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CONSIDERATIONS ON THE MIGRATION OF TUNAS IN RELATION TO THE HYDROLOGY OF THE STRAIT OF GIBRALTAR

J. C. Rey

Instituto Español de Oceanografía

INTRODUCTION.

A revision of the main species of tunas and tuna-like fish that the Mediterranean sea comprises habitually in its geographical distribution are : the bluefin tuna (Tunnus thynnus), albacore (Thunnus alalunga), skipjack (Katsuwonus pelamis), atlantic little tuna (Euthynnus alleteratus), atlantic bonito (Sarda sarda), frigate and bullet tuna (Auxis thazard and Auxis rochei) and plain bonito (Orcynopsis unicolor).
Bigeye (Thunnus obesus) has been caught sporadically in the "Aguas de Ceuta" trap in the Mediterranean sea near the strait of Gibraltar (Rey, unedited).
Three species of Istiophoridae are found in the Mediterranean : the sailfish (Istiophorus albicans), white marlin (Tetrapturus albidus) and spearfish (Tetrapturus belone). The only representative of the Xiphidae family, the swordfish (Xiphias gladius), is widely represented.

For certain types of the above mentioned species, the Strait of Gibraltar is an obligatory passage in their migrations, at least at some time during their biological cycle.
This passage is evident, to date, for three species : the bluefin, the atlantic bonito and atlantic little tuna. The same importance should exist in this communication route, for other tunas and tuna-like fishes whose migration lines are not as well known as the bluefin, between the Atlantic and Mediterranean.

At an hydrologic level, the Strait of Gibraltar is unquestionably of great interest and importance since it's the only mean of changing and renewing the mediterranean waters, the Mediterranean sea being completely closed. (Movement through the Suez Canal is not considered representative).

HYDROLOGY

1. General

The Strait of Gibraltar presents a complex and dinamic hydrology which is brought about by the interaction of many factors, such as winds, tides, the different charasteristics of the Mediterranean and Atlantic waters, the different surface levels of the Mediterranean and the Atlantic, the orography of the sea bed, etc.

It is far from easy to give a constant and simple picture of the above- mentioned dynamic, although a series of general observations on the currents of the Strait of Gibraltar help to clarify the migrations, that are known of to date, of certain speces of tunas.

The currents in the Straits of Gibraltar, on the surface and in the depths, are a complicate and variable phenomenon. Generally, due to the evaporation of the Mediterranean, a deficient supply of fresh water from the continent, the difference in level between the Mediterranean and the Atlantic in the areas adjacent to the Strait of Gibraltar (12'5 cm. approx.), etc.,there is a flow of Atlantic water which flows towards the Mediterranean between the surface and a depth of 180 metres. This Atlantic flow is met by Mediterranean waters leaving the Mediterranean basin (waters of a lower temperature and a higher salt content and so a higher density), in the depths.(Fig. 1).
The average depth of the separating layer between the Mediterranean waters and the Atlantic waters, varies between the northern part and the southern part of the Straits (it is deeper in the southern part than in the northern part), and also in the west compared to the east (it is deeper in the western part of the Straits in the Atlantic than the eastern part in the Mediterranean where it is situated at a depth of 80 metres).
The flow of the Atlantic current is stronger in the northern half

of the Strait of Gibraltar than in the southern half. This current, once it has passed the Strait of Gibraltar, enters the Alborán Sea, describing an anticicyclonic circulation, that in its northern half approaches the Spanish coast without reaching the continental shelf flowing later towards the African coast where, at cape Tres Forcas, it divides into two currents, one returning towards the Strait of Gibraltar closing the anticyclonic circulation, and the other current is distributed throughout the rest of Mediterranean (Cano, 1977),(Fig. 2).
All this surface circulation undergoes seasonal changes. All along the coast which surrounds the Alboran Sea there are coastal currents whose predominant direction is towards the Atlantic.(Stanley et all., 1975),(Fig. 3).

2. Circulation in the Strait of Gibraltar

The Atlantic flow like the Mediterranean flow, and the depth of the layer that separates the two types of waters, are influenced by factors already mentioned and described. The variations caused by tides have a special importance and so it is dealt with in more detail.

2.1 Variations of the surface current due to the tides

To describe the influences of the tides on the surface circulation in the Strait, first we must be taken into account the tides which are in the central sector of the Strait of Gibraltar, not including the areas between the continental shelf of the Spanish and Moroccan coasts, as shown in the figure 4.
The movement in this central sector are different depending on the value of the coefficient of the tide at the time.

2.1.a Variations of the current in the central sector with medium and low coefficients of tide (0.7 or below)

The direction of the current is usually eastwards at speeds of between 3 and 4 knots.
In relatively short periods and coinciding with high tide, the current can invert its direction, going westwards in the southern half of the central sector.

2.1.b Variations of the current in the central sector with high coefficient of tide (above 0.9)

In periods near to high tide in all the central sector, the general circulation eastwards can invert its direction, going towards the Atlantic at a maximum speed of up 2 knots.

For the sectors by the Spanish and Moroccan coast of Strait, close to the continental shelf on both sides, the currents are more obvious with intensities that depend on the coefficient of the tide. On the Spanish coast the tidal stream go in the direction of the Mediterranean three hours before high tide, and change their direction towards the Atlantic three hours after high tide, called " coastal countercurrent ", (Fig. 5).

On the Maroccan coast the coastal current begin to circulate towards the Mediterranean an hour after high tide, and they invert their direction, towards the Atlantic, five hours before high tide, forming the "coastal countercurrents" the same as off the Spanish coast, at the outlet to the Atlantic, (Fig. 6).

The limit of influence of the current and countercurrent would be found in the zone delimited by isobath of 100 meters,(Fig. 4) (Bustamante, 1979).

Another result of the modifications of the circulation of currents in the central area of the Strait of Gibraltar, as a result of the tide coinciding with the high coefficients of tide (0.9), the westward current extends from the Moroccan coast towards the Spanish coast, being able to reach it, (Bustamante, 1979). This circulation would explain satisfactorily the tags returns of the atlantic bonito and atlantic little tuna of south Atlantic coast of Spain and Portugal, (Rey and Cort, 1981 and 1981 bis.).

DISCUSSION

This dinamyc system of current and coastal current and countercurrents is used by the migratory species as a form of transport and also saving energy (Weish,1978)(Ramster et all.,1978),during migration between the Atlantic and Mediterranean through the Strait of Gibraltar.
To date, the migration of three species, has been proved by use

of tagging: the bluefin, the atlantic bonito and the atlantic little tuna.
The migration of tunas from the Atlantic towards the Mediterranean has been made clear by tagging (Rodriguez Roda, 1964 and 1969) and by the experiment carried out with echosounders (Lozano Cabo 1959). Lozano Cabo detected shoals of bluefin tunas swimming in the same direction as the Atlantic current going towards the Mediterranean sea, in genetic migration, through the north and center part of the Strait of Gibraltar. These shoals were found at an inferior depth than those where the average values of thermocline is found (60 meters in the center of the Strait), whose average value for the sam time as the genetic migration (spring) is 14.3 - 14.4 ^{o}C. (Cano y Fernandez Castillejo, 1968), (Fig. 7). Below the thermocline, the water of mediterranean characteristics, that is lower temperature and a higher salinity and density, the current move in the opposite direction, that is, from the Mediterranean towards the Atlantic.

All observations agree that bluefin tunas uses the Atlantic's strong incurrent that enters into Mediterranean basin as a means of transport, to cross the Strait of Gibraltar and migrate towards the important spawning grounds in the Mediterranean sea.

For other types of tunas, the atlantic bonito and the atlantic little tuna, their migration between the Mediterranean and the Atlantic has been proved by tagging (Rey and Cort, 1981 and 1981 bis). The geographical distribution of the tag return of both species depends on the circulation of thr coastal current and countercurrent that flow along the Spanish and Moroccan coast of the Strait of Gibraltar. These two species would use the before mentioned tidal streams as a means of transport for their migration towards the Atlantic.
It is very probable that the recruitment of bluefin tunas class 0, to the east Atlantic stock, coming from spawing grounds in the Mediterranean, takes place in the same way, (Rey, 1979).

CONCLUSIONS

Currents of normal circulation, or those modified by the tides (tidal stream), are used by three species of tunas as an effective means of transport to carry out their migration through the Strait of Gibraltar, in both directions.

The use of sonic traking, as well as the "in situ" sampling of the physical parameters in the Strait of Gibraltar area, is recommended to set the routes and mechanisms between the Atlantic and Mediterranean sea, for the species concerned.

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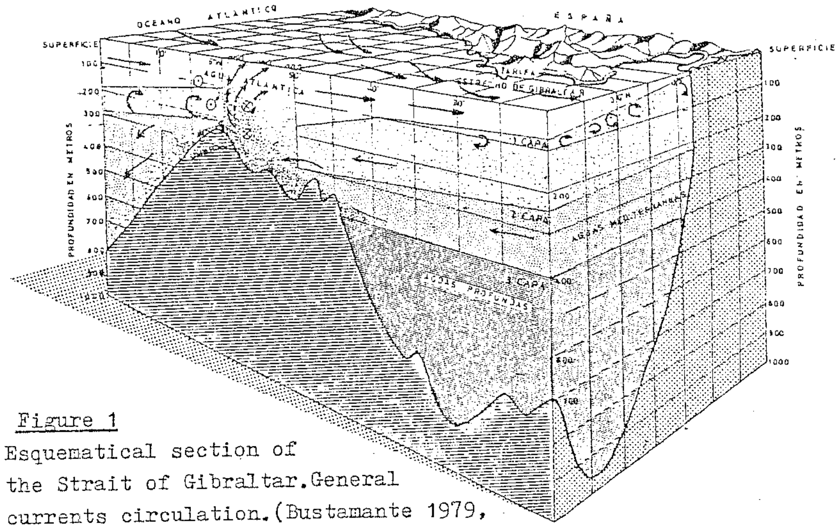

Figure 1
Esquematical section of the Strait of Gibraltar.General currents circulation.(Bustamante 1979, modificate of H. Lacombe 1964).

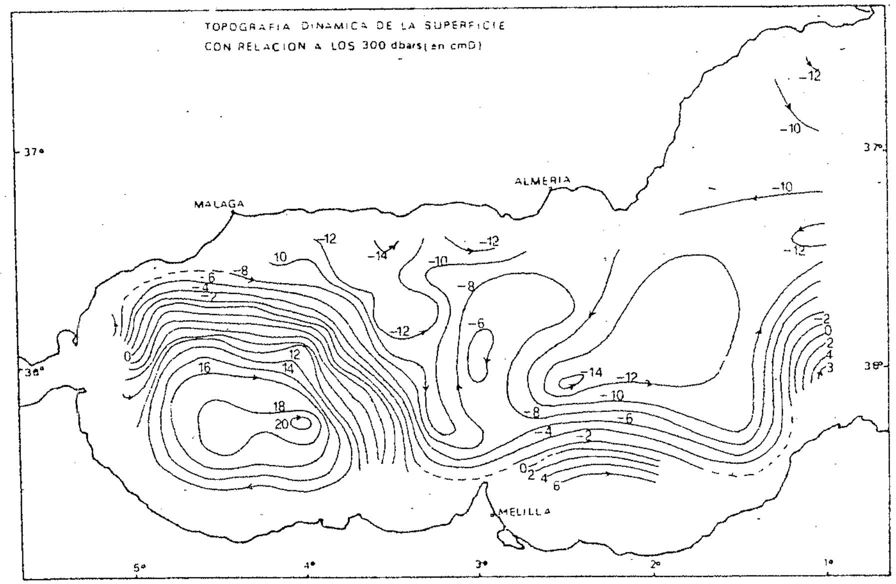

Figure 2
Antyciclonic general surface circulation in the Alboran Sea, may-july 1973.(Cano, 1977).

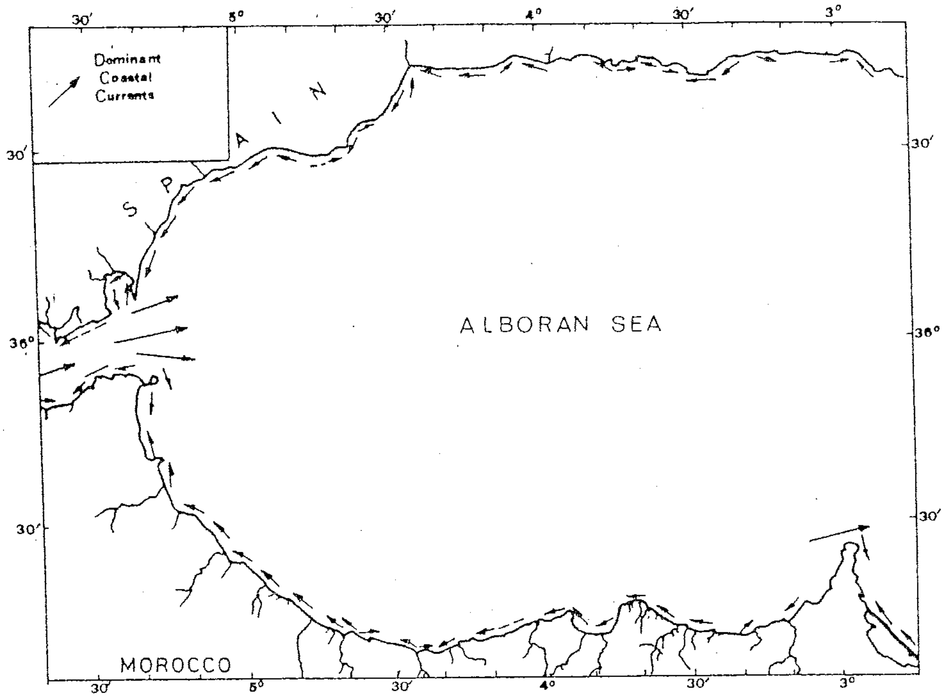

Figure 3

Dominant coastal currents in Alboran Sea (Stanley et al. 1975)

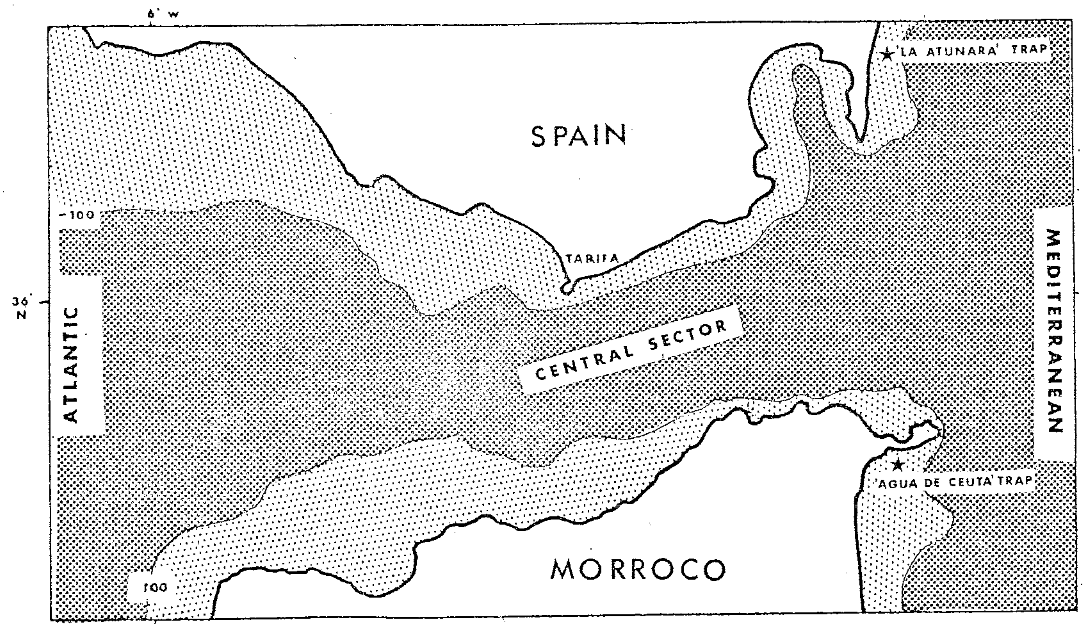

Figure 4

Sectors considered in the description of current circulation. Central and coastal sectors separated by the 100 m. isobath.

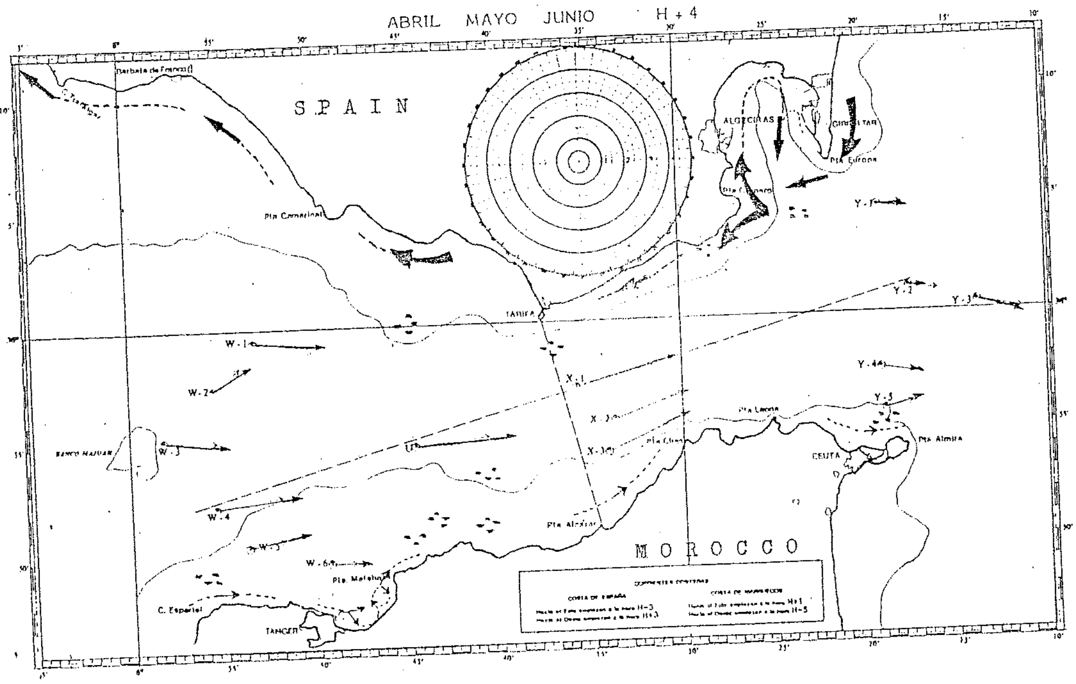

Figure 5

Current circulation in the Strait of Gibraltar four hours after high tide at Tarifa. The dominant countercurrents in spanish coast have been remarked.

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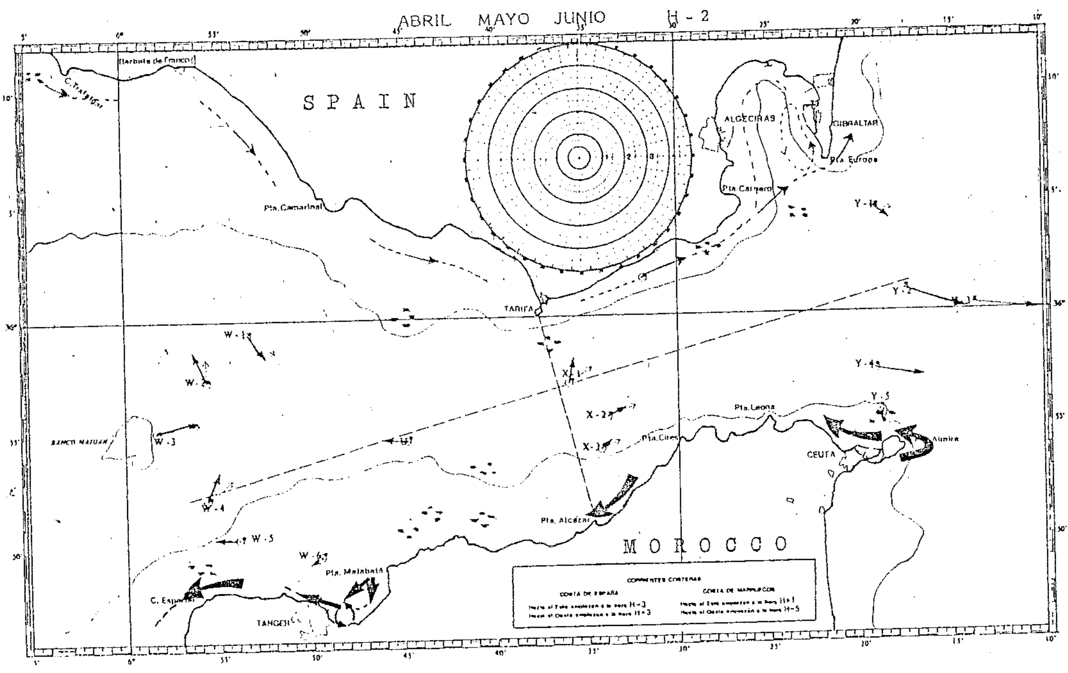

Figure 6

Current circulation in the Strait of Gibraltar two hours before high tide at Tarifa. The dominant countercurrent in moroccan coast have been remarked.

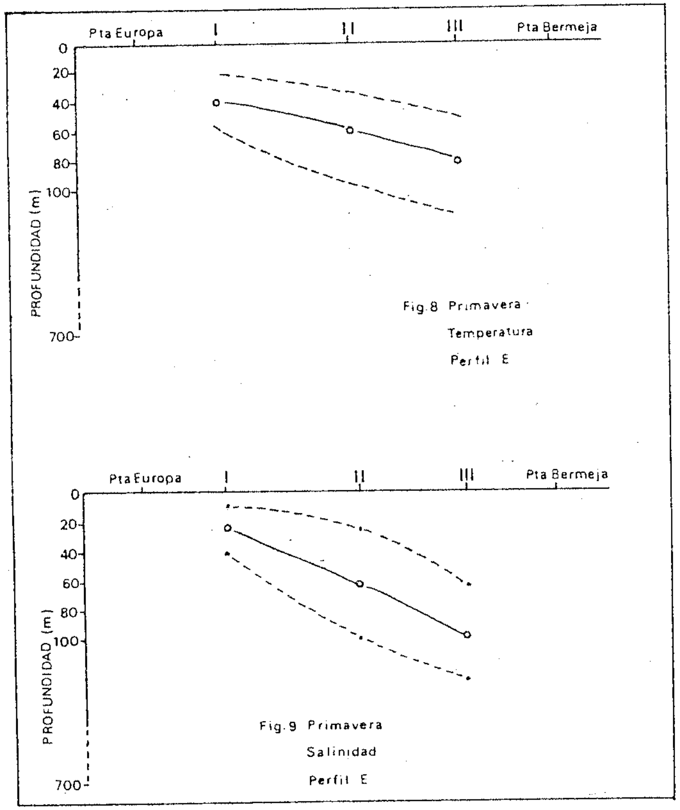

Figure 7

Thermocline and halocline position between Spain (Punta Europa) and Morocco (Punta Bermeja) during pring in the Strait of Gibral tar. (Cano y Fernandez Castillejo, 1968).