

## PECULIARITIES OF BIGEYE TUNA, THUNNUS OBESUS (LOWE), DISTRIBUTION IN RELATION TO SEASONAL CYCLIC PATTERN OF WATER CIRCULATION IN THE CENTRAL TROPICAL ATLANTIC

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## SUMMARY

Dynamics of boundaries of effective fishery of bigeye tuna in three areas of the tropical Atlantic is considered in relation to seasonal variability of circulation of tropical and equatorial currents. The most dense tuna aggregations are noted to be formed along the boundaries of counter-currents, in convergence and divergence zones. In convergence zones post-spawning specimens prevail, and divergence zones are mainly represented by prespawning and spawning fish.

## RESUME

La dynamique de la délimitation des zones de pêche effective de thon obèse dans trois secteurs de l'Atlantique tropical est examinée en fonction des variations saisonnières du déplacement des courants tropicaux et équatoriaux. Il a été noté que les concentrations de thonidés les plus denses se forment le long des limites des contre-courants, et dans les zones de convergence et de divergence. Les individus oeuvés prédominent dans les zones de convergence, alors que les zones de divergence sont caractérisées par la présence de poissons en état de pré-ponte ou de reproduction.

## RESUMEN

Se estudia la dinámica de los límites de las zonas productivas de pesca de patudo en tres zonas del Atlántico tropical, en relación con la variabilidad temporal de la circulación de las corrientes tropical y ecuatorial. Las agregaciones de tónidos más densas se observan a lo largo de los límites de las contracorrientes, en zonas de convergencia y divergencia. En las zonas de convergencia predominan ejemplares de postfreza, y en las zonas de divergencia los peces de prefreza y los reproductores en periodo de freza.

### Introduction

As can be stated from the results of studying hydrophysical environmental conditions in relation to the distribution of tunas, horizontal gradients of frontal values both of temperature and salinity are main conditions providing for formation of relatively dense tuna aggregations forming the fishery bases (Sigaev, Ovchinikov, 1984). On the whole, the variability of temperature and salinity determines the distribution of density, osmotic pressure, dissolved oxygen contents and nutrients. Formation of density gradient of the sea water is accompanied by that of velocity gradient of geostrophic currents. Gradient zones are formed and intensify along the boundaries of countercurrents, in particular, in the regions of generation of synoptical meanders and eddies, where the large-scale quasistationary horizontal transport of the waters slackens and gradient frontal zones become localized. It is likely that gradient zones serve as guidelines for selection of necessary migration routes for the species performing lengthy migrations, to which tunas belong. In this case, major migration routes of tunas are supposed to have the same direction as quasistationary geostrophic currents and current divergences and (or) convergences existing along gradient zones. Localization of such zones may influence the aggregation of migrants into relatively dense assemblages. To verify this assumption, the distribution of most dense bigeye tuna aggregations in pre-equatorial areas of the Atlantic Ocean was studied against the background of year-to-year changeability of the boundaries and intensity of the western and eastern transport of the waters in the system of

equatorial countercurrents, and circulation conditions corresponding to seasonal fluctuations of the boundaries of successful fishery of bigeye tuna in separate areas were investigated.

### Materials and methods

To begin the analyses, we compared the mean annual positions of the axes of tropical and subtropical vergences of the currents at the 200 db surface level (Burkov, 1980), and the distribution of the maximum mean annual Japanese catches of the bigeye tuna from the Atlantic and Pacific Oceans for 1976-1980 (fig. 1).

For detailed analysis of the longline fishery of the bigeye tuna in the Central Tropical Atlantic, mean monthly data of the Soviet longline fishery statistics for 1967-1980 averaged by 1° square in kg per 100 hooks were summarized. Mean data on the catches of foreign longliners on the quarterly basis for 1979-1982 averaged by 5° square were also used (Lee, Yang, 1984).

Three major grounds of the effective fishing for the bigeye tuna can be distinguished: 1 - Northern, 2 - the Gulf of Guinea and 3 - Southern (Gaikov, 1984) (fig. 2). Diagrams of the position of latitudinal and meridional boundaries of the effective fishery are constructed based on the mean monthly Soviet catch statistics for all the three areas (fig. 3).

Comparative background of the water motion field shown in fig. 4 is based on the data derived from the study of the structure and mean monthly changeability of the water expense and boundaries of the western and eastern water transport in the system of equatorial countercurrents of the Atlantic Ocean (Belevich et al., 1979; Burkov, 1980; Chlystov, Jiganshin, 1975), as well as

of the expense of the geostrophic western and eastern water transport in the 0-500 m layer across the section of the 30° meridian (fig. 5) from the materials kindly submitted by the Odessa branch of the State Oceanographic Institution. These data have been used to construct a diagram of the boundaries and intensity of the Northern branch of the Equatorial Countercurrents (NBEC) without mean annual smoothing of initial values of temperature and salinity during their processing by a dynamic method (fig. 6).

#### Discussion

As is evident from the comparison of the mean annual position of the areas of effective longline fishery of bigeye tuna and the position of the axes of divergencies and convergencies of main currents in subtropical and tropical zones of the Atlantic and Pacific Oceans, the aggregations are mainly formed in the zones of tropical divergencies and divergencies of eastern boundary currents, and in the zones of subtropical convergencies.

The extent of total boundaries of the areas of effective fishery is zonally oriented along the western and eastern water transport by equatorial countercurrents. Along the eastern boundary currents the fishing areas are distributed meridionally.

During the period of effective fishery, meridional and latitudinal boundaries of the northern area shift simultaneously in the northern and southern directions (fig. 3, area 1). The western boundary of the fishing area is most dynamic. The change of boundary positions takes place against the background of a sharp increase of intensity of the NBEC and the Northern Branch

of the Southern Trade Wind Current (NBSTWC), and a shift of the western boundary of the NBEC westward (fig. 6).

Fluctuations of the northern boundary of the NBEC and of latitudinal boundaries of the areas of effective fishery are similar and coincide in phase from May to September. In October, the fishery shifts southward of the divergence zone of the NBEC to the convergence zone of this stream and the NBSTWC (fig. 7). Shifting of meridional boundaries of the fishing area to the west occurs against the background of increased intensity of the NBEC and NBSTWC (fig. 5, curves 2,3).

In the Gulf of Guinea, to the north of the equator, shifting of meridional boundaries of the fishing area westward takes place in March-April and September-October (fig. 3, area 2). In the first case, that occurs against the background of the sharp slackening of the NBEC, and in the second case against the maximum development of the NBSTWC. During the period of the maximum development of the NBEC, which corresponds to the maximum seasonal development of its eastern side - the Guinean Current - the fishery is carried out in the eastern part of the fishing area. The range of shifting of latitudinal boundaries of the fishing area is not wide there, the northern and southern boundaries not overlapping the mean seasonal boundaries of the divergence zone of the Guinean Current (upwelling off the Ivory Coast) during the period of its intensification and divergence of the NBSTWC and the Lomonosov Current (LC). Like in the northern part of the area, a sharp shifting of the latitudinal boundaries to the south can be observed in September-October during the intensification of the NBSTWC.

In the southern part of the area (fig. 3, area 3), the distribution of the boundaries of the fishing area in December-February coincides with the process of intensification of the Central Branch of the Southern Trade Wind Current (CBSTWC) (fig. 5, curve 5). Back reconstruction of latitudinal and meridional boundaries of the fishing area in March-April again occurs against the background of the development of this stream. A marked reduction of latitudinal and meridional boundaries during that period evidently results from seasonal shifting of the center of the southern tropical cyclonic eddy to the west relative to traditional fishing ground where the Soviet fleet operates. The southwestern periphery of the eddy, the CBSTWC, in this case overflows the limits of the area under consideration, and occupies the area of foreign fishery in the southern hemisphere. The subsurface development of the Southern Branch of the Equatorial Counter-current (SBEC) may take place in the considered area in March-April, which cannot be observed across the section of the 30° meridian. The position of the northern limit of the fishing in the given area is most stable, and is within the limits of the divergence zone of the CBSTWC and the LC. The southern limit of the fishing moves to the south along with the convergence zone of the CBSTWC in accordance with the reconstruction of hydrological structure in the subequatorial areas of the southern hemisphere in summer (Belevich et al., 1979).

Thus, there exists a good agreement between seasonal fluctuations of the boundaries of the areas of effective fishery of the bigeye tuna and seasonal cycles in the intensity of equatorial countercurrents. At that, the movement of tuna aggregations in

the western direction is accompanied by a sharp increase of the intensity of the western transport of the NBSTWC and CBSTWC waters. So, it can be assumed that the tunas migrate from the east to the west along with the western water transport generated by trade winds to the fishing areas located on the both sides of the equator. In the northern hemisphere, back migrations coincide with the eastern transport of the NBEC waters, which can be clearly seen as boundaries of the fishing ground in the Gulf of Guinea shifted in the eastern direction. The position of latitudinal boundaries of the fishing ground on the eastern side in March, and equiphase shifting of meridional fishery limits in the southern part of the area westward and eastward during the process of intensification of the eastern transport of the CBSTWC waters in December-January are considered to be the peculiarities of seasonal reconstruction of the boundaries of the effective fishery and more information is needed concerning the eastern transport of the subsurface waters in the Gulf of Guinea.

Conditions of formation of dense bigeye tuna aggregations both in divergence and convergence zones of the currents are worth special attention.

According to Blackburn (1965), most dense tuna aggregations are distributed along the current axes. However, the pattern of formation of dense concentrations of the bigeye tuna against the background of changeability of boundaries and intensification of the NBEC indicates that the concentrations are formed not in the stream or along its axis, but in its periphery, near the axes of vergencies of countercurrents, where horizontal gradients of hydrophysical properties become more pronounced. It should be

noted that the vertical structure of the waters and orientation of hydrophysical processes are opposed in divergence and convergence zones. Along the convergence axes, the upper quasihomogeneous layer and the subsurface salinity maximum deepen, the thermocline becomes intensified and the heat supply increases in the upper quasihomogeneous layer. The processes developing along the divergence axes are opposed (Belevich et al., 1979). Due to rising of the waters from the intermediate layer, the subsurface salinity maximum in divergence zones reduces as well as the thermocline gradient, i.e. in subsurface waters, inhabited by the adult bigeye tuna, the temperature and salinity decrease along with formation or intensification of the convergence. Thus, within the system of one and the same geostrophic current the environmental conditions are continuously changed. They differ in horizontal gradients of the temperature, salinity and other characteristics, the distribution of which depends on horizontal variability. Therefore, a relation of specimens at the homeostasis level in the concentrations divided by the gradient zone to certain properties of the environmental conditions may differ. On one side of the gradient zone, dense tuna concentrations are formed under "divergence" environmental conditions, and on the other side - under "convergence" conditions. It is worth noting that the "divergence" and "convergence" concentrations may experience the influence of multioriented currents and, as a result, perform migrations in different directions.

As is evident from the comparison of the biological condition of tunas in the concentrations distributed in the zones of the NBEC divergencies and in the convergence zone of this counter-

current, prespawning and spawning specimens amounting to 63% in August predominate in the divergence zone, and postspawning and young specimens forming 70% of the catches occur in the convergence zone in September. With regard for the qualitative difference in the biological condition of bigeye tuna aggregations in convergence and divergence zones, it can be assumed that the postspawning specimens cross the gradient zone to the waters with higher temperature and salinity or from the zone affected by the NBEC to the area of the westward transport of the NBSTWC waters.

The process of movement of tunas to the divergence zone is likely to take place on maturation of gonads, and their stay in the divergence zone must be consistent with the duration of the spawning period, i.e. it must be short-term relative to their stay in convergence zones. Such a distribution pattern is confirmed to a certain extent by the occurrence of feeding bigeye tuna aggregations northward of the axis of the northern subtropical convergence and southward of the axis of the southern subtropical convergence. The density of tuna aggregations increases during the winter period in the corresponding hemisphere. The gonads of tunas during that period are resting after spawning or are in early maturation stages (Gaikov, 1983).

#### Conclusions

1. Seasonal fluctuations of the boundaries of the areas of effective fishery of the bigeye tuna are in good agreement with seasonal cycles of intensity of equatorial countercurrents.
2. Dense concentrations of the bigeye tuna are formed both in divergence and convergence zones of the currents.

3. Prespawning and spawning specimens predominate in divergence zones, and postspawning and young specimens are common in convergence zones.

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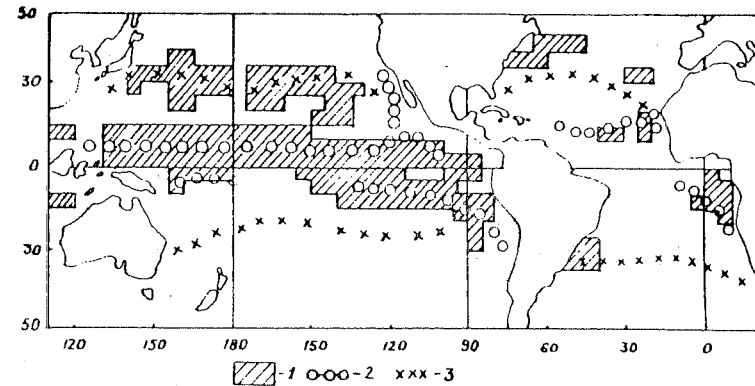


Fig. 1. Distribution of maximum mean annual Japanese catches of bigeye tuna in 1976-1980 (1), and position of divergence (2) and convergence (3) axes at the 200 db surface level.

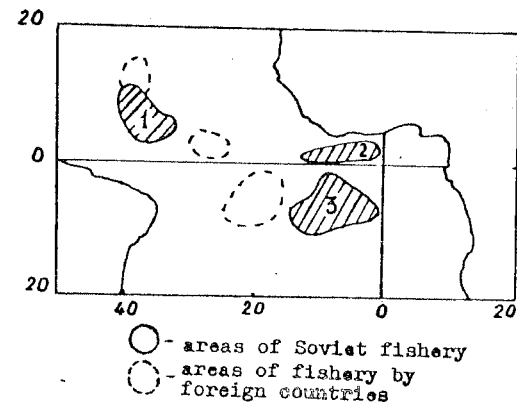


Fig. 2. Mean annual distribution of the Soviet fishery in 1967-1980: 1 - Northern area, 2 - Gulf of Guinea, 3 - Southern area, and areas of foreign fishery of bigeye tuna in 1979-1982.

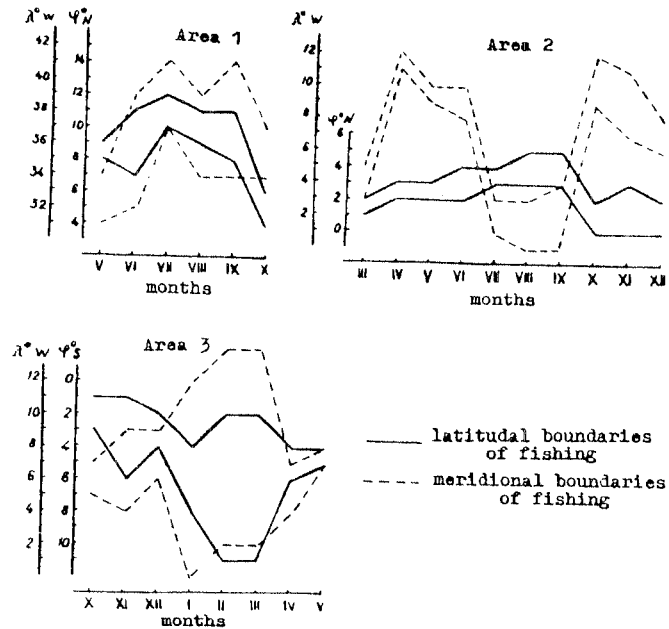


Fig. 3. Mean monthly shifting of limits of effective fishery of bigeye tuna in areas 1-3.

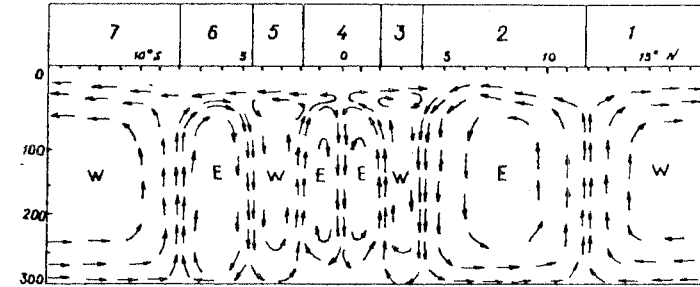


Fig. 4. Structural scheme of transversal circulation across the plane of the meridian in the upper 300 m layer of tropical zone of the Atlantic Ocean (after Chlystov, 1976).

- 1 - Northern Trade Wind Current (NTWC)
- 2 - Northern Branch of the Equatorial Countercurrent (NBEC)
- 3 - Northern Branch of the Southern Trade Wind Current (NBSTWC)
- 4 - Lomonosov Current (LC)
- 5 - Central Branch of the Southern Trade Wind Current (CBSTWC)
- 6 - Southern Branch of the Equatorial Countercurrent (SBEC)
- 7 - Southern Branch of the Southern Trade Wind Current (SBSTWC)

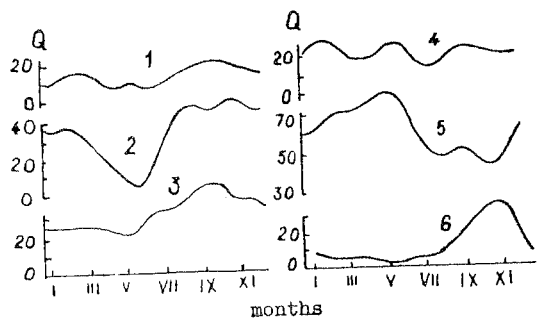


Fig. 5. Mean monthly expenses  $Q$  ( $10^6 \text{ m}^3 \text{ c}^{-1}$ ) in equatorial and tropical countercurrents across the  $30^\circ\text{W}$  meridian for the 0-500 m layer (after Belevich et al., 1979).

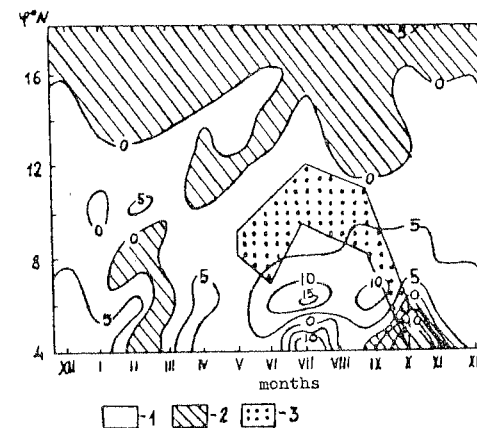


Fig. 7. Mean monthly expenses  $Q$  ( $10^6 \text{ m}^3 \text{ c}^{-1}$ ) during the eastward (1) and westward (2) water transport in the 0-500 m layer across the  $30^\circ\text{W}$  meridian, and latitudinal shifting of effective fishery of bigeye tuna (3).

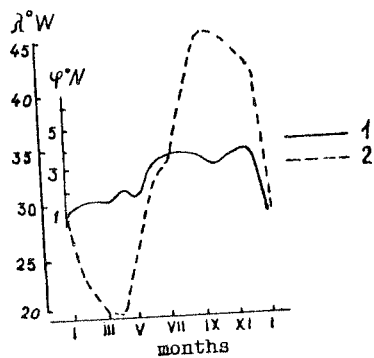


Fig. 6. Mean monthly run of shifting of southern (1) and western (2) boundaries of the Northern Branch of the Equatorial Countercurrent from longterm data on ship's drift.