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ACOUSTIC IMAGING, VISUAL OBSERVATIONS, AND OTHER INFORMATION USED FOR CLASSIFICATION OF TUNA AGGREGATIONS ASSOCIATED WITH FLOATING OBJECTS IN THE PACIFIC OCEAN

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Acoustic imaging, visual observations, and other information used for classification of tuna aggregations associated with floating objects in the Pacific Ocean

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Abstract

Purse seiners operating in the Pacific Ocean catch large quantities, in various proportions, of skipjack, yellowfin, and bigeye tunas associated with floating objects, in particular fish-aggregating devices (FADs). There is concern about the high fishing mortality rates on small bigeye and yellowfin tunas associated with floating objects from purse-seine fisheries, and the negative impact on sustainable yields from those populations. Most captains of large-scale industrial purse-seine vessels operating in the Pacific Ocean have 10 or more years experience fishing for tunas in association with FADs. Through the use of echo-sounders and sonars on the bridges of these vessels, along with *a priori* knowledge of the acoustic signatures, depth distributions, and behavior, by geographical region and oceanographic conditions, of the various species, along with visual observations of the mixed-species aggregations, captains should have a fairly good idea of the quantities and sizes of each species before they set their nets. Each set provides an opportunity to verify their estimates, and thus develop their expertise in determining the species and size compositions of the fish in the aggregations before they set their nets. This paper describes the anatomical and behavioral differences in these three tuna species, their acoustic images, and other relevant information used for estimation of their presence, quantity, and sizes when associated with floating objects in the Pacific Ocean.

1. Introduction

Purse seiners operating in the Pacific Ocean catch variable quantities of relatively small skipjack, yellowfin, and bigeye tunas associated with floating objects, particularly moored and drifting fish-aggregating devices (FADs) (Lennert-Cody and Hall, 2000; Itano et al., 2004). The estimated species composition for the retained catch by the purse-seine fleet in the western and central Pacific Ocean (WCPO), from fishing on floating objects during 2002-2006 was 85.3% skipjack, 12.5% yellowfin, and 2.2% bigeye (compiled by the Oceanic Fisheries Programme, Secretariat of the Pacific Community). The length-frequency data from port sampling of the catches of the U.S.- flag purse-seine fleet that fished in the WCPO during 2004-2006 on schools associated with floating objects shows one prominent mode for skipjack between 40-60 cm, a prominent mode at 40-60 cm and a less prominent mode at 80-100 cm for yellowfin, and a prominent mode at 40-60 cm and a less prominent mode at 60-80 cm for bigeye (Anonymous, 2007).

Based on the retained catch and dock-side species composition sampling for the purse-seine fleet operating in the eastern Pacific Ocean (EPO), the estimated species composition during 2002-2006 for fish caught in association with floating objects was 62.1% skipjack, 26.2% bigeye, and 11.7% yellowfin (compiled by the staff of the Inter-American Tropical Tuna Commission). The length-frequency data from the dock-side species composition and size sampling program during 2002-2006 for fish caught in association with floating objects shows one prominent mode at 45-75 cm for skipjack, a prominent mode at 45-80 cm and a significant amount of fish at 80-130 cm for bigeye, and a prominent mode at 40-65 cm and a significant amount of fish at 70-140 cm for yellowfin (compiled by staff of the Inter-American Tropical Tuna Commission).

There is concern by the Western and Central Pacific Fisheries Commission (WCPFC) and the IATTC about the high fishing mortality rates on small bigeye and yellowfin tunas resulting from fishing for fish associated with floating objects and the impact on sustainable yields resulting from this mortality. Numerous management measures for reducing fishing effort and mortality on small tunas associated with floating objects by the purse-seine fisheries have been proposed. Individual vessel quotas which could provide a practical solution by providing an incentive for vessels that are more selective in reducing their catches of small yellowfin and bigeye tunas have been considered (Harley et al., 2004).

The objectives of this paper are to present and discuss the role of underwater acoustics, visual observations, and other criteria used by captains of purse-seine vessels to estimate the species composition, size frequency, and tonnage of tunas associated with floating objects before setting their nets.

2. Morphological differences between skipjack, yellowfin, and bigeye tunas

There are differences in the shape, coloration, internal anatomy, and sizes of skipjack, yellowfin, and bigeye tunas (Collette and Nauen, 1983). These morphological characteristics, which are quite distinct, provide the ability to differentiate between the species underwater through visual and/or acoustic observations.

Skipjack have no swimbladder. In yellowfin, the inflated swimbladder extends from the rostral end posteriorly about half the length of the body cavity. The inflated swimbladder in bigeye extends along most of the length of the body cavity. Swimbladder volumes are significantly greater for bigeye than for yellowfin greater than 60 cm in length (Figure 1). At the surface of the ocean swimbladder volumes for yellowfin and bigeye, of about 10 kg, are estimated to be about 2% and 7% of body volume, respectively (Schaefer, 1999). At greater depths the swimbladder volumes would be expected to be reduced in accordance with Boyle’s law. Larger swimbladders in bigeye than yellowfin are an obvious adaptation to the depths that these two species commonly inhabit (Schaefer and Fuller, 2002; 2007).

3. Behavioral differences among skipjack, yellowfin, and bigeye tunas associated with floating objects

The simultaneous behavior of skipjack, yellowfin, and bigeye tunas while associated with drifting FADs in the equatorial central Pacific Ocean was investigated, using ultrasonic telemetry by Matsumoto et al. (2006). The swimming depths of the yellowfin and bigeye tunas were similar during the night and day, the fish remaining above the mixed layer depth of about 100 m and the average depth during the day being significantly greater than during the night. The skipjack tuna were slightly closure to the surface than the yellowfin and bigeye tuna during both the day and night (Figure 2). Smaller tunas of all three species were commonly at shallower swimming depths than the larger individuals, although these differences were not consistent.

Schaefer and Fuller (2005) investigated the horizontal and vertical movements of skipjack and bigeye tunas within large multi-species aggregations associated with moored buoys and a drifting vessel, using ultrasonic telemetry and archival tags, along with acoustic imaging and visual observations, in the equatorial eastern Pacific Ocean. The dynamics of the aggregations were passively monitored throughout for describing the temporal changes in orientation of the aggregations. The sonic-tagged skipjack and bigeye tunas remained within the aggregations throughout the 48-hour study periods. The pairs of acoustically tagged skipjack and bigeye, and also the entire aggregations, were primarily upcurrent of the moored buoy and downcurrent of the drifting vessel during the day. At night the aggregations were observed to be more diffuse, and the fish were feeding on organisms of the deep-scattering layer. The aggregations returned to positions upcurrent of the buoy or downcurrent of the drifting vessel at dawn, commonly breezing at the surface within cohesive monospecific schools. The skipjack and bigeye had concurrent changes in depth records, occupying in most cases significantly greater mean depths at night than during the day, but remaining above the mixed layer depth of about 30 m. When associated with a moored buoy, bigeye depth distributions were deeper during the day and night than those of skipjack (Figure 3), but bigeye depth distributions were shallower during the day and night than those of skipjack when associated with the drifting vessel. Simultaneous depth records of a large and a small bigeye with archival tags associated with a moored buoy also indicated diel changes in depth. The mean depths during both the day and night were significantly greater for the larger bigeye than for the smaller ones.

4. Acoustic imaging

Most large-scale industrial purse-seine vessels currently targeting tropical tunas in the Pacific Ocean are equipped with one or more high-tech color echo-sounders and sonars (Itano, 2003). The most common echo-sounders used by these vessels in the EPO and WCPO are probably the Furuno FCV 1100 (28/200 kHz), costing about US$3,000. The new current generation Furuno FCV 1200, costing about US$6,000, has dual-frequency options of 28, 50, 88, or 200 kHz. The 28 kHz option is popular because the lower frequency provides a deeper and wider beam performance, which is useful for FAD fishing. Higher frequencies, such as 200 kHz, are suitable for shallower and higher resolution. Many of the newer Spanish purse seiners have Simrad ES60 38 kHz echo-sounders with split-beam transducers. This echo-sounder which costs about US$25,000 is considered by some experts to be the best echo-sounder on the market. Also, light boats used for pre-dawn sets by purse-seine vessels on FADs commonly have dual-frequency echo-sounders on board as well.

Air-filled swimbladders may account for 50% to 95% of the acoustic target strength for some fish (Foote, 1980). Fishes that lack a swimbladder, such as skipjack tuna, apparently have an acoustic target strength that is only about one-quarter to one-tenth that of comparable swimbladdered species. For species with swimbladders the strongest echo (maximum dorsal aspect target strength) is obtained at the direction perpendicular to the longitudinal axis of the swimbladder (Ona, 1999). Because of size differences in yellowfin and bigeye swimbladders and the absence of a swimbladder in skipjack, the acoustic images seen on echo-sounders of mono-specific schools are characteristic of the species.

A sonar operates with an adjustable tilt of the projection and programmable beam in which the beam is instructed to transmit in sequential sectors with one or more transmissions per sector. The more advanced systems are multibeam/multisector or omnidirectional in which several beams cover a large sector or 360° in each transmission. With these sonars, the complete horizontal extent of a school may be projected for each transmission. The more advanced omnidirectional sonars also have an additional vertical beam that enables the vertical extent of the fish school to be projected as well (Brehmer et al., 2006). The displays are in color, using the heat spectrum concept, with higher densities, such as fish with swimbladders, showing as red. The transducers on these sonars are mostly retractable, and rotate so they can protrude well below the vessel. Automatic tracking of an identified school is also common in most of the new omni sonars. The operator puts a marker on the detected and selected school before activating the tracking function. Sonars provide acoustic images used by captains of purse-seine vessels for estimation of the total weight of tunas within a mixed-species aggregation, but can also provide estimates of the weight for each species after obtaining images of the mono-specific schools within aggregations.

There is a wide range in the cost and performance of sonars on board purse-seine vessels fishing for tunas throughout the Pacific Ocean. The Furuno FSV 30, costing about US$175,000, is a low-frequency long-range omni-directional sonar which pings 360 degrees. This sonar is reported by Furuno to be able to detect a 10-mt school of tuna at 4,000 m. Many of the Japanese, Korean, and Taiwanese flag vessels operating in the WCPO have these or similar performance Furuno sonars aboard, as do the U.S.-flag vessels. The Simrad SP90, costing about US$200,000, is used on board many of the newer Spanish vessels. Many of the Ecuadorian-flag FAD fishing vessels operating in the EPO have lower-priced Furuno short range sonars, costing about US$50,000, but still with omni-directional performance.

In conjunction with IATTC tuna tagging cruises to the equatorial EPO during March to May of 2002 through 2006, field studies were conducted in close proximity to two Tropical Atmosphere Ocean (TAO) moorings at 2°S 95°W and 2°N 95°W, utilizing the chartered M.V. *Her Grace*, a live-bait pole-and-line vessel (Schaefer and Fuller, 2005). Upon arriving at a TAO mooring, observations of the relative orientation and movements of the tuna schools making up an aggregation were monitored through sonar (Wesmar HD 600E-6 series, 160 kHz) and echosounder (Furuno FCV 1000) imaging, from which selected images were recorded with a digital camera. The Furuno FCV 1000 is a 50/200-kHz dual beam 1-kW echosounder. The sonar was used for observing the aggregation's bearing range, size, and behavior. The echosounder was used to observe the aggregation's vertical distribution and behavior, to identify presence or absence of bigeye tunas, and to monitor the diel vertical migrations of the deep-scattering layer. Confirmations of species present within aggregations were obtained during intensive fishing and tagging events. In addition, a hard-wired Fisheye underwater color video camera connected to a monitor and VCR recorder was suspended horizontally at a depth of 20 m under the vessel. The camera maintained a constant bearing into the current because of the large vertical fin fixed to the trailing edge of the camera housing. The video images provided additional confirmation of species identification and behavior.

Selected images to illustrate differences in the presence or absence of tuna species within an aggregation associated with a floating object in the equatorial EPO, as observed from an echosounder, are presented in Figures 4-6. The image of an estimated 20-mt school of skipjack tuna (about 50-70 cm length) associated with the drifting vessel is shown in Figure 4. The signals from the skipjack appear as granular, yellow to orange, lower-density targets seen from about 10 to 19 fathoms (18-35 meters). The image of an estimated 50-mt school of yellowfin tuna (about 50-75 cm in length) associated with a TAO mooring, without skipjack or bigeye tunas present is shown in Figure 5. The signals from the yellowfin appear not so granular, but more condensed and solid, mostly orange, higher-density targets seen from the surface to 25 fathoms (0-46 meters). The image of an estimated 100-mt mixed-species aggregation consisting of bigeye and skipjack tunas associated with the drifting vessel is shown in Figure 6. The presence of bigeye tuna is indicated by the dark red, high-density, confluent targets seen from the surface to 36 fathoms (0-66 meters). The strong return signals from the bigeye overshadow the signals from the skipjack, when the species are mixed together. The image from the sonar of the estimated 50-mt school of yellowfin associated with the TAO mooring shown in Figure 5, is shown in Figure 7. The image was taken at night, at about 2200 h, when the aggregation was somewhat dispersed in the vicinity of the mooring while foraging on prey organisms of the deep scattering layer.

5. Visual observations

During an IATTC tuna tagging cruise to the equatorial EPO in March-May 2000, we observed large multi-species tuna aggregations associated with several drifting FADs. Skipjack schools associated with the FADs at night would usually move away shortly after dawn, sometimes up to several kilometers, to either return the next night or not at all. The associated bigeye schools would typically remain within about 2 km of the drifting FAD throughout the day and cluster tightly under the FADs at night with the other tunas or disappear, commonly not remaining for more than about two days at a drifting FAD. In most instances tuna aggregations we have observed associated with moored and drifting floating objects were often seen “breezing” near dawn, with horizontal separation into monospecific breezing schools of bigeye and skipjack for which we were able to visually estimate the species quantities and approximate lengths of the fish. Tightly packed schools of tuna, with strong cohesion and synchronized sequential behaviors are commonly referred to as “breezer,” “black spot,” “white spot,” or “shiner” (Scott, 1969).

During an evaluation for the presence and size composition of tunas associated with a floating object, purse-seine fisherman always attempt to obtain visual confirmations, since the accuracy in their estimates can be significantly improved over that of just the acoustic images. They are familiar with the morphological and behavioral differences of tunas, including differences in these characteristics relative to size. They are also aware of differences in behavior and depth distributions relative to time of day, and the appearance of tuna schools at night as well as during the day. Visual observations into the water can be improved by viewing from the “crow’s nest” high up in the mast and from helicopters. Binoculars are commonly used for this purpose.

The ability to obtain visual confirmations of tuna species and sizes is highly dependent on water clarity and visibility, which are related to geographic area and oceanographic conditions. In the EPO, because of a relatively shallow mixed layer depth of 20 to 40 m, it is common to be able to get a visual confirmation of the species present and their size ranges. If skipjack are present, most of the time there will be a breezer and/or a “white spot” observed. Experienced purse-seine fisherman can tell by the fineness of breezers, and from the variation in the color of white spots the tuna species and approximate sizes. Tunas associated with floating objects in the EPO are normally quite curious when a vessel approaches, or a helicopter comes down close to the water and ripples the surface. Most purse-seiner captains are well aware of this curiosity, and will commonly circle FADs slowly and look for the tunas to ascend nearby or under the vessel, providing a good image on their echo-sounders, and also visual confirmations. Many captains are more cautious, and will use a helicopter or the workboat to attempt to obtain visual confirmations.

In the WCPO, where the mixed-layer depth may be 100 to 150 m, the average depth distributions of tunas associated with floating objects, make visual confirmation of species far less common. Although big breezers of skipjack associated with floating objects were commonly seen 20 years ago during the day in the WCPO, in recent years it is reported by captains that those are rarely seen. Skipjack schools, however, will commonly rise near dawn to depths at which visual confirmations of species and size could be made in the WCPO, but purse-seine vessels normally set in the dark, at least one hour before dawn.

6. Other information

There is apparently a considerable amount of spatial and temporal variation in the species composition and size frequency of tunas captured by purse-seine vessels in association with floating objects throughout the Pacific Ocean. There have been some studies in recent years utilizing catch data attempting to elucidate such patterns (Fonteneau et al., 1999). It has been reported by purse-seine captains that sets in specific time/area strata in the EPO and WCPO are quite consistent from year to year in regards to the composition of bigeye and yellowfin within aggregations consisting primarily of skipjack tuna. There is apparently a level of expert knowledge by captains of the species composition and sizes within regions, both longitudinal and latitudinal, historic and current. In addition to that information taken into consideration by captains planning their fishing trips and planting their FADs, they also utilize the detailed information provided daily by other vessel captains within their code group, including information on species quantities and sizes within areas. In addition, there is apparent consistency in the catches of tunas associated with drifting FADs within small areas during fishing trips, which is also taken into consideration by the captains.

7. Discussion

Before captains of purse-seine vessels set their nets around an aggregation of tunas associated with a FAD, they derive estimates of the species composition, quantities, and sizes present, using acoustics and, when possible, visual observations, along with knowledge of historic and current catch information for the time/area strata in which they are operating. The accuracy of these estimates is highly dependent on geographic area, oceanographic conditions, time of day when the set is made, the time spent evaluating the aggregation, and the size of the aggregation. The accuracy is reported by captains to be quite good for aggregations of 50 mt or less, but less so for aggregations over 100 mt, unless considerable time is spent evaluating the aggregation before making a set. The accuracy of the estimates is expected to be better in the EPO, where visual confirmations can commonly be used in addition to acoustic imaging. However, estimates in the WCPO should be considered reasonably accurate, based on horizontal and vertical separations by species and sizes observed through acoustic imaging, along with historical and current time/area fishing information. Captains make these estimates over and over again, and obtain verification of their accuracy when they load the catch on board their vessels. They do this because it is of interest and economically important to not be making a set, for instance, on fish for which there is no market and wasting precious fishing time.

Scientists have conducted acoustic experiments in the field with Simrad 38 kHz scientific echosounders and obtained target-strength (TS) to size relationships for yellowfin, bigeye, and skipjack tunas to be used for acoustic assessments of biomass and behavioral studies (Bertrand et al., 1999; Bertrand and Josse, 2000; Josse and Bertrand, 2000; Miguel et al., 2006). Although conducting *in situ* studies of acoustic target strengths are the most appropriate for obtaining potentially reliable estimates, there are numerous biases, including fish orientation, packing density, and depth, which provide uncertainty in their usefulness for species identification and sizes within large tuna aggregations associated with FADs.

Misund (1997) stated in a review paper on acoustics in marine fisheries that the acoustic identification of species and size is possible, but difficult. Some studies, which were cited when analyzing the frequency spectra by classical discriminant analysis or by neural networks have obtained fairly precise species classifications in the gadoids, and in aggregations of anchovies, sardines, and mackerel. There appears to be a need for extracting more acoustic information from sonars and utilizing image analysis software and artificial intelligence for classifications and estimations.

Scientists are now attempting to develop “expert systems” that incorporate the data from scientific echo-sounders and sonars coupled with what is known about behavior of tunas to attempt to predict from acoustical data the species composition and sizes present in aggregations associated with FADs. This concept has led to the term “acoustic selectivity,” and raised the awareness of the value of acoustic imaging as a potential tool for reducing the catches of small tunas associated with FADs. It would appear that the proposed synthetic “expert systems” have less input information than the intuitive systems currently used by the true experts, experienced captains of purse-seine vessels, for making such predictions on a routine basis. Much of what many scientists are trying to understand about the potential for “acoustic selectivity,” behavior of tunas, and the complex dynamics of purse-seine fishing effort on FADs could be learned more readily through collaboration with experienced captains who may share their extensive knowledge and their suggestions for solutions to perceived problems.

Based on our experiences using a hard-wired submersible camera for observing tunas associated with floating objects (Schaefer and Fuller, 2005), it would seem practical to experiment on purse-seine vessels with cameras either lowered to depths at which tunas are observed on echo-sounders, or using remotely operated vehicles, for further verification of species and size frequencies. Reasonably high resolution cameras with fish eye and zoom capability are now quite inexpensive, and could prove to be quite useful in conjunction with acoustic imaging.

8. Acknowledgements

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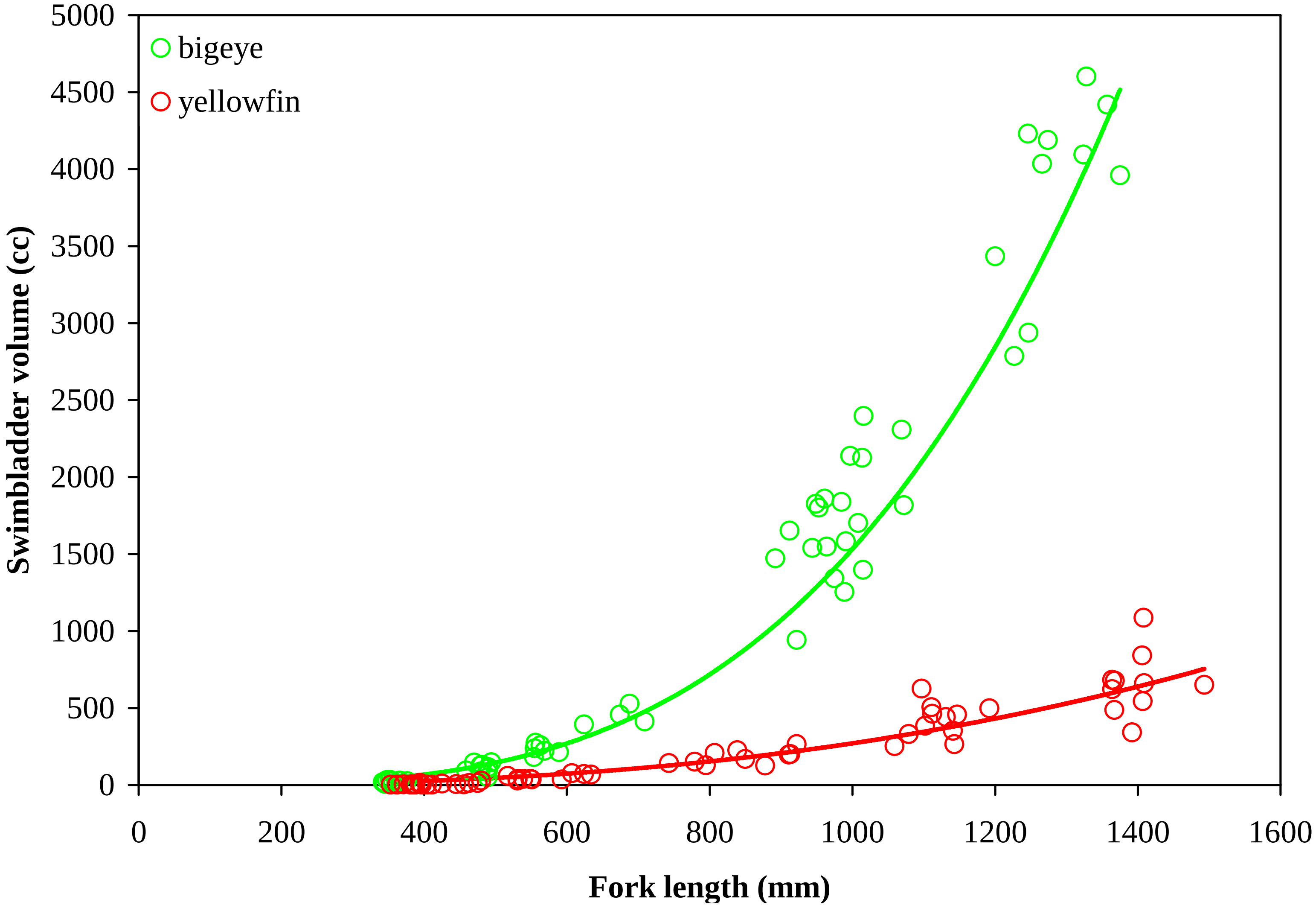

Figure 1. Relationships between swimbladder volume and fork length for yellowfin and bigeye tunas (from Schaefer, 1999).

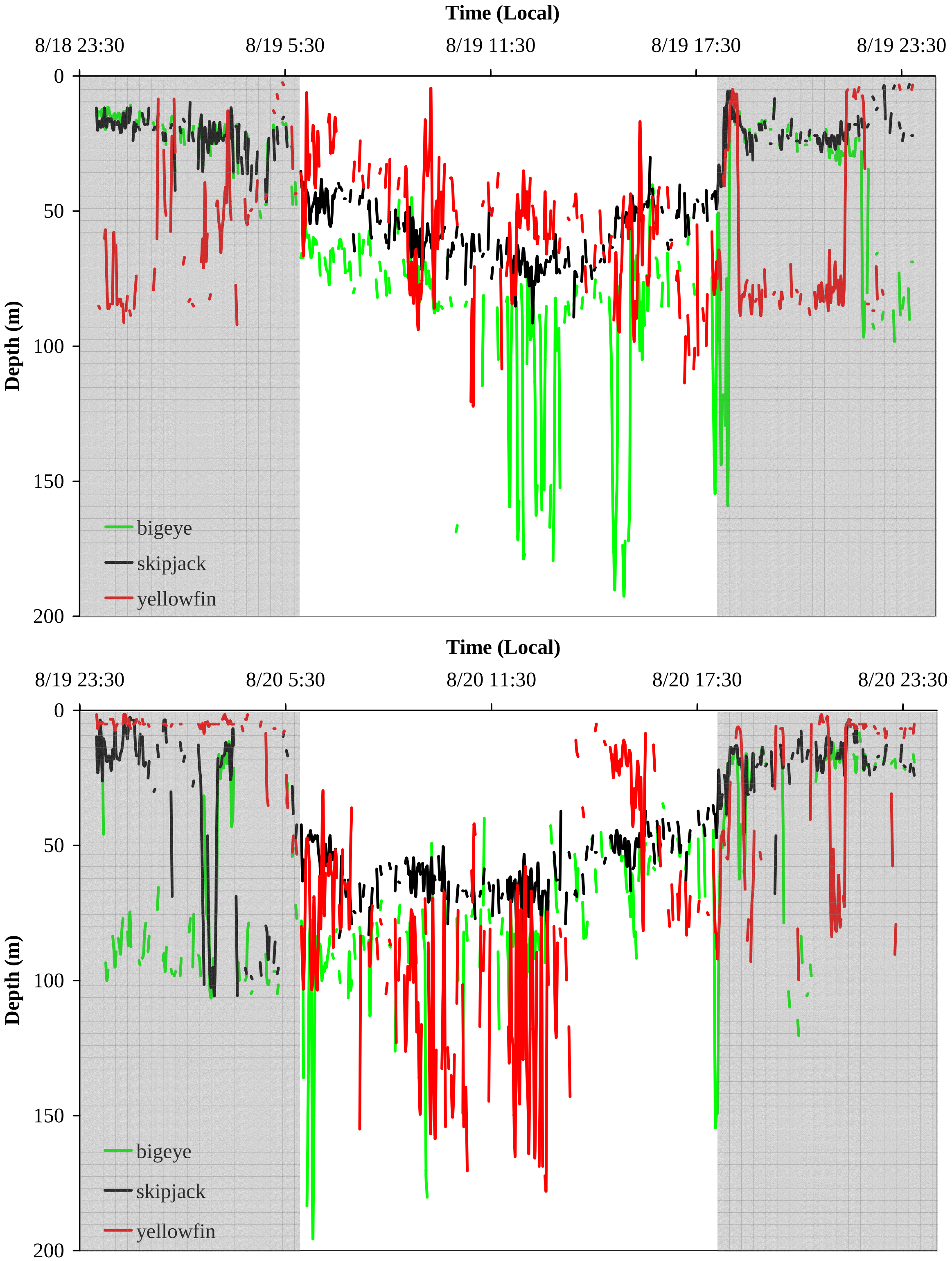

Figure 2. Concurrent depth records from ultrasonic telemetry for skipjack, yellowfin, and bigeye within a multi-species aggregation associated with a drifting FAD in the equatorial central Pacific Ocean during a 48-h period in August 2005 (from Matsumoto et al., 2006). Grey panels indicate night time.

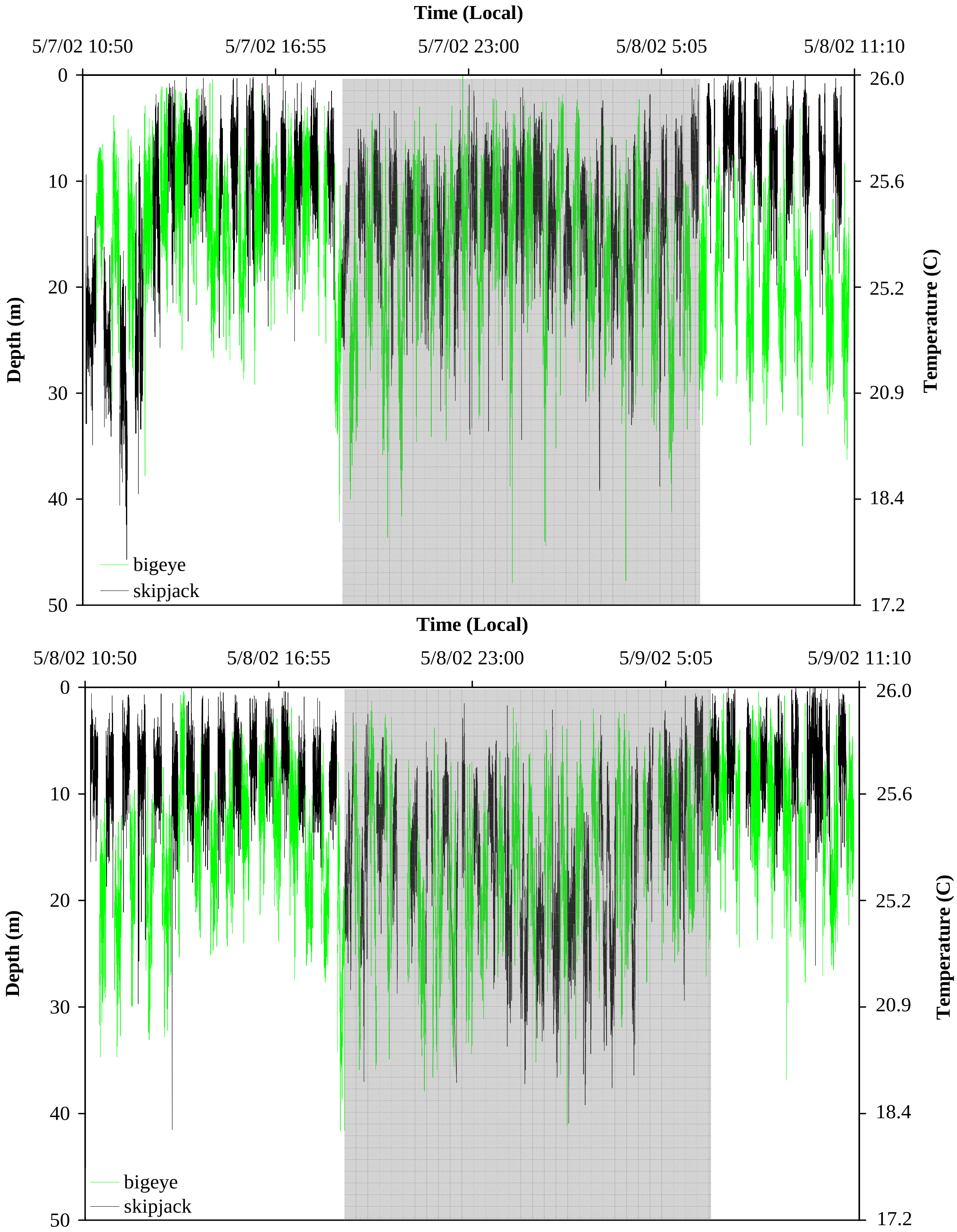

Figure 3. Concurrent depth records from ultrasonic telemetry for skipjack and bigeye tunas within a large multi-species aggregation associated with a TAO mooring in the equatorial eastern Pacific Ocean, during a 48-h period in May 2002 (from Schaefer and Fuller, 2005). Grey panels indicate night time.

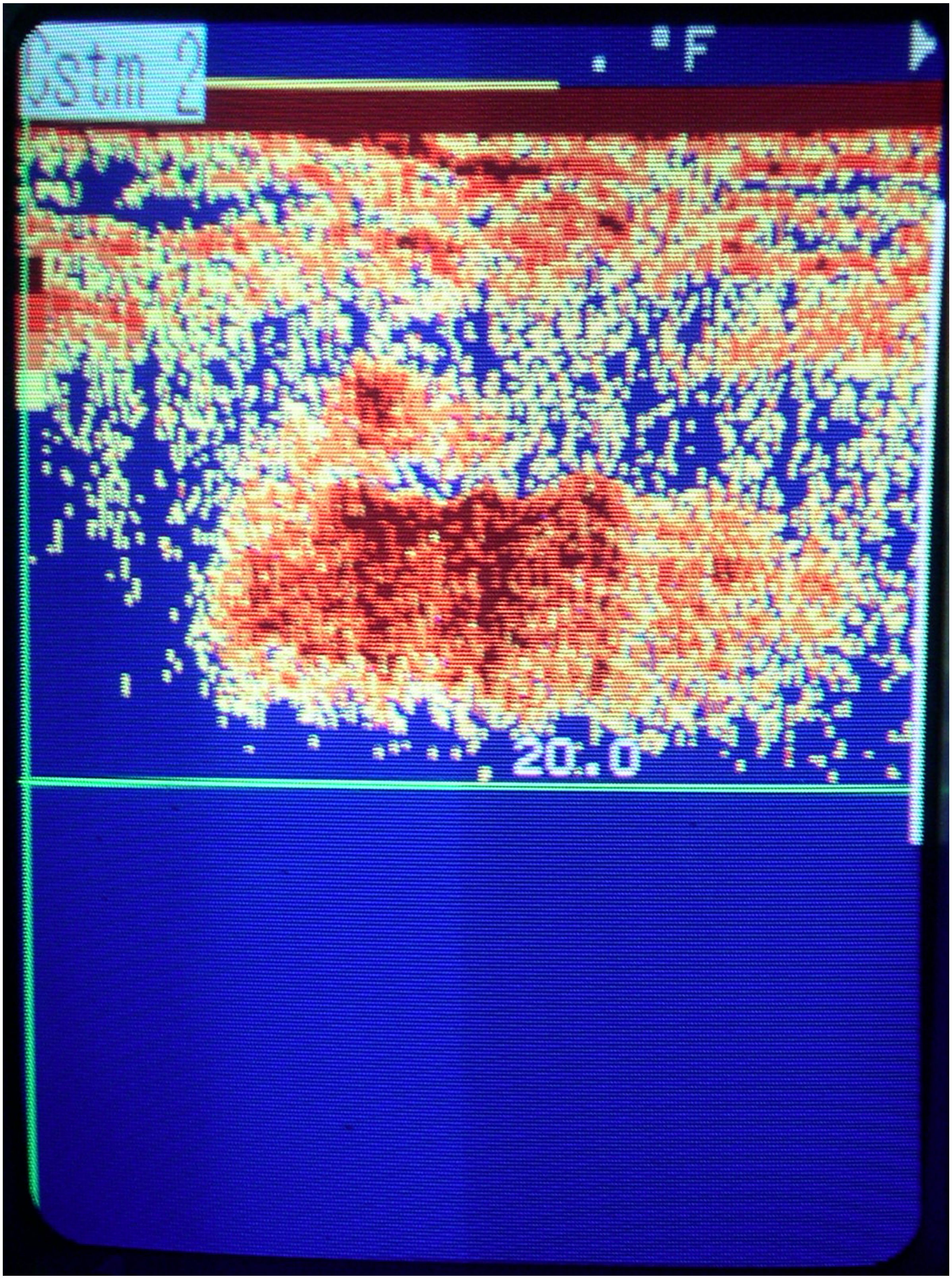

Figure 4. Echosounder image (50 kHz signal) of a school of skipjack tuna associated with the drifting vessel in the equatorial EPO.

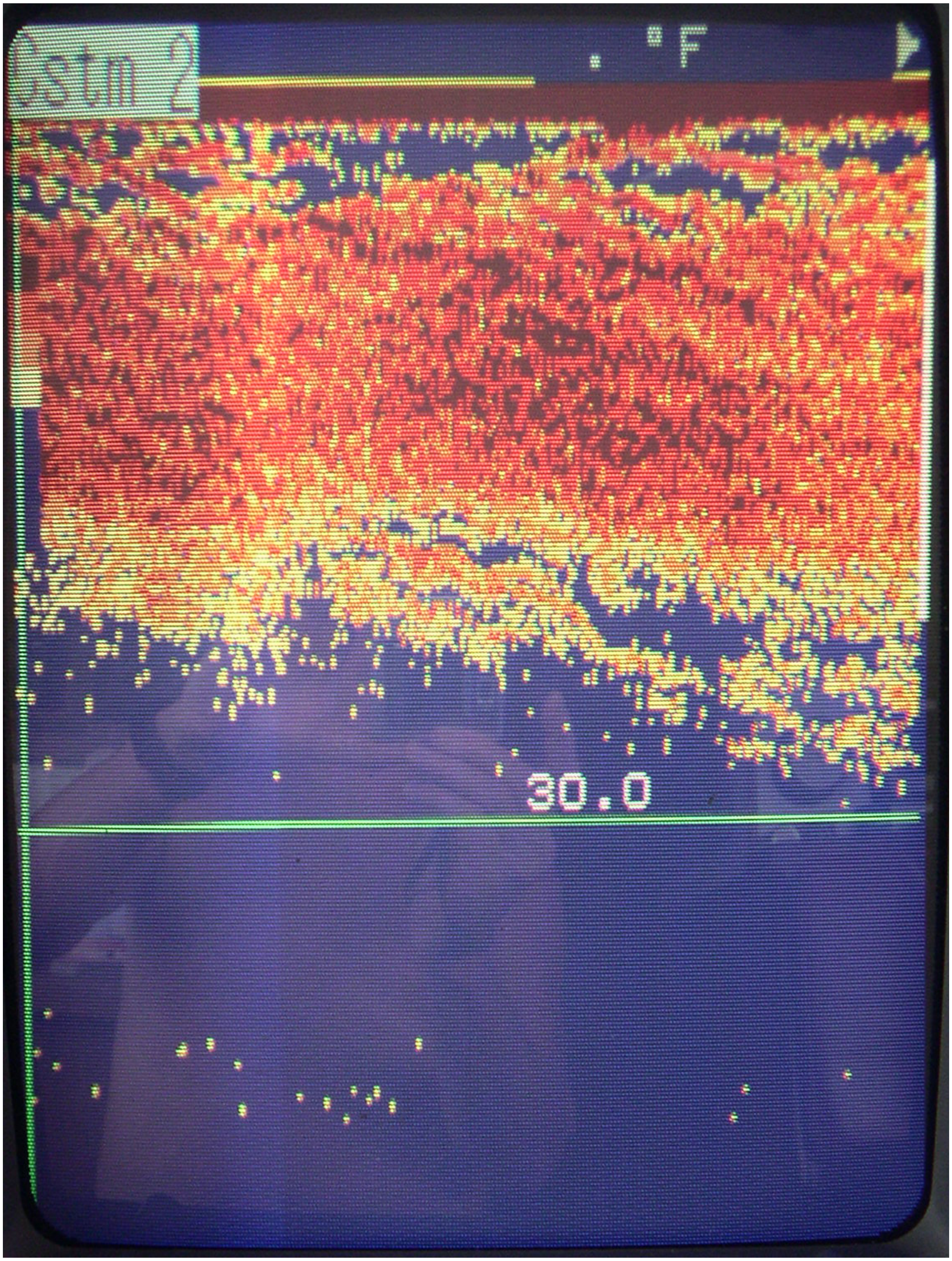

Figure 5. Echosounder image (50 kHz signal) of a school of yellowfin tuna associated with a TAO mooring in the equatorial EPO.

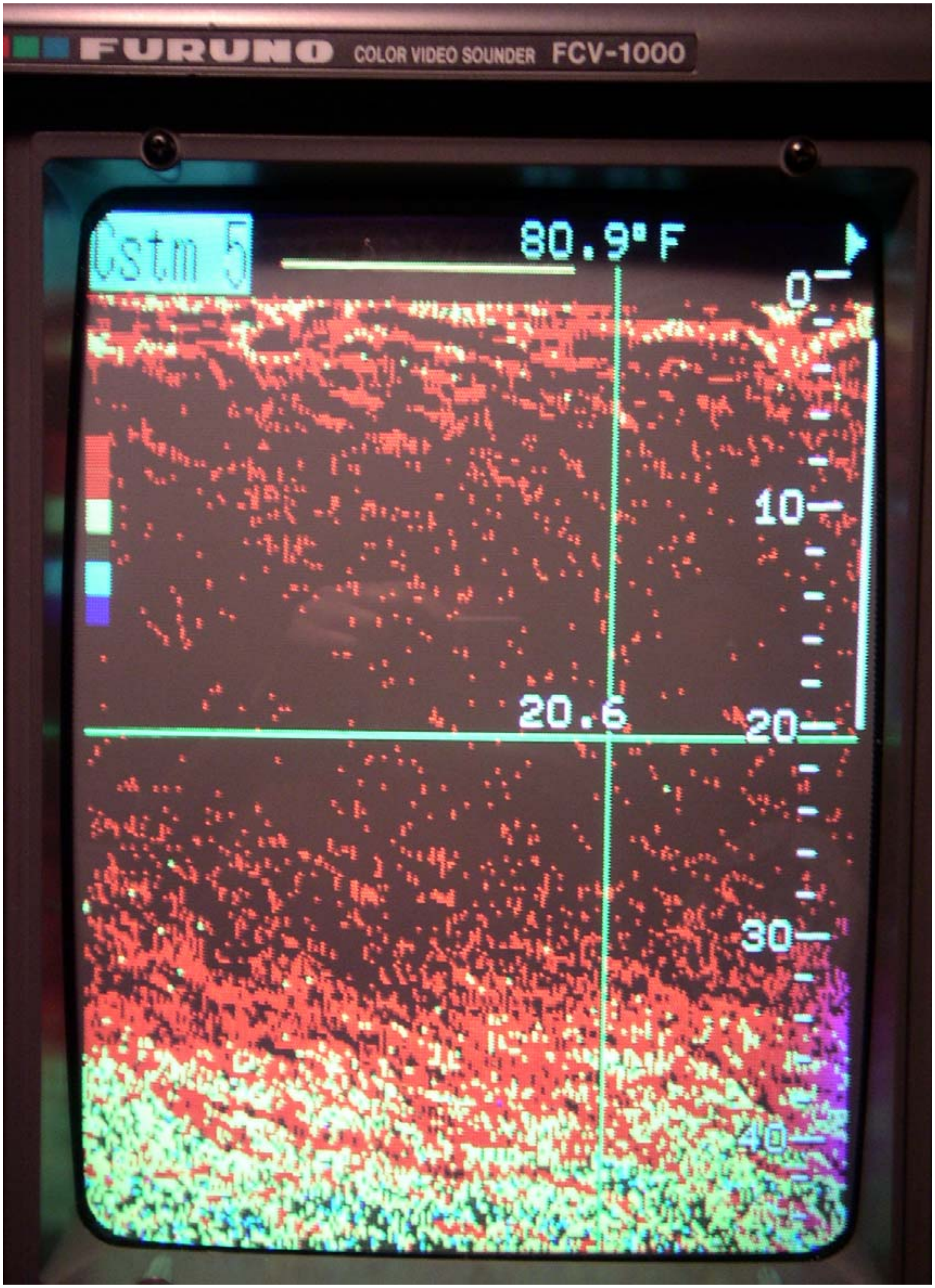

Figure 6. Echosounder image (50 kHz signal) of an aggregation of bigeye and skipjack tunas associated with the drifting vessel in the equatorial EPO.

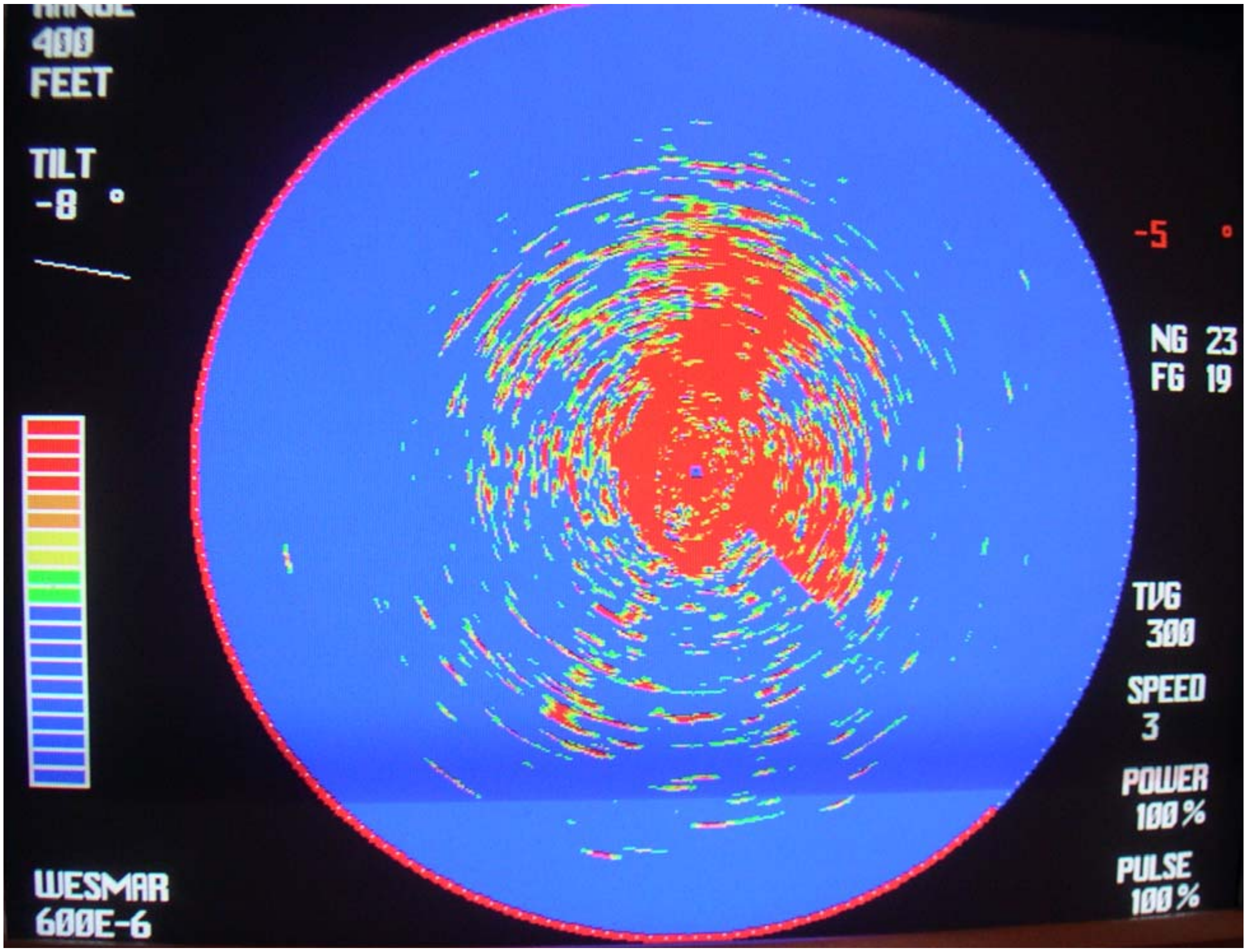

Figure 7. Sonar image of an estimated 50-mt school of yellowfin tuna associated with a TAO mooring in the equatorial EPO. This is the same school shown in Figure 5.