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Spatiotemporal distribution of fish schools around drifting fish aggregating devices

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ABSTRACT

Omnidirectional sonar surveys were conducted in close proximity to drifting fish aggregating devices (FADs) offshore Seychelles, western Indian Ocean, to investigate the number, size, and distribution of FAD-associated fish schools. Echotrace detection techniques applied on the raw multibeam data enabled the extraction of empirical statistics regarding inter-school distances, and allowed the visualization of the temporal evolution of the pelagic aggregation on a FAD-centered coordinate system. The sonar recordings revealed the concurrent existence of multiple fish schools that were spatially clustered and exhibited low permanence in size and structure. Schools were predominantly detected within a radius of 500 m from the FADs, although 15% of detections occurred between 500 to 1500 m from the floating devices. Fish school biomass detected with the sonar was aggregated into a few, large schools during daytime, and dispersed into a larger number of small schools during nighttime. Compared to daytime observations, nighttime schools maintained smaller inter-school distances and were located closer to the drifting FADs. The study demonstrates that horizontal sonars are powerful tools for studying the spatiotemproral distribution of large pelagic schools in the vicinity of drifting FADs.

1. Introduction

Several pelagic fish species show a behavioral tendency to associate with floating objects (Castro et al., 2002). The reasons why fish have evolved such a behavioral trait are still open to research, and several hypotheses have been proposed to explain the associative mechanisms (see review by Fréon and Dagorn, 2000). This phenomenon has been exploited by fishers to augment their catch, and, over the past few decades, artificial fish aggregating devices (FADs) have grown to be a key component of tropical tuna industrial fishing fleets (Bromhead et al., 2003; Dagorn et al., 2013; Davies et al., 2014). Primarily targeting schools of skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), and bigeye (*Thunnus obesus*) tuna, FAD-related purse seining is nowadays a technologically advanced fishery that yields over half of the worldwide recorded tuna landings (Fonteneau et al., 2013, 2000a). In the western Indian Ocean alone, over 10,000 drifting FADs are concurrently in deployment (IOTC, 2014), many of which are equipped with positioning systems and echosounders that remotely report on the presence of tuna schools (Lopez et al., 2014; Moreno et al., 2007a).

The large number of drifting FADs in the oceans has raised concerns regarding adverse effects on migratory patterns (Hallier and Gaertner, 2008; Ménard et al., 2000), school composition status (Fonteneau et al., 2000b), and growth (Jaquemet et al., 2011) or predation rates (Essington et al., 2002) of tuna species. Identifying and reducing FAD bycatch of juvenile bigeye and yellowfin tuna is also important, due to the negative impact of juvenile catches on maximum sustainable yield (Fonteneau et al., 2013). Moreover, some characteristics of the drifting FAD fishery are difficult to quantify accurately, given that number and type of FADs, fleet efficiency, search time and fishing strategies are all evolving with advances in adopted technology (Lopez et al., 2014; Moreno et al., 2007a). This hinders measurement of effective fishing effort and introduces uncertainties in the estimates of fishing pressure on tuna stocks (Fonteneau et al., 2013; Gaertner et al., 2001). Fisheries independent information on the temporal evolution and spatial organization of pelagic aggregations around drifting FADs can facilitate management of this fishing mode, and improve our understanding on the role of FADs as a component of the fishing effort (Dagorn et al., 2013). Mathematical models describing

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the formation and behavior of fish aggregations around FADs (e.g., Dagorn et al., 2000; Robert et al., 2014) or the effects of FADs on stock biomass and catch (Cabral et al., 2014) also require experimental data on schooling dynamics and FAD attraction distance.

Sampling drifting FADs, however, is challenging in terms of logistics, cost, and technology, considering that FADs are dispersed over broad, offshore areas (Hyrenbach et al., 2000). In situ data typically concern anchored FADs, while reports on drifting devices are comparatively scarce (see review by Dempster and Taquet, 2004). Taquet et al. (2007) and Gaertner et al. (2008) conducted underwater visual censuses on drifting FADs to characterize the associated multi-species fish communities and provide baselines of species diversity. Fish tagging and acoustic telemetry has also been used to describe species-specific FAD-associative behavior, depth distribution, residence times and diel movements of individual fish (Dagorn et al., 2007; Matsumoto et al., 2014; Schaefer and Fuller, 2013, 2002). Applying a star-shaped survey pattern, Moreno et al. (2007b) used vertical echosounders to characterize the structure of FAD-associated aggregations in the western Indian Ocean, and reported on the spatial distribution of acoustic backscatter relative to the distance from the floating device.

Currently, little information is available about the simultaneous behavior of FAD-associated schools and the temporal evolution of the pelagic aggregation associated with an offshore drifting FAD. Insight into these parameters has mostly been provided by personal interviews of fishing masters (Moreno et al., 2007a) or by tagging experiments involving the release of fish within multi-species aggregations and the subsequent monitoring of their behavior using telemetry data (Matsumoto et al., 2014; Schaefer and Fuller, 2013). Horizontal, omnidirectional multibeam sonars can be valuable tools in this context, due to their high sampling volume, increased detection range, and ability for concurrent insonification of multiple fish schools (Brehmer et al., 2006). In this study, we provide a quantitative description of the temporal evolution of fish aggregations around drifting FADs, using in situ multibeam sonar measurements acquired in the open ocean. We apply echotrace detection techniques on the raw multibeam data, and display the spatiotemporal distribution of associated pelagic schools on a FAD-centered coordinate system. We also report on descriptors of school size, inter-school distances, and number of fish schools per unit time versus their distance from the drifting FADs.

2. Materials and methods

2.1. Survey area

Acoustic surveys were conducted in close proximity to opportunistically-selected drifting FADs offshore Seychelles, western Indian Ocean, on board RV “Indian Ocean Explorer” (LOA 34 m). The surveys were part of the FADIO research project (Dagorn et al., 2006) and took place within the fishing grounds of tuna purse seine fleets that operate in the Seychelles equatorial area (Fig. 1).

2.2. Sonar recordings

The acoustic device used was the Simrad SP90 omnidirectional multibeam sonar (20–30 kHz). The SP90 is a long range horizontal sonar with an observation range of 150–3000 m (theoretical max: 8000 m) that is commonly used by purse seine fleets for the location of free-swimming or FAD-associated tuna schools (Itano, 2003). The sonar transducer provides a 360° fan-shaped volume for each ping transmission, automatically stabilized to compensate for pitch and roll. Beams can be tilted, and beam width is 11° horizontal, 9° vertical. The beam data array consists of 64 beams that are subsampled into 256 range bins, resulting to a 256 × 64 frame per ping. Next to

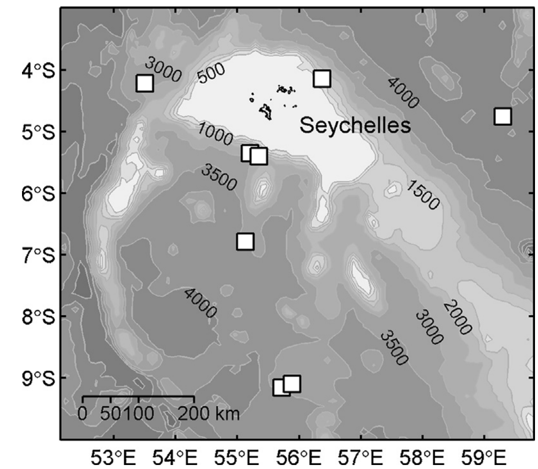

Fig. 1. Map of the study area (Seychelles, western Indian Ocean) with indicative positions of the drifting FADs sampled (white squares). Isobaths denote depth in meters.

Table 1
Metadata for the drifting FADs sampled. Location and time correspond to the beginning of each survey.

FAD	Latitude	Longitude	Date	Time[a]
1	5°21′S	55°12′E	25 January 2004	08:20 (d)
2[b]	5°24′S	55°21′E	25 January 2004	14:57 (d)
3[b]	4°13′S	53°40′E	30 January 2004	18:29 (n)
4	6°47′S	55°07′E	8 Febuary 2004	08:25 (d)
5	9°10′S	55°48′E	12 Febuary 2004	14:51 (d)
6	9°06′S	55°53′E	12 Febuary 2004	05:40 (n)
7	4°56′S	56°18′E	16 Febuary 2004	05:06 (n)
8	4°09′S	56°23′E	15 October 2004	02:19 (n)

[a] Local time (+4 h UTC); letter in parenthesis denotes daytime (d) or nighttime (n) status, according to local sunrise and sunset time.
[b] Vessel moored to the drifting FAD.

sonar display screenshots, the scientific output of the SP90 consists of one binary-formatted file per acoustic transmission. Each raw data file corresponds to a single ping, and encapsulates the beam data array, the insonification settings, as well as information from peripheral or navigational equipment interfaced with the sonar. A complete description of the SP90 and its data format is reported in Brehmer et al. (2007) and Trygonis et al. (2009). The brand-new transducer used in this study was installed on board RV “Indian Ocean Explorer” (hull unit model: SP91) and was not calibrated.

Upon reaching the indicative position of a drifting FAD (Table 1), the sonar was configured with a long observation range (1500–3000 m) to help locate the floating device and/or the FAD-associated pelagic aggregation; visual observations were simultaneously performed. During acoustic sampling, the vessel was positioned near the FAD at a distance of 50–300 m, and sonar data acquisition was conducted in drifting mode (Brehmer et al., 2007). Vessel repositioning or disengagement from drift mode was occasionally necessary depending on wind, ocean currents, sea state, and FAD visibility. In the case of particularly calm sea conditions, the vessel was moored to the FAD and drifted alongside the floating device. During the surveys, the sonar was operated with full transmission power at 26 kHz, with a time varied gain (TVG) function of 30 log R (where R is the range in meters). Sonar observation range was typically 900 or 1200 m, but occasionally varied from 150 to 1500 m depending on the FAD setting. The tilt angle of the sonar beams was set between −3° and −10° from horizontal, focusing the sampling on the upper 100 m depth layer. Actual sonar recording time for the data sets analyzed herein varied from