Distribution of Tuna Larvae Between Madagascar and the Equator, Indian Ocean

F. Conand

Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), B.P. A5 - Noumea cedex (New Caledonia)

W.J. Richards

Department of Commerce
National Oceanic & Atmospheric Administration
National Marine Fisheries Center
Miami Laboratory
Miami, Florida

Abstract A total of 433 plankton tows, made in the Indian Ocean between the equator and Madagascar, were examined for the presence of scombrid larvae. In order of abundance, those found were: *Katsuwonus pelamis* (73%), *Thunnus albacares* (15%), *Auxis* sp. (7%), *Euthynnus affinis* (2%), *Acanthocybium solandri* (0.6%), *Thunnus obesus* (0.3%), and *Thunnus alalunga* (0.3%). The distribution and abundance of larvae were examined in terms of temperature and salinity data collected concurrently. Ranges of both parameters were well within normal limits of larval occurrence. Larvae of *K. pelamis* and *T. albacares* were most abundant during the summer season. *K. pelamis* were scarce at temperatures lower than 24°C, but salinity conditions showed no effect. For *T. albacares* temperatures below 27°C correlated with low abundance, and high temperatures and salinities correlated with high abundance.

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This paper reports on scombrid larvae from plankton hauls made by R/V *Vauban* on 22 oceanographic cruises carried out from February 1971 through March 1975 in the western Indian Ocean between Madagascar and the equator. The primary objective of these cruises was oceanographic studies, and the data are deposited at the National Oceanographic Data Center, Rockville, MD, under the serial numbers 550012 VA−550033 VA. Since a tuna fishery was developing, we had the opportunity to investigate tuna reproduction by studying larval occurrence and distribution from the plankton collections made on these cruises. Very few studies have been made on larval tuna in the Indian Ocean. Jones and Kumaran (1963) summarize information on Indian Ocean tuna larvae and show that the abundance of tuna larvae was high in the area west of 50°E long. between 0° and 25°S lat., the location of our study area. The purpose of this study is to describe the distribution and seasonal abundance of tuna larvae in terms of temperature and salinity data collected concurrently.

General Hydrographical Conditions of the Area

Several oceanographic studies have been made by Magnier and Piton (1973), Piton and Magnier (1975), and Piton (1976) of the ORSTOM Center of Nosy-Be (Madagascar). These studies detailed the water circulation pattern and the hydrographical characteristics of the surface waters of the region, and from their work the following trends can be pointed out: the climatic conditions are characterized by the permanent trade winds from May to November during the southern winter. The winds become intermittent in summer, and their direction, east−southeast, off the coasts of Madagascar, between 10° and 20°S, changes to the south and then the southwest, north of 5°S. During the southern summer (December to March) the intertropical convergence is located between 10° and 20°S, and the general direction of the wind is from west−northwest near the Madagascar coasts and north−northeast, north of 10°S; this is the cyclone season.

Surface temperature does not change very much during the year. In summer it is about 28° or 29°C, and the thickness of the mixed layer is about 30 to 40 m. In winter the temperature decreases to an average of 25°C, and the mixed layer becomes thicker (40 to 100 m, depending on the region). Thermal fronts are uncommon, but when they do occur they are fairly weak.

The surface waters can be differentiated into three groups by their salinity: (1) the water from the South Equatorial Current with low salinity during the whole year (34.5–34.8°/$_{oo}$); (2) the water from north of the Mozambique Channel, highly saline from August to January (35.0–35.5°/$_{oo}$) followed by lower salinity after the southern summer (34.7–35.0°/$_{oo}$); (3) the equatorial water, the most saline, reaching 35.5°/$_{oo}$. Salinity fronts have been observed close to the coasts during the rainy season (southern summer) and also at the interface of the South Equatorial Current and the equatorial waters.

Methods

The study location was between 2°N and 20°S and between the African coast and 55°E long. Unfavorable weather conditions in winter, with trade winds usually over 20 knots, particularly on the east coast of Madagascar, are responsible for the lower sampling effort during these seasons. Figure 1 gives the number of plankton tows by 1° areas for the two main seasons of the year.

The plankton samples were collected with a FAO-type larval tuna net with a mouth opening diameter of 1 m and 500 microns mesh size. The double oblique hauls were from the surface to 100 m and return. Studies of the vertical distribution of larval tunas of various species indicate that these larvae live exclusively in the mixed surface layer (Klawe, 1963; Strasburg, 1960). It follows, therefore, that almost all the plankton tows sampled the entire vertical range of tuna larvae. The hauls lasted about 20 min at a speed of 2 to 3 knots. The volume of water strained, usually around 1,000 m^3, was measured by a flowmeter.

The plankton were fixed in 10% formalin on board, and the fish larvae were sorted at the ORSTOM Center of Nosy-Be. The tuna larvae were later studied at the National Marine Fisheries Service in Miami and also at the ORSTOM Center of Noumea (New Caledonia).

Identification of skipjack larvae was made following the descriptions given by Matsumoto (1958). For larvae of the genus *Thunnus*,

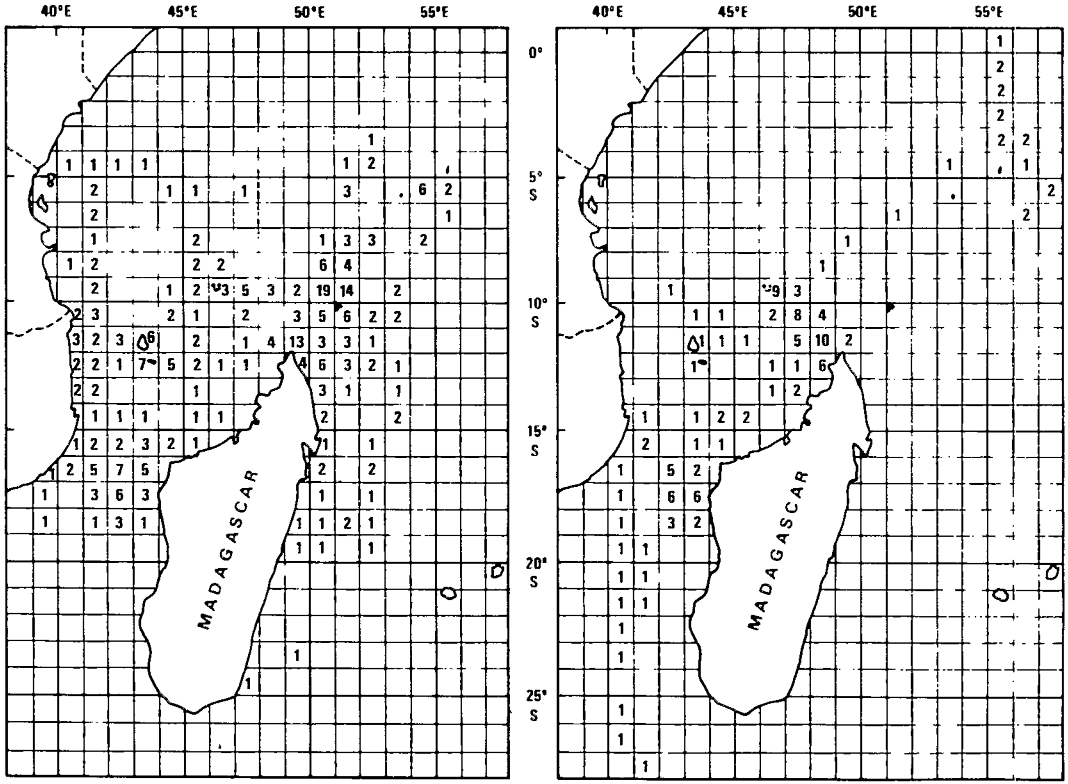

FIGURE 1. Charts of number of plankton tows by 1° areas. Tows made in the November to April period (left) and May to October (right).

we have followed Richards and Potthoff (1974) and Matsumoto et al. (1972), but we often had doubts about the separation of specimens of *T. albacares* and *T. alalunga* less than 5 mm SL. Some larvae larger than 8 mm were cleared and stained with alizarin, and the osteological characters were used for the diagnosis, referring to the work of Potthoff and Richards (1970) and Potthoff (1974). Identification of *Auxis* and *Euthynnus* larvae was based on Matsumoto (1959) and *Acanthocybium* larvae on Matsumoto (1968).

The larval abundance, N, at each station is expressed as the number under 10 m^2 sea surface according to:

$$N = \frac{n \cdot d}{v} \times 10$$

where n = number of larvae in the sample, v = volume of water strained, and d = maximum depth reached by the net during the oblique haul (calculated from the wire out and the angle of the wire).

The mean abundance under 10 m^2 is calculated for each 1° square of area over six-month periods: November to April (summer season) and May to October (winter season).

To determine larval abundance in relation to temperature and salinity of surface waters, the mean number of larvae per haul $\overline{X}$, was calculated for various temperature and salinity conditions.

Results

The occurrence and the relative abundance of the different species are presented in Table 1. The seasonal distribution and its relation with the hydrographical condition will be analyzed for each species.

Skipjack Katsuwonus pelamis

Skipjack tuna larvae are present most of the time north of 20°S (Figure 2). The few observations south of this latitude were made during winter, and no larvae were found. This could indicate that during the southern summer spawning occurs south of the area, since the warm water extends as far as 25° to 30° S. The northern part of the Mozambique Channel appears favorable for the spawning of skipjack,

Table 1
Specific composition of scombrid larvae collected and identified in the Madagascar region.

Species	*Number*	*Percentage of Total*	*Occurrence*	*Percentage of Occurrence*
Katsuwonus pelamis	859	73.5	253	58.3
Thunnus albacares	181	15.5	99	22.6
Thunnus alalunga	4	0.3	2	0.5
Thunnus obesus	4	0.3	3	0.7
Auxis sp.	85	7.3	32	7.4
Euthynnus affinis	29	2.5	9	2.1
Acanthocybium solandri	7	0.6	7	1.6
Total larvae	1,169			
Total stations	433			

and in summer the abundance of larvae is very high, particularly when compared with the area east of Madagascar. The very low sampling effort from August to October does not allow us to make conclusions on the presence of larvae in the region at that time. Stequert (1976) studied the sexual cycle and reproduction of skipjack tuna females in the Nosy-Be area during a one-year period. He found four spawning periods, with two major ones in summer alternating with recovery periods. The larval distribution and abundance analyzed for a larger area and for several years confirm that spawning occurs most of the time, but with a well-defined minimum in winter (from June to October). The seasonal variation in abundance of larvae is shown in Figure 3.

In the Pacific Ocean, Matsumoto (1974) considered 24°C to be the lower limit for the spawning of skipjack tuna. Similarly, Caveriviere et al. (1976) observed that in the Atlantic Ocean the larvae are never found when the surface temperature is below this value. They also observed that the larvae can occur in a very wide surface salinity range (31 to 37‰). In our region of the Indian Ocean, the surface temperature is seldom below 24°C, and the salinity is between 34‰ and 36‰ most of the time.

The relation of skipjack abundance to temperature and salinity is given in Table 2. No larvae occurred in waters below 24°C, but

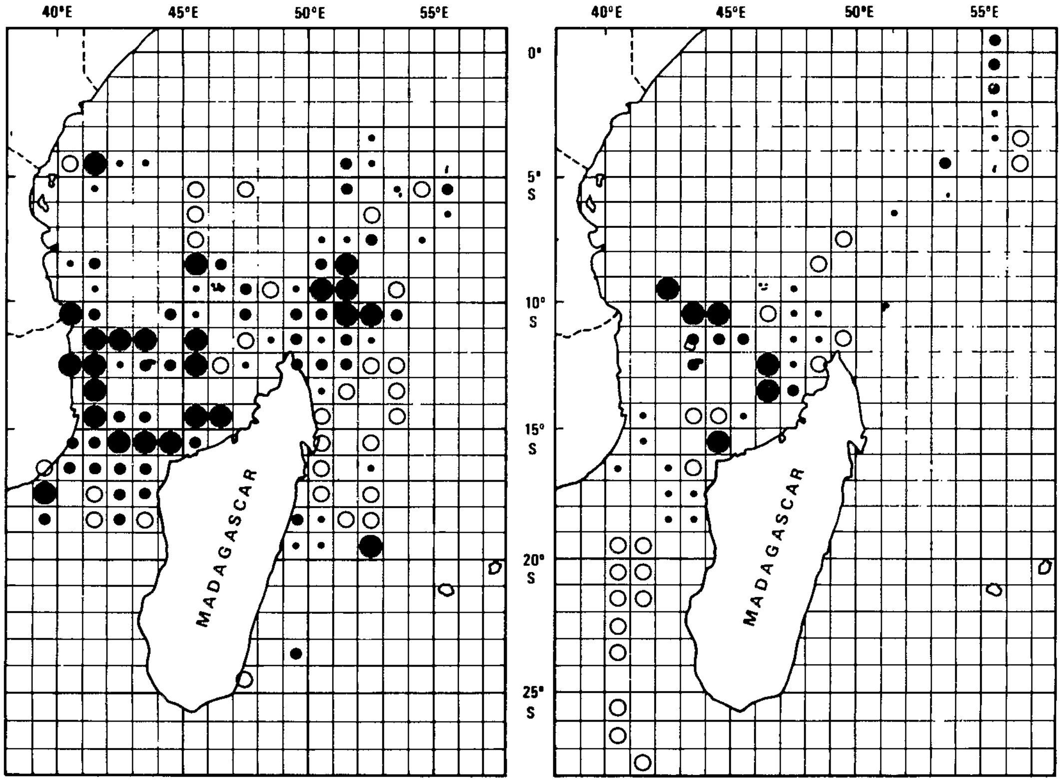

FIGURE 2. Charts of seasonal distribution and abundance of skipjack larvae. November to April period is on the left and May to October on the right. Open circles = absence, small closed circles = 0.1 to 1 larvae under 10 m^2 of sea surface, large closed circles = 1.1 to 4.9 larvae under 10 m^2 of sea surface.

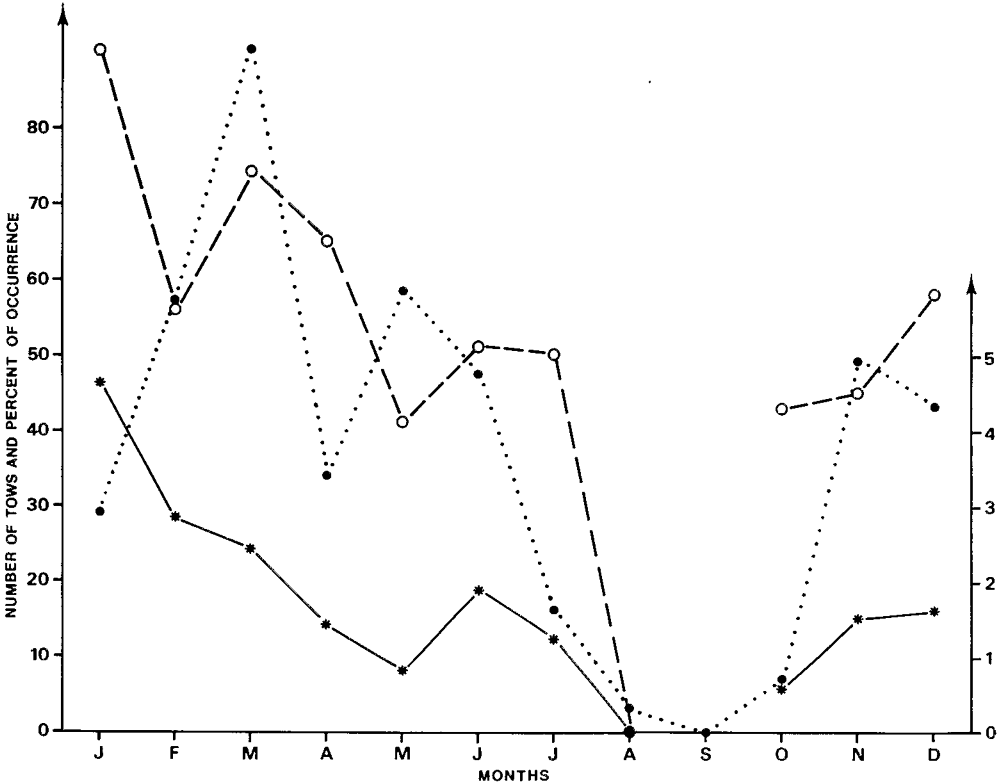

FIGURE 3. Monthly values of the mean number of skipjack larvae per tow, number of tows, and percentage of occurrence. Number of tows indicated by solid circles connected with dotted lines. Percentage of occurrence indicated by open circles and dashed lines; mean number of larvae per tow by stars and solid line.

Table 2
Number of plankton hauls (n), mean number of skipjack tuna larvae ($\bar{x}$), and its standard deviation (sd) in relation with the temperature and the salinity.

Temperature		*22°–23°*	*24°–25°*	*26°*	*27°*	*28°*	*29°–30°*
35<S‰<36	n	6	17	32	54	94	36
	$\bar{x}$	0	0.24	0.75	0.80	2.33	2.72
	sd		0.14	0.18	0.58	0.35	0.61
34<S‰<35	n	0	17	30	54	71	24
	$\bar{x}$		1.12	0.75	1.87	2.13	2.83
	sd		0.39	0.24	0.57	0.33	0.55

between 24° and 27°C some larvae were collected, but the abundance was low. There were no significant differences in number of larvae per haul when compared between different salinity and temperature ranges. Temperatures above 27°C appear to be optimal for spawning, and temperatures below 24°C appear to limit spawning. This latter condition prevails during a brief interval (August–September), and conditions are optimal during seven to eight months. Salinity conditions are never adverse.

Yellowfin, Thunnus albacares

During the southern summer, yellowfin tuna larvae are frequently observed, but not in very high concentrations (Figure 4). They were relatively abundant northeast of Madagascar compared to skipjack, although skipjack absolute abundances were still higher than those of yellowfin (Figure 5). During the May to October period, north of 10°S, larvae occurred in about 50% of the samples, but were scarce south of this latitude (Figure 4).

Tuna fishing in the area has been studied by Stequert et al. (1975) for the years 1973 and 1974. No obvious seasonal variations appear in the yellowfin tuna landings. Therefore, the fish are present during the southern winter, but there is no reproductive activity, probably due to the lower sea temperatures.

Similarly, as was done for skipjack, the mean number of larvae per haul and its standard deviation was estimated for various temperature and salinity conditions (Table 3). No significant differences were

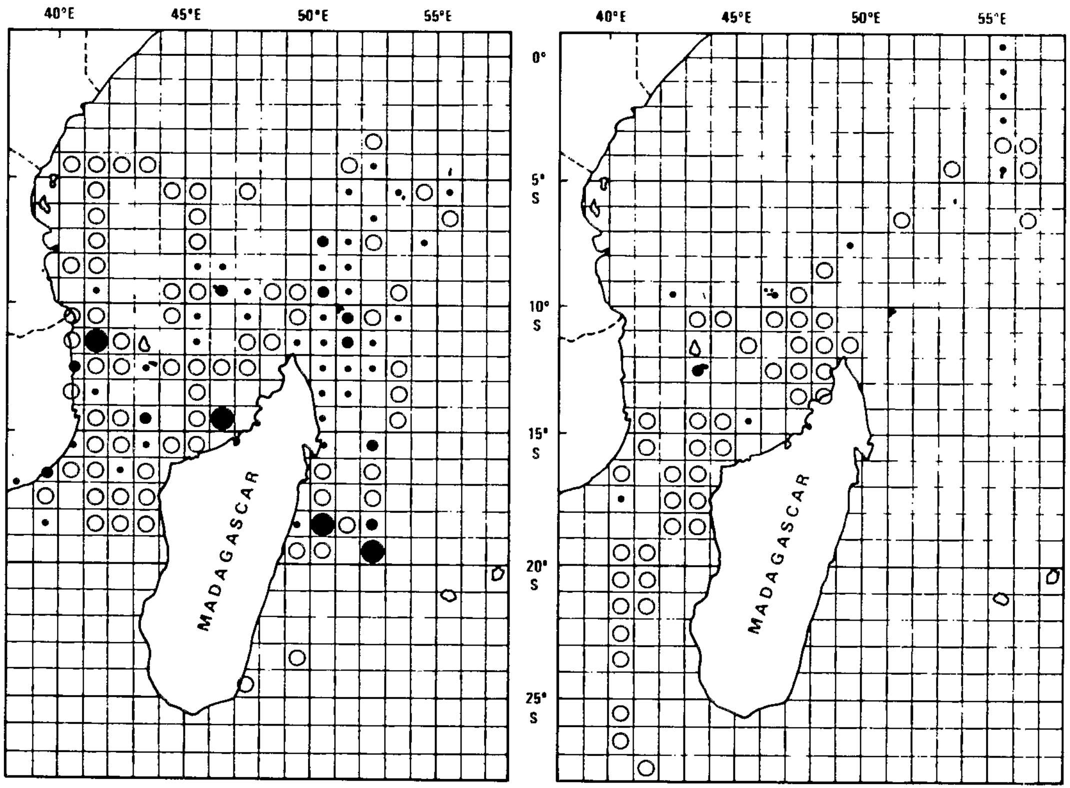

FIGURE 4. Charts of seasonal distribution and abundance of yellowfin tuna larvae. November to April period is on the left and May to October on the right. Open circles = absence, small closed circles = 0.1 to 1 larvae under 10 m^2 of sea surface, large closed circles = 1.1 to 4.9 larvae under 10 m^2 of sea surface.

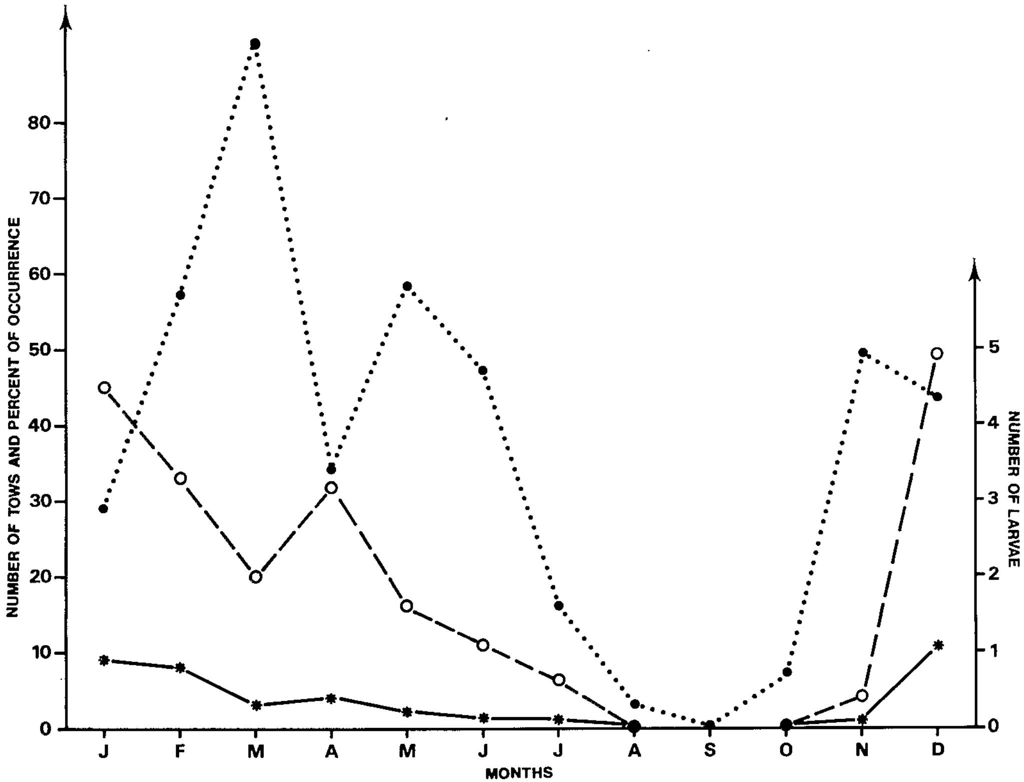

FIGURE 5. Monthly values of the mean number of yellowfin tuna per tow, number of tows, and percentage of occurrence. Number of tows indicated by solid circles connected with dotted lines. Percentage of occurrence indicated by open circles and dashed lines; mean number of larvae per tow by stars and solid line.

Table 3

Number of plankton hauls (n), mean number of yellowfin tuna larvae ($\bar{x}$), and its standard deviation (sd) in relation with the temperature and the salinity.

Temperature		22°–23°	24°–25°	26°	27°	28°	29°–30°
35<S°/₀₀<36	n	6	17	32	54	94	36
	$\bar{x}$	0	0	0.03	0.61	0.72	0.61
	sd			0.03	0.20	0.13	0.16
34<S°/₀₀<35	n	0	17	30	54	71	24
	$\bar{x}$		0.06	0.03	0.30	0.39	0.46
	sd		0.06	0.03	0.10	0.11	0.20

found in number of larvae per haul when compared between different salinities and temperatures. We concluded that spawning occurs when temperature is high and preferentially in high salinity waters. These observations are in accordance with the results of Caveriviere et al. (1976), who observe for the Atlantic Ocean a lower salinity limit of 34°/₀₀ for the occurrence of yellowfin tuna larvae.

Other Scombrids

Of the 1,169 tuna larvae captured, there were only four bigeye tunas (*T. obesus*) and four albacore (*T. alalunga*). The larvae of bigeye tuna were found in January and February at 10°S and 50°E in waters with surface temperature of 28°C and salinity 35.0°/₀₀. The albacore larvae were caught during March southeast of Madagascar at 23° to 24° S in surface waters 28°C and 34.6°/₀₀.

The identification of frigate mackerel and bullet mackerel (*Auxis* sp.) larvae to the species level is still doubtful, and so only the genus is considered. A total of 85 larvae was collected, and their distribution is given in Figure 6. During the southern summer the larvae were collected in the Mozambique Channel and north of Madagascar, where shallow waters and islands are frequent. They did not occur in the east, where the conditions are more typically oceanic. Some larvae were also found during the cold season. The temperature and salinity conditions in which spawning occurs are wide and are not limiting in this region.

The adults of kawakawa (*Euthynnus affinis*) are frequently caught

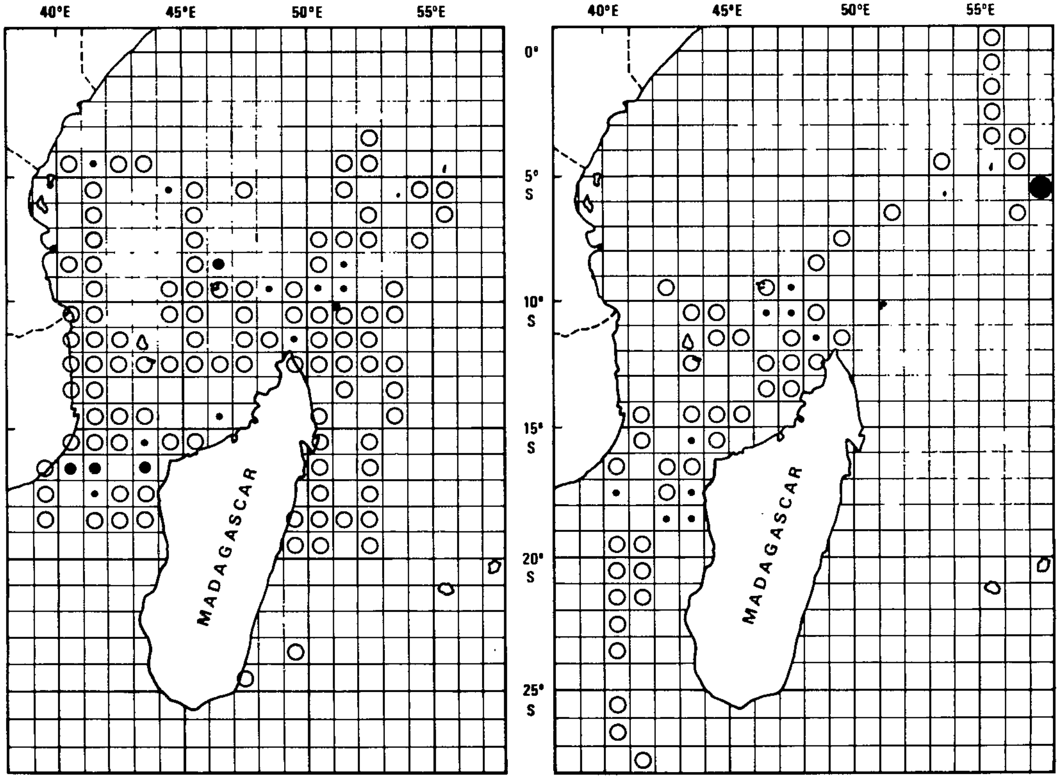

FIGURE 6. Charts of seasonal distribution and abundance of *Auxis* larvae. November to April period is on the left and May to October on the right. Open circles = absence, small closed circles = 0.1 to 1 larvae under 10 m^2 of sea surface, large closed circles = 1.1 to 4.9 larvae under 10 m^2 of sea surface.

by fishermen, although they have no commercial value (Stequert et al., 1975). Nevertheless, it is rather surprising that only 29 larvae occurred during the warm season. They were collected close to the western Madagascar coast and coast of Mozambique.

Seven larvae of wahoo (*Acanthocybium solandri*) were observed in warm waters in the Comores Islands area.

Discussion

Matsumoto (1974) discussed the 5:1 skipjack to yellowfin larvae relationship (which we also found) and noticed that the relative abundance of larvae is related to factors such as the fecundity of the population, its demographic structure, the growth and the mortality rate of the larvae, and their catchability by the fishing gear. Therefore, the preponderance of the larvae of one species does not allow us to conclude the same for the adults. Interestingly, a similar 5:1 ratio of the catch by weight of skipjack tuna and yellowfin tuna by the pole and line fishery in the north of Madagascar was shown by Stequert et al. (1975).

The comparative abundance of tuna larvae observed by Nakamura and Matsumoto (1966) in the central Pacific (Marquesas area) is similar to that observed by us near Madagascar, but has an even higher skipjack-to-yellowfin ratio. Conversely, in the eastern Atlantic, Caveriviere et al. (1976) observed higher numbers of yellowfin than skipjack tuna larvae. The distribution atlas of tuna larvae by Nishikawa et al. (1978) presents maps of all the oceans with schematic scales of density. In the western Atlantic as well as in the western Pacific there is a greater abundance of skipjack tuna larvae than yellowfin larvae, while in the eastern part of these oceans the opposite occurs. Our observations also show a skipjack tuna dominance in the western Indian Ocean, but very little sampling has been done in the eastern Indian Ocean.

Auxis and *Euthynnus* larvae, both coastal species, are not abundant in this region, but are very common in the Atlantic off the African coast (Richards, 1969; Richards and Simmons, 1971).

We investigated the possibility of correlations between the concentration of tuna larvae and hydrological features such as temperature or salinity fronts. Maps of surface isotherms and isohalines were drawn for the cruises where strong abundances were observed, but no obvious relations were seen. This does not mean that such relationships do not exist, but more refined sampling designs are required to detect or accurately measure such relationships.

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