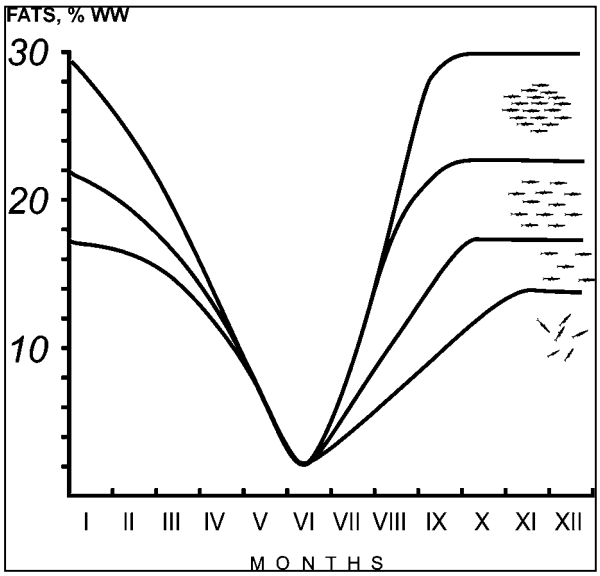

Fig. 3. Relation between fatness and character of wintering migration of Azov anchovy
Рис. 3. Отношение между жирностью и характером зимовальной миграции азовского анчоуса

Close relation between fatness and density of schools and as result with catch value was shown on many species; besides enumerated species Black Sea sprat [16,37] and Pacific saury [17] may be mentioned.

3) We have already remarked that very diverse kinds of factors: water temperature, transparency, character of currents, food supply etc. may be by the external (exogenous) impulses of wintering migrations [54—56]. For Azov and Black Sea anchovy such factor is temperature fall through defined number of degrees (Fig. 4 & 5). Just now we consider the most remarkable phenomenon which we named as "dosage principle [56]. It concludes in close relation between level of fat stores accumulated by fish and its sensitivity to external migration impulse:

temperature fall is for anchovy case. For fish with high fatness this fall occurs at more high temperature and its range may be minimal (Fig. 6).

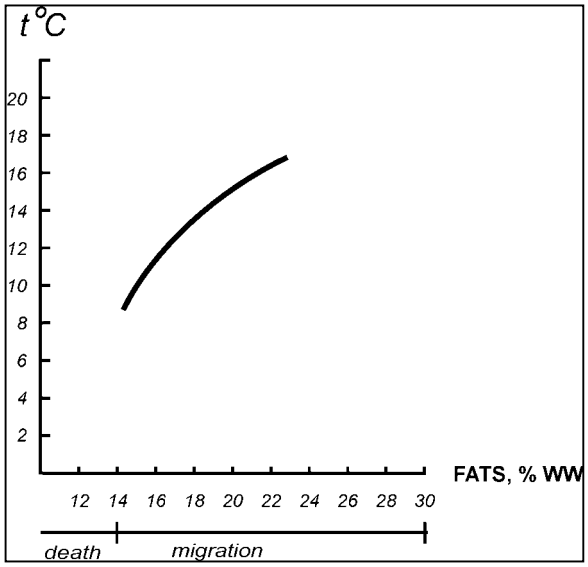

Fig. 4. Relation between fatness of Azov anchovy and start temperature of its wintering migration
Рис. 4. Отношение между жирностью азовского анчоуса и начальной температурой его зимовальной миграции

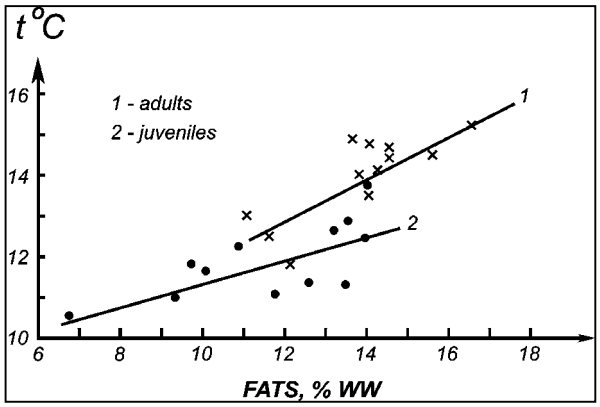

Fig.5. Relation between fatness of Black Sea anchovy and temperature of its approach to Caucasus region during wintering migration [5]
Рис. 5. Отношение между жирностью черноморского анчоуса и температурой его подхода к кавказскому региону во время зимовальной миграции [5]

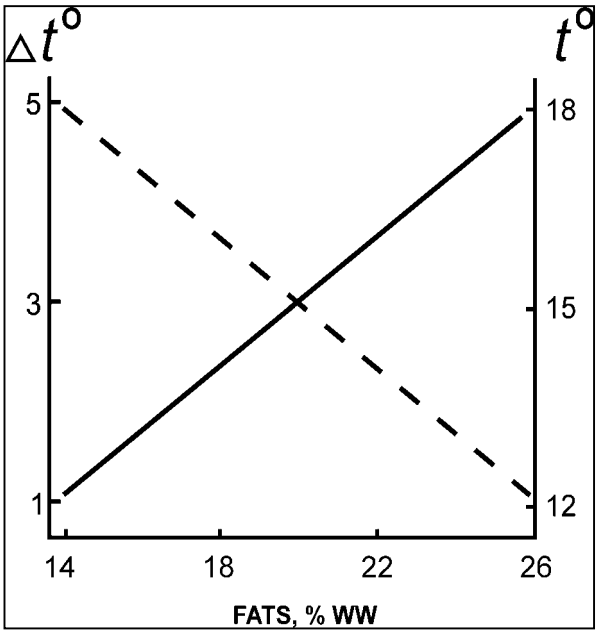

Fig.6. Relation between fatness of Azov anchovy and its perception for temperature migration impulse
Рис. 6. Отношение между жирностью азовского анчоуса и восприятием им температурного импульса для миграции

For that one with low fatness the fall occurs at much less temperature and its range must be considerable. Thus the terms of anchovy school ways out Kerch Strait have direct relation with their fatness (Fig. 7).

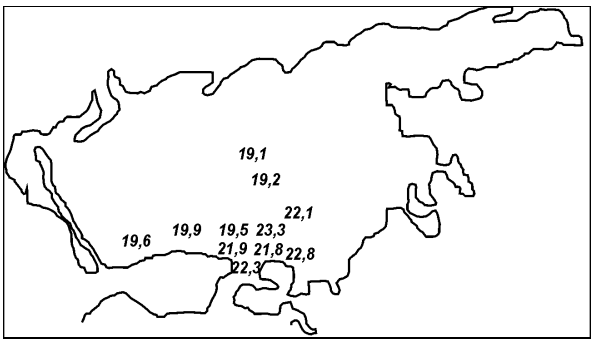

Fig. 7. Fatness of Azov Sea anchovy schools during prewintering period, October 1995 [50]
Рис. 7. Жирность азовского анчоуса в предзимний период, октябрь 1995 г. [50]

4) Researches of relation between accumulation of fat stores in fish, external migration impulse, terms and character of wintering migrations must not be confined to statement in general manner but requires determination of exact quantitative parameters. Unfortunately such researches are very rare. But they are necessary not only for truly scientific aims but for applied predictive ones. Without them reliable substantiated forecast of terms and character of migration is impossible.

5) What is more but it is necessary to consider unfortunately that interest for similar investigations even not increases but for some reason diminishes. During last years it was not published just only a few works on the significance of fat provision of wintering migrations of truly marine fishes. Perhaps the paper of Vdovin et al. [66] on spiny-rayed flounder *Psettodes etrumei* from the Sea of Okhotsk is an exception. But there are quite a number of publications on the significance of hydrological (first of all, temperature) factors for migrations, including Azov and Black Sea region [42, 43, 73].

6) Do we not return again to 30s time when hydrology was considered as prevailing factor in fish behavior under full ignoring of fish physiology?

7) We consider that objectives of farther investigations in the field of wintering migration of fish must be:

- Comprehensive expansion of ecologo-physiological researches of the process with maximal involving of new yet unstudied species;
- Determination exact quantitative parameters of relations between internal (value of fat stores) and external (temperature, food supply etc.) migration impulses;
- Study of interaction between lipid metabolism and neuro-endocrine system for reveal the mechanisms of forming migration impulse;
- Search of new physiological and biochemical indicators for estimation fish populations condition under periods of premigratory feeding and wintering migrations;
- Elaboration of foundation for prediction of terms and character of wintering migrations of fish.

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