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Satellite-linked acoustic receivers to observe behavior of fish in remote areas

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Abstract – Automated acoustic receivers are now widely used by biologists to study the behavior of fish. However, currently available acoustic receivers require physical recovery of the units to download stored data. Such operation is often difficult in remote study areas like in the open ocean. We present a new satellite-linked acoustic receiver (Vemco VR3-Argos) that allows downloading data through a satellite uplink (Argos). The VR3-Argos can last up to one year, sending GPS positions and tag data at regular time intervals. We illustrate the advantages of this new technology with tagging data from 121 fish of seven species (yellowfin tuna, bigeye tuna, skipjack tuna, wahoo, dolphinfish, silky shark and oceanic triggerfish) caught and released around drifting fish aggregating devices (FADs) in the Western Indian Ocean, far from any land. In opposition with the classic acoustic receivers (Vemco VR2), the use of VR3-Argos allowed to collect data for several weeks after leaving the drifting FADs. Maximum residence times of 3 days for bigeye tuna, 7 days for skipjack, 8 days for wahoo, 10 days for silky shark and 15 days for yellowfin tuna, dolphinfish and oceanic triggerfish could be recorded. VR2 and VR3-Argos are equivalent in terms of quality of residence times data, however depth data obtained through satellites are aggregated in 8 classes for compression purposes, which leads to a loss of precision available with raw data. Future directions of this technology are discussed.

Key words: FAD / Acoustic receiver / Fish telemetry / Tuna / Pelagic fish

Résumé – Récepteurs acoustiques avec liaison satellite pour l'observation du comportement de poissons dans des zones éloignées. Les récepteurs acoustiques automatiques sont maintenant largement utilisés par les biologistes pour étudier le comportement des poissons. Cependant, les récepteurs acoustiques actuellement disponibles nécessitent leur récupération physique pour charger leurs données. Cette opération est souvent difficile dans des zones d'étude éloignées comme en haute mer. Nous présentons un nouveau récepteur acoustique avec liaison satellite (Vemco VR3-Argos) qui permet de récupérer les données à travers une liaison satellite (Argos). Le VR3-Argos peut fonctionner plus d'un an, envoyant des données GPS et des données de marques à intervalles réguliers. Nous illustrons les avantages de cette nouvelle technologie avec des données de marquage de 121 poissons de 7 espèces différentes (thon albacore, thon obèse, listao, thazard, coryphène, requin soyeux, baliste océanique) capturés et relâchés autour de dispositifs de concentration de poissons (DCP) dérivants dans l'Ouest de l'océan Indien, loin de toute terre. Au contraire des récepteurs acoustiques classiques (Vemco VR2), l'utilisation du VR3-Argos permet de récolter des données plusieurs semaines après avoir quitté les DCP. Des temps de résidence maximum de 3 jours pour le thon obèse, 7 jours pour le listao, 8 jours pour le thazard, 10 jours pour le requin soyeux, et 15 jours pour le thon albacore, la coryphène et le baliste océanique ont pu être enregistré. Les VR2 et VR3-Argos sont équivalents en termes de qualité de données de temps de résidence, mais les données de profondeur de nage des poissons, obtenues par liaison satellite, sont agrégées en 8 classes pour des soucis de compression, ce qui amène à une perte de précision disponible dans les données brutes. Les futurs développements de cette technologie sont discutés.

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1 Introduction

Over the last years, the use of automated acoustic receivers by marine or freshwater biologists to study fish behavior has significantly increased. This technology has been employed for many purposes: site fidelity (e.g. Heupel M.R. et al. 2004; Ohta and Kakuma 2005; Topping et al. 2006; Dagorn et al. 2007), movements (e.g. Lacroix et al. 2004; Skomal and Benz 2004; Topping et al. 2006; Vaudo and Lowe 2006; Dagorn et al. 2007), school fidelity (e.g. Klimley and Holloway 1999), mortality/survival (e.g. Heupel and Simpfendorfer 2002; Lacroix et al. 2005), habitat use (e.g. Simpfendorfer et al. 2002; Lacroix et al. 2004), and MPA related research (e.g. Lowe et al. 2003). The basic concept is that a set of receivers is deployed underwater in specific locations, either sitting on the bottom or attached to buoys floating on the surface. Animals are then equipped with coded acoustic transmitters (which can be instrumented with sensors providing data on depth or temperature), which emit acoustic signals (ID, and sensor data if available) at a rate set by the user (usually from tens of seconds to a few minutes). When the fish is within the detection range, the receiver stores the ID (and sensor value if available) in its memory. The low cost of these receivers, their ease of use, the long battery lives of tags and receivers (allowing for long-term studies) and the simplicity of data collected by the acoustic receivers (code number and time-date stamp) are the main reasons for their recent popularity. However, one limitation of this technology is the need to physically retrieve the receiver from the water to download stored data. In most cases where field sites are usually accessible this is completely feasible. However, when study sites are located in remote areas, this represents a major issue as retrieving the receivers often implies very high costs and time consumption, and sometimes, high risk of losing the equipment before accessing the data. This is the case for some studies dealing with large pelagic animals that inhabit remote areas, for instance studies on fish behavior around fish aggregating devices (FADs) which are floating objects that naturally attract and aggregate open ocean fish. They can be either natural (e.g. logs) or fabricated by fishers for the purpose of attracting fish (e.g. rafts, buoys). These artificial FADs can be anchored near the coasts or drifted by ocean currents. In the last 15 years, FADs have been a major tool for industrial tuna purse seine fisheries worldwide as more than 50% of the world catch of tropical tuna come from fishing under these floating objects (Fonteneau et al. 2000). Although understanding why fish associate to floating objects is an important fundamental question that should be addressed (see Fréon and Dagorn 1999; Castro et al. 2002 for reviews of hypotheses), studying how FADs impact the spatial and temporal behavior of tuna and other species represents one of the first research priorities to help stock assessment and fisheries management (see Marsac et al. 2000 for the ecological trap hypothesis). The residence time of fish around drifting FADs and their swimming depths represent key variables that must be measured to study the impact of FADs on fish behavior and to understand the effects of FADs on tuna vulnerability.

The use of automated acoustic receivers to investigate the behavior of tropical tuna around FADs has been possible when FADs were anchored near the coasts, and therefore easily accessible (Klimley and Holloway 1999; Ohta and Kakuma 2005; Dagorn et al. 2007). So far, no study has been done on drifting FADs, except Taquet (2004) on experimental drifting FADs and a recent work by Matsumoto et al. (2006), mainly due to the fact that drifting FADs employed by fishers are located hundreds of kilometers from any land. In these conditions, field studies are barely feasible and time limited. Therefore, there was a need for automated acoustic receivers that could transmit data through remote links such as satellites.

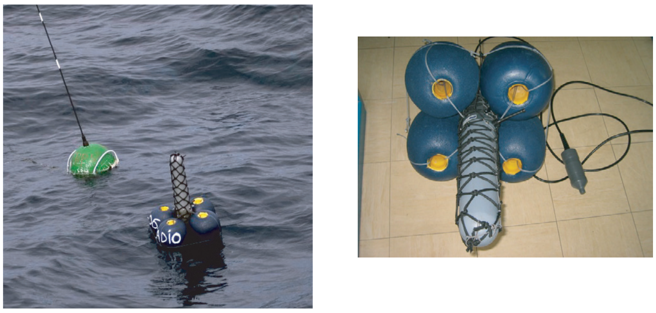

Fig. 1. The VR3-Argos receiver.

Herein we describe a satellite-linked acoustic receiver designed to remotely observe individual fish behavior. We illustrate the implementation of this new technology, its advantages and drawbacks as compared with previous technology, with the first data ever collected on the behavior of pelagic species that aggregate around drifting FADs.

2 Materials and methods

2.1 The satellite-linked acoustic receiver

The satellite-linked acoustic receiver (Fig. 1), called VR3-Argos (Vemco, Canada), inherits from the technology of the VR2 (Vemco, Canada), with the difference that in addition to the underwater (acoustic receiver) unit, there is a surface unit containing the satellite link. Due to this additional surface unit, it is larger than the VR2 (Surface unit: 11.5-cm diameter * 94.5-cm high, excluding cable – 7.52 kg – Hydrophone: 6.5-cm diameter * 18-cm high, excluding cable – 0.54 kg). It has a 9V alkaline battery, 54 Ah capacity (18D cells), a 8MB flash memory for data logging, and a RS232 service port that connects the unit to a PC for configuration and data transfer. The unit contains a GPS receiver and Argos antenna. On a regular use, the battery life is of the order of 12 months. Like the VR2, it detects and stores data from single frequency (usually 69 kHz) tags.

How does the VR3-Argos work? The VR3-Argos records all tag detections in internal flash memory. If the VR3-Argos is recovered, it is possible to read all the raw detection data through the service port. Over the course of a long deployment, the unit can collect up to 8 MB of raw data, which corresponds to more than 1 million tag detections. Of course, it is not possible to send all the raw data through Argos due to the limited data rate, so the VR3-Argos compresses it. A long sequence of detections of a given tag is reduced to a single data record, which indicates the times when that tag entered and exited the

Table 1. Acoustic tagging and residence times of fish around drifting FADs.

	Yellowfin tuna	Bigeye tuna	Skipjack tuna	Wahoo	Dolphinfish	Silky shark	Oceanic triggerfish
N	55	3	10	13	26	8	6
Max (days)	15.22	3.06	7.03	8.10	14.91	10.70	15.02
Mean (days)	1.04	1.43	0.91	1.57	3.96	5.33	12.49
SD (days)	2.23	1.46	2.17	2.73	3.86	3.16	6.08
Median (days)	0.24	1.03	0.13	0.50	2.92	5.83	14.94

detection range of the receiver, and the number of detections during that interval. For that purpose, the user must set the tag absent time, which defined when the user considers that an animal has left the area around the receiver. The tagged fish is then assumed to have remained within range during the entire time. There is no particular minimum for the absent time lower settings in general result in more Argos data. The user also sets the interval at which the unit sends compressed data to Argos (from 1 to several days).

The ARGOS-VR3 contains a GPS receiver, which is used to keep the on-board clock synchronized to UTC. This allows the ARGOS-VR3 to fully utilize each transmit day for maximum data throughput, without accidentally spanning two different days, which would incur an addition day of Argos service fee. The GPS also provides an accurate periodic position fix. These positions are time stamped, stored, and transmitted along with tag data so it is possible to track the movement of the platform over time.

For tags equipped with sensors (such as depth or temperature), data stored in a VR2 or in the flash memory of the VR3-Argos are collected each time the receiver detects the tag. In order to compress data for satellite transmissions, sensor data are classified into 8 classes, with values depending on the specifications of each tag (slope and intercept). Therefore, the user gets an histogram of the swimming depths of the tagged animal (one histogram per interval at which the unit sends compressed data to Argos, or one histogram per periods of presence around the receiver if the fish performed several visits to the receiver within this interval), without information on the time.

2.2 Tagging

Tagging operations were conducted during four cruises conducted from the Seychelles (Indian Ocean) in February 2004 and 2005, October 2004 and 2005. Tagging was done around commercial FADs deployed by fishers located between 2° and 9° South and 53° and 61° East. Fish were captured using trolling lines around the FADs. Different types of tags were used, depending on the size of the fish (V8, V13, and V16 tags), some of them being equipped with depth sensors. Acoustic tags were inserted in the peritoneal cavity of fish using standard implantation techniques (e.g., Schaefer and Fuller 2002).

Residence times and depth data collected by VR2s (previous technology) and VR3-Argos (new technology) are compared. For VR2 experiments, we usually tried to stay close to the studied FADs up to 1 or 2 days after tagging in order to collect data during these periods. Radio buoys were attached to the FADs in order to be able to locate them after they were abandoned. When possible, we came back to these FADs later to collect new data, but it was limited to a few days (maximum 7 days) as FADs were drifting far away. When we tested the VR3-Argos, we attached them to FADs, and left them soon after tagging. Their location could be obtained directly by the satellite link sending GPS data.

3 Results

A total of 121 fish from seven different species (yellowfin tuna *Thunnus albacares*, bigeye tuna *Thunnus obesus*, skipjack tuna *Katsuwonus pelamis*, dolphinfish *Coryphaena hippurus*, wahoo *Acanthocybium solandri*, silky shark *Carcharhinus faciformis* and oceanic triggerfish *Canthidermis macularus*) were tagged (Table 1).

3.1 Residence times at FADs

Figure 2 shows two examples of residence times of fish tagged around drifting FADs, measured from VR2s. In some cases no valuable data could be collected on residence time of fish at FADs (Fig. 2a – FAD 1129) as the observations were artificially stopped soon after release while in others some valuable data could be collected (Fig. 2b – FAD 543) when the vessel was able to come back to the FAD seven days after the first visit. But duration of observation was therefore limited to the ability to come back to the FAD a few days after tagging. These examples data show that not all dolphinfish left the FAD together at the same time and that some were still associated to the FAD when the FAD was abandoned.

Figure 3 illustrates the advantages of using VR3-Argos in such a context. For instance, two bigeye tuna, two silky sharks and two dolphinfish were tagged around FAD 1165, equipped with a VR3-Argos. The FAD was abandoned after 24 hours. This FAD drifted far away from the fishing grounds, and was observed during 4 months from Argos, before disappearing (when the FAD certainly sank). We could observe natural departures of all tagged fish from the FAD. The maximum residence time was obtained for a silky shark which stayed almost 12 days around the FAD. Similar to what was observed on FAD 543 (Fig. 2a), tagged fish did not leave the FAD at the same time.

The use of VR3-Argos permitted to measure the longest residence times. Yellowfin tuna, dolphinfish and triggerfish were observed staying around FADs up to 15 days, while bigeye tuna stayed a maximum of 3 days around a FAD, and skipjack tuna, wahoo and silky sharks up to 7-10 days (Table 1).

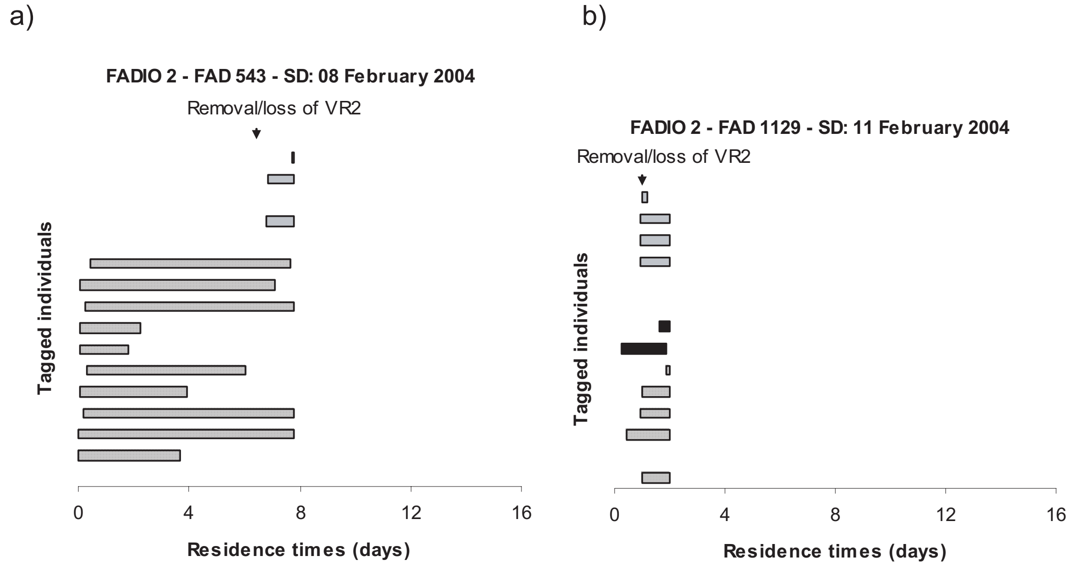

Fig. 2. Residence times of fish around two drifting FADs (FADs #1129 and 543) during cruise FADIO 2 measured with Vemco VR2. SD means Starting Date, which is date of first tagging and release. X-axis represents days and Y-axis represents individual fish: each bar corresponds to one fish (grey: yellowfin tuna, dashed: bigeye tuna, crosses: dolphinfish, black: silky shark).

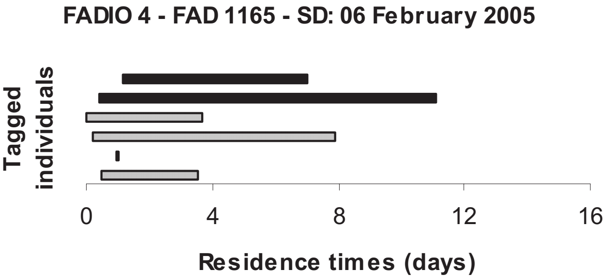

Fig. 3. Residence times of fish around a drifting FAD (FAD # 1165 during cruise FADIO 4) using Vemco VR3-Argos. X-axis represents days and Y-axis represents individual fish: each bar corresponds to one fish (grey: yellowfin tuna, dashed: bigeye tuna, crosses: dolphinfish, black: silky shark).

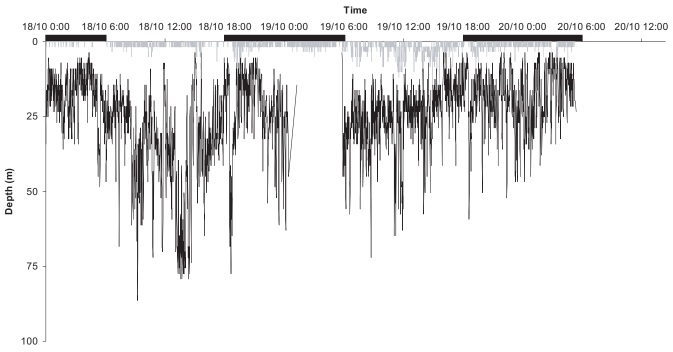

Fig. 4. Depth data of fish around a drifting FAD using a Vemco VR2 (grey line: 102-cm FL dolphinfish, black line: 47-cm FL yellowfin tuna).

3.2 Vertical behavior

Figure 4 shows depth data collected with a VR2 for fish tagged around one FAD (FAD 958). The detailed depth data of the dolphinfish (FL 102 cm) and the yellowfin tuna (FL 47 cm) clearly show a change occurring during daylight hours on day 19/10, as compared to day 18/10. Considering daylight hours (0600-1759), on 18/10, the dolphin fish was swimming at a mean depth of 4.0 m (sd 0.8), while it swam a little bit deeper on 19/10: mean depth of 5.3 m (sd 2.5). On the contrary, the yellowfin tuna swam shallower on 19/10 (mean 25.0 m, sd 9.9) than on 18/10 (mean 36.0 m, sd 16.9). Such details could not be obtained with the VR3-Argos transmissions since the present configuration aggregates in 8 bins, for each time period between two Argos transmissions (or each period of presence around the receiver if the fish performed several visits to the receiver within this interval) in order to compress data. Figure 5 (FAD 186) shows depth data of two yellowfin tuna, one wahoo and one bigeye tuna collected by Argos for 24 hours, the time period set to transmit data to Argos. If differences between individuals can be observed, it is not possible to know if this is due to some particular time periods (day/night for instance). In the same way, two tagged fish showing the same depth pattern could correspond to opposite diel behavior.

By aggregating VR2 depth data in classes, we could combine them with VR3-Argos data to provide the very first data on depth distribution of seven species around drifting FADs. Only fish for which a minimum of 100 depth data (number of hits) were collected were retained for this analysis. A clear vertical stratification appears (Fig. 6), when ranking fish from the shallower to the deeper species: dolphinfish, silky sharks, yellowfin tuna and then bigeye tuna. Most of the fish spent the majority of their time within the first 35 m below the surface, with the exception of bigeye tuna (but data for this species correspond to a single fish).

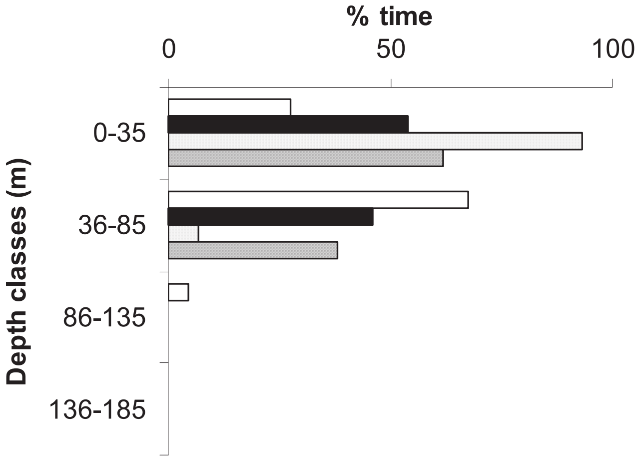

Fig. 5. Vertical distribution of fish around a drifting FAD using a Vemco VR3-Argos (WAH: wahoo, YFT: yellowfin tuna, BET: bigeye tuna).

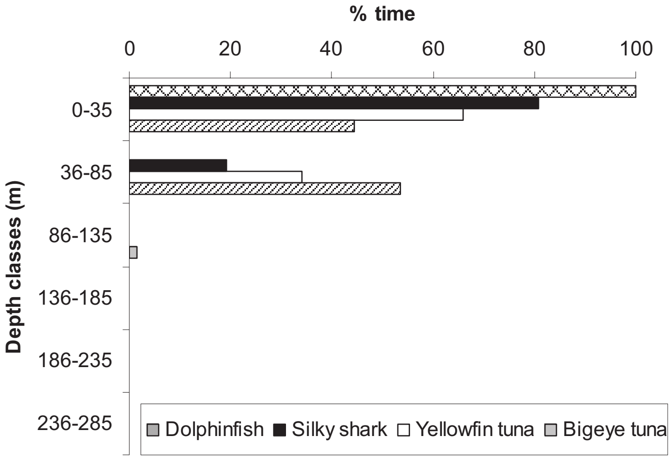

Fig. 6. Vertical distribution of four species (dolphinfish $n = 2$, $d = 7.5$, silky shark $n = 6$, $d = 6.3$, yellowfin tuna $n = 7$, $d = 7.3$, bigeye tuna $n = 1$, $d = 2.9$) associated to FADs (n: number of individuals, d: cumulative number of days of observations).

4 Discussion and conclusion

4.1 VR3-Argos as tools to observe behavior of fish in remote areas

From our tests on drifting FADs in the fishing grounds of tuna purse seiners in the Western Indian Ocean, we could show that acoustic tags and satellite-linked acoustic receivers are appropriate instruments to observe individual behavior of fish in remote areas such as open ocean waters. Thanks to the satellite uplink, it is possible to download data at regular intervals, so that tag data are never lost. There is no loss of information in terms of residence times data, although the date and time of each detection event are not transmitted. However, because depth data are aggregated in bins, the precision of data differs from regular acoustic receivers (e.g. VR2). Of course, all this information is stored by the VR3-Argos and is available if the unit is recovered.

Typical applications would concern remote areas where physical access to data is impractical or when loss of equipment is highly probable. For instance, thanks to that technology, it is now possible to conduct large-scale studies to better understand the behavior of fish around drifting FADs. For instance, the international project Ocean Tracking Network (www.oceantrackingnetwork.org) of the Census of Marine Life plans to track movements of marine animals through networks of acoustic receivers. VR3-Argos units will be used in remote areas difficult to access by scientists in order to observe the behavior of animals in remote areas.

4.2 Future directions

The VR3-Argos units described here were prototypes developed to determine the usefulness of this kind of product for this type of application. Technically, all objectives were met but, as discussed above, the little amount of data that can be transmitted to Argos introduce some limitations. Some of these can be easily overcome within the constraints imposed by the Argos system. For example, the parameters (number of bins and boundaries between them) of sensor histograms could be selectable so that the user could tailor them to the requirements of a particular study. Alternately, processing of sensor data could be carried out within the unit before transmission.

Ultimately, however, the one way, low data rate channel provided by Argos is too limiting for these applications and, therefore, the next version will replace Argos (likely with Iridium) and offer users ample bandwidth to transmit all detection data and the ability to query and reconfigure the unit remotely at a data cost comparable or less to current system.

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