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EXPLORING TECHNOLOGIES FOR REMOTE IDENTIFICATION OF FADS

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EXECUTIVE SUMMARY

Fishers have taken advantage of the aggregative behavior of tunas to fish around fish aggregating devices (FADs – man made floating objects) for decades, which rapidly became the predominant way to capture tuna in the purse-seine fishery of the eastern Pacific Ocean (EPO). FAD fishing presents several advantages when compared to other purse-seine fishing modes: it is very efficient, relatively easy to plan (i.e., FADs are deployed with electronic equipment to allow remote monitoring of their trajectories and the aggregated biomass), and has a lower proportion of null sets, among others. However, this form of fishing also presents several negative ecological impacts, such as proportionally greater amounts of some key bycatch species or juvenile tunas, impacts on the behavior and movements of the species, and damage on sensitive coastal habitats.

Quantification of these impacts requires efficient collection methods for high-quality data, including accurate tracking and monitoring methods for individual FADs throughout their lifetime. Currently, FADs are identified using satellite-buoy identifiers (see Resolution C-19-01), and accurately obtaining buoys'

alphanumeric serial numbers has traditionally been difficult for observers, and not possible with current electronic monitoring (EM) capabilities. However, this information is key to merge and connect different IATTC databases and support scientific research on FAD-related activities. Thus, an electronic system to automatically and remotely detect and identify individual FADs would improve the value and utility of all types of data. The IATTC staff, in collaboration with technological partners, tested these technologies under controlled conditions in the Achotines laboratory in Panama to assess their detection range and performance, with promising results. Different configurations of the LoRaWAN technology (Low Power Wide Area Networking communication protocol that functions on LoRa – a 'long range' physical proprietary radio communication technique), were tested to read signals from sensors to a receiver located at different distances (100-1250 meters). Results showed high detection probabilities for status (> 75%) at distances of 500-550 m and 675-750 m for hub configurations without and with antenna, respectively. For location data, high probabilities of detection (>75%) were expected at distances of 100-350 m and 450-500 m for a hub without and with antenna, respectively. Similarly, 50% of detection rates for status were found at distances of 600-650 m and 775-850 m for the hub without and with antenna, respectively, while for location data, distances were 300-480 m and 575-650 m for a hub without and with antenna, respectively. Therefore, overall status signal could be detected at higher distances more reliably, compared to location data (i.e., 500-750 m versus 100-500 m). Moreover, the hub shows higher detection capabilities when an antenna is added for both status and location data, generally increasing detection capabilities about 150-300 meters. These results suggest that this technology could be feasible to automatically and remotely identify satellite buoys by vessels approaching FADs they have interacted with. The IATTC staff's conclusions, future actions, challenges and lessons learnt during this initiative and from positively engaging with the buoy manufacturers are also presented.

1. BACKGROUND

Fishers have taken advantage of the aggregative behavior of tunas to fish around floating objects for decades (Watters 1999; Hall and Román 2013). In the 1980s, fish-aggregating devices (FADs), man-made objects constructed to attract tunas, started to be used in the eastern Pacific Ocean (EPO). Their use has significantly expanded ever since, and FAD fishing rapidly became the predominant way to capture tuna in the purse-seine fishery of the EPO (Lennert-Cody and Hall 1999; IATTC 2019; Hall and Román 2013). FAD fishing presents significant advantages when compared to other fishing modes: is very efficient, relatively easy to plan (i.e. FADs are deployed with satellite buoys to allow remote monitoring of the trajectory and the aggregated biomass) and have lower proportion of null sets, among others (Lopez et al*.* 2014; Lopez et al*.* 2016; Cillari et al*.* 2018). However, this form of fishing also presents several negative ecological impacts. For example, FADs have higher proportion of some key bycatch species, they significantly impact the catch of juvenile tuna (i.e. bigeye and yellowfin), contribute to the alteration of normal movements and behavior of species, including school dynamics, and, if lost or abandoned, may cause impacts in sensitive coastal habitats and contribute to the accumulation of marine debris in the ocean (Maufroy et al*.* 2015; Sinopoli et al. 2020).

However, the quantification of these impacts requires efficient collection methods for high-quality data, including accurate tracking and monitoring methods for individual FADs throughout their lifetime. Currently, FADs are identified using satellite-buoy identifiers (see Resolution C-19-01), and appropriately obtaining buoys' alphanumeric serial numbers has traditionally been difficult for observers, and not possible with current electronic monitoring (EM) capabilities (Legorburu et al. 2018). However, this information is key to merge and connect different IATTC databases and support scientific advance. The staff, the FAD Working Group and the Scientific Advisory Committee have discussed and reiterated the importance to access FAD/satellite buoy identifiers and repeatedly recommended to explore efficient ways to mark and track FADs (e.g. FAD-03-INF-A, SAC-11-INF-M).

EM can generate certain data on FADs, such as deployments and removals, but only those types of data that can be collected through cameras and other sensors. Observers collect several type of data on FADs but their access to information often depends on the fishing crew, such as the FAD or buoy identifier, with associated risks as regards to data quality and accessibility. Without the ability to identify individual FADs across trips, the utility of the observer data related to FADs is only of limited value because no inference can be made about their life story records and activities. Therefore, an electronic system that automatically and remotely detect and identify FADs would improve the value and utility of all data types. Several technologies for remote object identification are available on the market, but none have been explored in detail yet by the scientific community, buoy manufacturers, or EM service providers. These technologies should ideally be tested under controlled conditions to assess performance capabilities and better understand their advantages and disadvantages, and to help transitioning towards automated key data collection by both observers and EM systems. The IATTC's Achotines laboratory in Panama is an ideal location for such experiments under controlled conditions, with equipment and facilities for indoor and outdoor testing. The laboratory includes tanks, vessels, skilled staff, access to its own bay, and easy access to the open sea.

The IATTC staff is currently concluding an initial series of EU-funded experiments to assess EM capabilities for the purse-seine and longline fleets operating in the EPO, and is collaborating in other EM pilots in the region (e.g., Costa Rica's mediana and avanzada escala fleet). Similarly, the staff has been investigating FAD fishery impacts in recent years (e.g. FAD-05-INF-A, FAD-07-01, FAD-08-01) using both traditional (e.g. observers' data) and new types of data (e.g. active FADs/buoy data provided under Resolution [C-17-02 and C-21-04]). Initiatives like these have improved staff's knowledge on EM system capabilities and satellite-buoys and strengthened relationships with key EM service providers and buoy manufacturers. A positive relationship and connection with leaders in the field, as well as improved knowledge on EM systems and other technological devices, are key to conduct the project successfully. Any fruitful exploration and implementation of technologies should be supported by technological partners (i.e., buoy manufacturers and EM providers), as they will potentially apply the results of the project in their products in the short-medium term. As mentioned above, such a technological improvement would significantly improve data collection and quality and support scientific advance and subsequently, the development of comprehensive management recommendations for target and non-target species in the EPO. In this document, the performance capabilities and suitability of different technologies and configurations to identify FADs remotely and electronically are described, along with the details on the methodology and results of the trials and ideas for future work and implementation of the technologies in EPO tuna fisheries.

2. OBJECTIVE

The objective of this study is to evaluate the suitability of different technologies and configurations to remotely and electronically identify FADs (i.e., satellite-linked echo-sounder buoys) in real conditions. Discussions with technological partners and other relevant stakeholders on the suitability of these technologies to be incorporated into electronic monitoring systems, as well as by other devices (i.e., satellite buoys, hand-held sensors for observers), and to improve data collection and traceability of FADs are also be central to this work.

3. METHODS

3.1. Assessment of candidate technologies

Bibliographic research (e.g., Mrag, 2017, Benelli and Pozzebon, 2013, FAO, 2018) and consultation with experts in the field were conducted to collect information on the most suitable technologies to be tested in the experiment. The following considerations were taken into account when assessing different technological options:

i. it should perform efficiently under any environmental conditions (e.g., good versus rough sea conditions, heavy rain) and at a reasonable distance (i.e., ideally at a distance where the vessel has detected the presence of the FAD or is ready to conduct an activity with it).
ii. it should not be used for remote/active searching and detection of buoys (i.e., does not increase vessels' buoy searching abilities);
iii. it should be affordable and not incur significant increases in the cost of production of satellite-buoys, EM sensors or observers' equipment;
iv. it should be capable of transmitting actively (e.g., continuously) or passively (e.g., when called, intermittently), depending on the battery needs and communication system used;
v. it should be compatible with external electrical power supply (e.g., solar panels or the batteries of the satellite-buoy) and not have a high energy requirement;
vi. it should be of small size (i.e., does not incur significant changes in current satellite-buoy and EM equipment designs);
vii. it should not interfere with other equipment of the vessel (i.e., does not create interferences with onboard equipment or vessels' structures);
viii. it should be tamperproof (i.e., made so that it cannot be interfered with or changed) and not trackable (i.e., protects and guarantees privacy and restricts access to fishing companies' commercial data);
ix. it should be portable and easy to deploy (i.e., for the cases in which helicopters/speedboats are used to access the FAD); and
x. it should be able to be mass produced.

The preliminary assessment of candidate technologies was discussed over several meetings involving IATTC scientific staff and the technological partners of the project, including engineers and experts from Satlink and DOS. At these meetings, the potential capabilities and performance of these technologies were discussed based on the literature review and the expertise of team, as well as the criteria mentioned above, with the goal of preselecting the most suitable technology or configurations for use in at-sea trials.

As a result, the only technology selected that could fulfill all the requirements at this stage was the LoRaWAN (Low Power Wide Area Networking communication protocol that functions on LoRa – a 'long range' physical proprietary radio communication technique). The LoRa technology has the following advantages, among others, it is configurable at different intensities and gains, it can transmit both actively or passively and is very low battery intensive (i.e., batteries can last 10 years). It is often composed by two elements: 1) a LoRaWAN gateway or receptor, which refers to the physical box or encasement housing the hardware/receptor (hereafter, hub) and application software that performs essential tasks to connect internet devices to the cloud or other communication systems, and 2) a LoRaWAN sensor device (the transmitter, hereafter called sensor), which sends radio frequency signals with sensed information (e.g., the FAD buoy ID, the location) to be picked up by any gateway/receptor/hub in range, which can pass this information onto the cloud and ultimately to a reading computer program or an app (Figure 1). Two types of hubs (Milesight UG67 and Kerklink – both with similar characteristics and configured the same way for the trials) and sensors (Abeeway Compact and the Mokosmart LW001 GPS trackers) were explored in the study (Figure 2).

Before shipping the equipment for at sea testing, the materials were manipulated and configured in the Satlink headquarters in Madrid to meet the project goals. Two gateways and two sensors were prepared, along with four satellite-buoys for at sea experiments. Two sensors were configured to communicate automatically every 5 and 10 minutes while the other two were configured to communicate when requested only. The detection capability of the gateway could be extended with the addition of an antenna; therefore, additional antennas were also made available for the trials.

3.2. Trials with the selected technology in at-sea conditions

Two different trials were carried out in different locations. The first one conducted in a estuary of Galicia, Spain, in January 2024 was designed as an exploratory trial to have a rough idea of the technology's performance capabilities at sea and to ensure the equipment functioned as expected before shipping it to Panama. The main at-sea trial was conducted in the IATTC Achotines laboratory in Panama in March 2024.

3.2.1. Exploratory Galicia trials:

Two types of sensors were used, along with a Gateway Hub (Milesight UG67) with and without antenna. A pair of both types of sensors were placed over two satellite buoys and anchored in a fixed location. The sensors sent the status and location transmission signals to the hub and readings (successful or unsuccessful) were recorded using different distances and configurations (antenna or not-antenna) between the hub and the sensors (800, 1,600, 1,900, 2,400 and 3,200 m).

An artisanal vessel of about 10 m LOA was used for the trials and conditions were clear and sunny.

3.2.2. Achotines trials:

A Kerlink hub with and without antenna and two identical sensors "Mokosmart LW001" GPS Trackers were used for the trials. The sensors were mounted on satellite buoys and anchored together next to the cage located at about 650 m off the Achotines pier. The sensors were configured to send information on the status and location (GPS transmission signals) to the hub (Figure 3). Because with the current configuration for the at sea trials the hub uses cloud-based systems to execute commands that require communication between the sensor and the hub, a regular cell phone modem was used to provide internet access to the system, and a power inverter device provided 110V AC current to the equipment from a DC-12V battery. The status and GPS readings were requested and obtained in situ through the IQMenic computer/smartphone application.

Status and GPS readings from sensors (successful or unsuccessful) were recorded using different distances between the hub and the sensors (100, 250, 375, 500, 750, 1,000, and 1,250 m; see Figure 4) with different configurations of antenna or no-antenna. Distances between the hub (i.e., vessel) and the sensors were measured by using the Gaia GPS smartphone application (https://www.gaiagps.com). The trials were first executed with a hub with no antenna, starting at 100 m and ending at 750 m. The trials with hub with antenna started at 500 m, as positive readings were assumed for ranges below 500 m.

A 8 meters LOA panga was used for the trials, and the hub was set 2 meters above the water level. The weather conditions were mild, with winds below 12 knots and a Beaufort sea states between 0 and 2, with occasional levels of 3.

3.3. Data analysis

The communication probabilities as a function of distance between the sensors and the hub were modelled using a general linear logistical regression with a binomial family distribution (McCullagh and Nelder, 1989). Individual models were established for different information type provided by the sensors (i.e., status, location), as well as different configuration of hub (i.e., antenna versus no-antenna). Model diagnostics were checked, and performance metrics estimated. Similarly, statistical comparisons were conducted between models for all combinations of hub configurations and type of data provided by the sensors.

All statistical analysis and visualizations were conducted using the statistical freeware R (R Core Team 2021), as well as the R packages "ggplot2" (Wickham, 2016) and "lmtest" (v0.9-40; Zeileis & Hothorn, 2002).

4. RESULTS

In the exploratory trials conducted in the estuary of Galicia, no location data was received at 800 m when using the hub without antenna. Conversely, location data was positively received up to around 1,900 m with a hub with antenna. However, the location data was not received by the hub with antenna at 3,200 m, and mixed results were obtained at 2,400 m (Table 1).

During the 3-day 'real condition' trials in the Achotines lab, a total of 84 data requests were made to sensor no. 1 (39 for the hub with antenna and 45 without antenna); of these, 18 status readings were successful with the hub with the antenna and 35 without antenna, and 8 GPS readings were successful with the hub with the antenna and 28 without antenna. A total of 85 data requests were made to sensor no. 2 (39 for the hub with antenna and 46 without antenna); of these, 22 status readings were successful with the hub with the antenna and 36 without, and 12 GPS readings were successful with the hub with the antenna and 19 without antenna (Table 2).

The modeling of the detection rates for the sensors status and GPS readings for the hub with or without antenna (Figure 5) showed that high detection probabilities for status (> 75%) are expected at distances of 500-550 m and 675-750 m for hub configurations without and with antenna, respectively. For location data, high probabilities of detection (>75%) were expected at distances of 100-350 m and 450-500 m for a hub without and with antenna, respectively. Similarly, 50% of detection rates for status are found at distances of 600-650 m and 775-850 m for the hub without and with antenna, respectively, while for location data, distances were 300-480 m and 575-650 m for a hub without and with antenna, respectively. Therefore, overall status signal could be detected at higher distances more reliably, compared to location data (i.e., 500-750 m versus 100-500 m). Similarly, the hub shows higher detection capabilities when an antenna is added for both status and location data, generally increasing detection capabilities about 150-300 meters.

In this sense, comparisons between models using Likelihood Ratio Test (LRT) showed that adding an antenna to the hub significantly increases detection range (p-values < 2.2e-16) for sensors readings, both status and GPS location information, the former being detected significantly at greater distances than the later (p-values < 2.2e-16) (Table 3).

5. DISCUSSION

Several delays, directly and indirectly linked to the COVID-19 pandemic, hindered project progress in initial stages. Supply chain disruptions, shortages of electronic components and custom delays impeded the acquisition and shipping of the required technologies in the due time, which persisted through much of 2021 and 2022. The equipment was finally acquired and received in 2023, and following the development of a manual and protocol, as well as an exploratory trial in Spain, the equipment was shipped to Achotines in early 2024 for immediate initiation of the trials.

The trials conducted in Achotines provided significant insights into evaluating the LoRaWAN technology's effectiveness for transmitting radio frequency signals between a transmitter (i.e., sensor) and a receptor (i.e., hub) within a specific range, including potential communication between satellite buoys to nearby vessels, enabling data recording on various electronic devices, including EM equipment or other technologies available at the vessel bridge. Radio-frequency technology is cost-effective, safe, and feasible to be seamlessly integrated with EM or other vessel electronic systems. Since its inception over three decades ago, it has been poised to dominate the market of auto identification systems (Xiao et al., 2006).

Recently, this technology has been intended to replace the WiFi technology in sensors connected to an electronic crane scale for catch weights during a pilot study on transshipment vessels (Heberer and Itano, 2023). The use of LoRaWAN is expected to increase the bandwidth and provide more consistent communication between devices at greater range of distances, and less affected by vessel structures compared to the WiFi systems previously tested in the study.

Technological equipment, although produced following manufacturing standards, can show slight differences in performance between individual devices. Therefore, conducting experiments with duplicated devices improves the understanding of technologies' performance variability, as well as provides a general sense of its capabilities in real conditions. The models established for each sensor, type of information and distance were generally significant (see Figure 5). Notably, only sensor 2's GPS location readings without the antenna showed less consistency in the model (i.e., r-squared = 0.23). However, sensor 1's GPS readings fit well with the model. This disparity in results might be attributed to manufacturing or performing variability and malfunctions. For instance, while sensor 2 initially provided 44% successful GPS readings to the antenna-less hub at a 100 m range, it later achieved 50% success rates at a 500 m range under similar at-sea conditions. This device specific variability needs to be considered in the future when implementing this technology at large scale to make sure the technology is reliable and consistent in space and time and will meet potential data collection requirements established by RFMOs.

Results showed significant differences in the communication distances between sensors and different hub configurations (hub with antenna versus without it), and for the different type of information provided by the sensors (i.e., status and the GPS location information). Hubs with antenna are able to successfully communicate with sensors at greater distances, compared to hubs without it. Similarly, sensors are capable of transmitting status information to greater distances, compared to GPS location data.

In general, results suggested high probabilities (>75%) of positive communication between transmitters location data (i.e., sensors) and receptors (i.e., hub) with antenna within a range up to 450-500 m (100-350m for a hub with no antenna), suggesting that this technology could be a reliable option for identifying satellite buoys from vessels approaching FADs at short-medium distances. These results are promising as ideally, the communication between devices should happen at a distance where the vessel has detected the presence of the FAD or is ready to conduct an activity with it. Most of the times, when a vessel has interacted with a FAD is because i) the vessels is monitoring the trajectory of the FAD and knows its location or ii) opportunistically runs into them when cruising or looking for tuna schools or FADs at sea. In most of the cases, when identifying and checking a FAD before setting on it, the vessels approaches the FAD at distances shorter than 500 m (often less than 100 m), where the associated target species biomass is explored. Therefore, technologies that go beyond 500 m may not be necessary, or even advisable, and will not incentivize active searching of FADs not monitored by the vessel. In occasions, the vessel may send a speedboat or a helicopter to do a first exploration of the FAD and its associated biomass. Therefore, it is important to consider how this technology could be implemented in commercial settings, not only in the vessel's bridge or the EM equipment, but on other type of vehicles used by the fleet to explore FADs, as it could be the case of speedboats or helicopters. However, this should be considered with caution as implementing such technologies in helicopters may cause interferences with the equipment onboard the helicopter and thus, create safety issues. Vessels' and other vehicles structures may impact the communication capabilities of the technologies. Since trials were conducted with small non-fishing vessels with simple deck layouts and few physical barriers, the structural characteristics of industrial fishing vessels should also need to be considered for future experiments and adaptation of current results for commercial purposes.

The results obtained in the trials conducted in Achotines are promising, but only represent technologies capabilities under favorable sea conditions. The communication capabilities of technologies are known to decrease under rough sea conditions (Benneli and Pozzabon, 2013). Heavy rain, strong winds, etc. can impact the radio signal intensity and range and reduce the effective distance of communication between the transmitter and the receiver. Unfortunately, 2023-2024 has been an El Nino year, drier and hotter than usual, and as of late-April and early-May, there has not been consistent rain and bad weather in Achotines. Future experiments should ideally test the performance capabilities of the technology under unfavorable conditions at sea to better understand the full performance spectrum of the technology.

Looking into the future, a significant reduction in the dependency on internet connectivity can be foreseen. Initially, the necessity of internet connectivity was justified in a pilot project because the managing software accessed data stored on cloud servers. However, with future technological developments, there's the potential for the information to be stored locally on devices. This would enable the transmission of data without the need for an active internet connection. Another option would be to receive and visualize the information exclusively locally, eliminating the need for remote access to external servers. This approach would offer greater autonomy and flexibility in managing data to be transmitted, reducing reliance on external connectivity infrastructure.

The active engagement, leadership and feedback from buoy manufacturers were pivotal for the project's success. Therefore, ensuring a clear understanding of objectives, methodology, and project dynamics, as well as providing timely technical support during the technological development phase and at-sea trials, remains essential. In addition, technological partners play a critical role in considering the next steps and action plan to follow for the commercial deployment of this technology in purse-seine fisheries, which, if implemented, could inform comprehensive data collection recommendations at regional level. In that sense, any implementation plan should consider a reasonable timeline, not only the development of international manufacturing standards but also to incorporate potential data collection requirements and needs from RFMOs.

6. CONCLUSION AND RECOMMENDATION

The IATTC staff collaborated closely with technological partners to improve purse-seine fishery data collection methods. With the integration of EM and other onboard electronic devices, including technologies that allow remote and automatic communication, collecting fishing activity data could become less challenging. Conducting research that improves scientific data quality, resolution and availability is key for developing science-based management recommendations for the EPO tuna fisheries.

Efficient marking and tracking of FADs via FAD/satellite buoy identifiers and appropriate data collection methods have been consistently recommended by the IATTC staff, the FAD Working Group, and the Scientific Advisory Committee (e.g., FAD-03-INF-A, SAC-11-INF-M). The LoRaWAN technology, as tested in this study, can reliably transmit information between a transmitter and a receiver at short-medium distances (500 m) (e.g., satellite-buoy identification to vessels approaching the FAD), potentially addressing issues related to data collection of observers, both human and electronic, and satellite-buoy serial numbers. Moreover, this promising technology could be explored to be used in various fisheries data collection needs, such as using electronic scales to record tuna catches remotely and automatically in purse seiners, transshipments, or other systems, enhancing data accuracy and reliability.

With all these elements into consideration, the IATTC staff makes the following recommendations:

- Consider the LoRaWAN technology for the development of sensors transmitting the FAD buoys' serial number to receivers located at distances no greater than 500 m.
- Consider exploring the LoRaWAN technology for applications with other fishing activities that require remote and automatic data collection (e.g., electronic scales for weight estimates).

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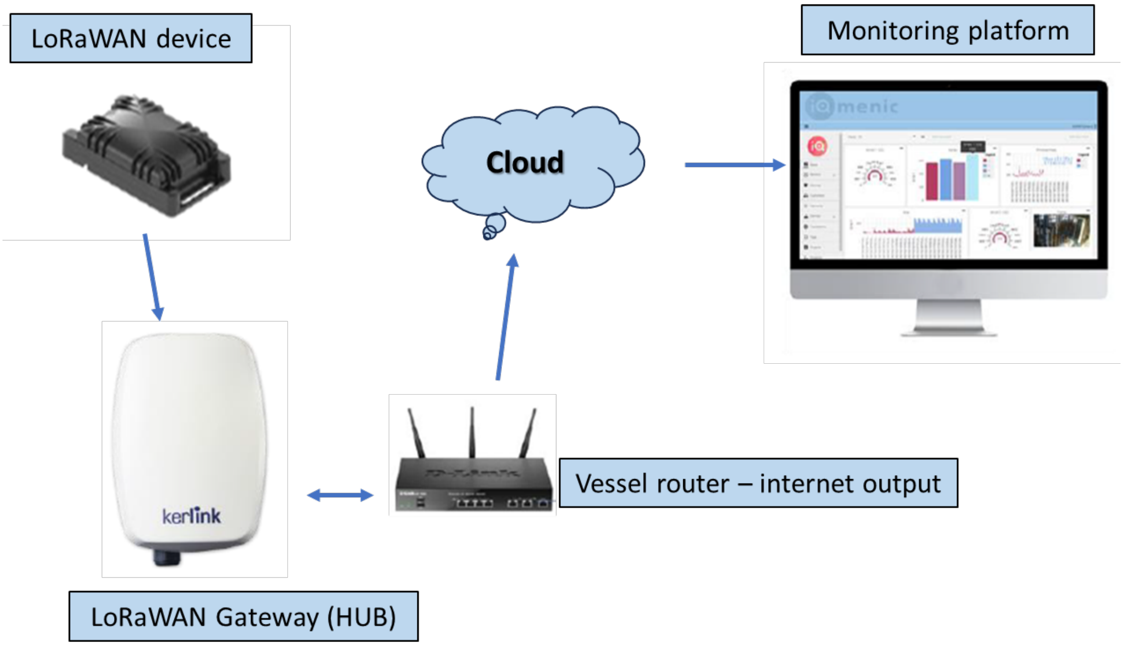

FIGURE 1. Architecture of the LoRaWAN technology.

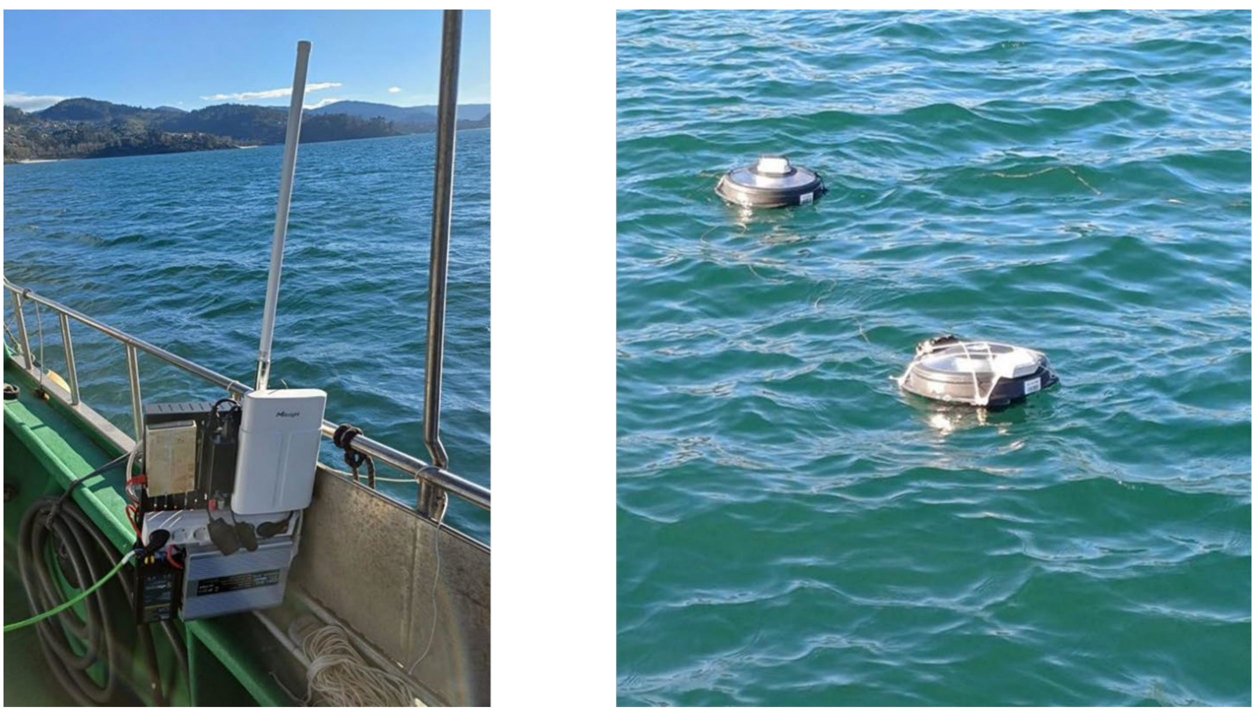

FIGURE 2. Equipment setup for the trials made in Galicia-Spain, with the HUB with antenna (left panel) and the sensors over the satellite buoys (right panel).

FIGURE 3. Equipment setup for the trials made in the Achotines lab, with the electrical and internet set up (left panel), hub (i.e., receiver) with the antenna (central panel) and the sensors (i.e., trackers, transmitters) on the satellite buoys (right panel).

FIGURE 4. Tracks of the trials at the Achotines lab. Added, for reference, the distances tested during the at sea trials.

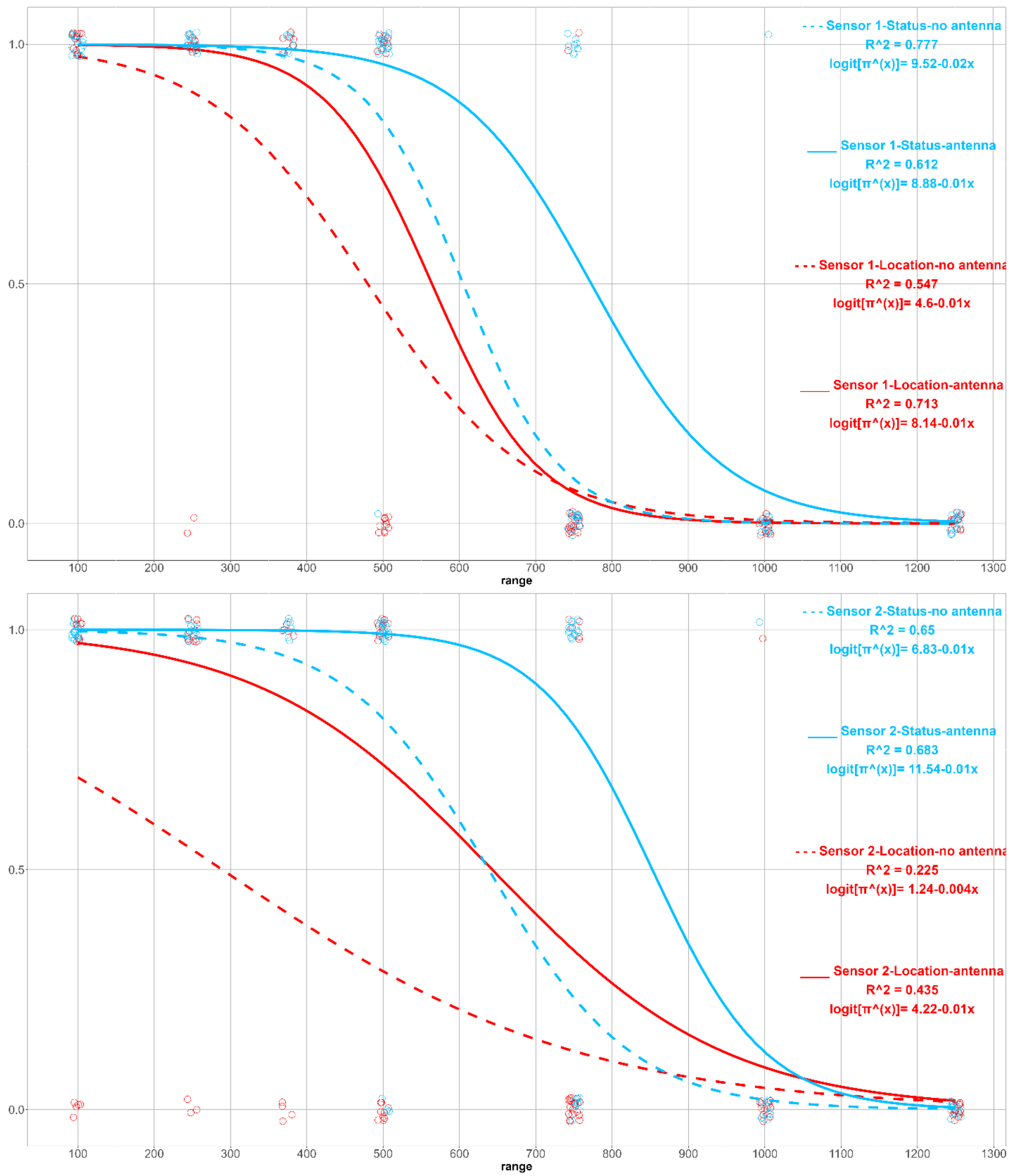

FIGURE 5. Statistical results of the status and GPS location communication between the sensors and hub with and without antenna during the trials at the Achotines lab (sensor 1, upper panel; sensor 2, lower panel).

TABLE 1. Summary of the data collected during the trials in Galicia-Spain.

HUB antenna	Range (m)	Date	Sensor Call time	Sensor GPS reading successes	Sensor GPS time
No	800	1/19/2024	16:01	0	
No	800	1/19/2024	16:21	0	
Yes	800	1/19/2024	16:31	1	16:41
Yes	1600	1/19/2024	16:41	1	16:51
Yes	1900	1/19/2024	16:31	1	16:41
Yes	2400	1/19/2024	17:11	0	
Yes	2400	1/19/2024	17:21	1	17:31
Yes	3200	1/19/2024	16:51	0	
Yes	3200	1/19/2024	17:01	0	

TABLE 2. Summary of the data collected during the trials in the Achotines lab.

Range (m)	HUB antenna	Sensor 1 Calls	Sensor 1 status reading successes	Sensor 1 GPS reading successes	Sensor 2 Calls	Sensor 2 status reading successes	Sensor 2 GPS reading successes
100	No	10	10	10	10	10	5
250	No	8	8	6	8	8	5
375	No	8	8	8	8	8	4
500	No	10	8	3	10	7	5
500	Yes	10	10	7	10	10	6
750	No	9	1	1	10	3	0
750	Yes	14	7	1	14	11	5
1000	Yes	7	1	0	7	1	1
1250	Yes	8	0	0	8	0	0

TABLE 3. Diagnostics of model comparisons.

Sensor	Antenna	Reading	#Df	Log-Lik	Df	Chisq	Pr(>Chisq)
1	Yes	Location	2	-9.93			
	No		2	-17.88	0	15.89	< 2.2e-16 ***
2	Yes	Location	2	-20.35			
	No		2	-28.41	0	16.12	< 2.2e-16 ***
1	Yes	Status	2	-13.43			
	No		2	-8.47	0	9.91	< 2.2e-16 ***
2	Yes	Status	2	-10.3			
	No		2	-13.47	0	6.35	< 2.2e-16 ***
1	Yes	Status	2	-13.43			
		Location	2	-9.93	0	6.99	< 2.2e-16 ***
1	No	Status	2	-8.47			
		Location	2	-17.88	0	18.81	< 2.2e-16 ***
2	Yes	Status	2	-10.3			
		Location	2	-20.35	0	20.11	< 2.2e-16 ***
2	No	Status	2	-13.47			
		Location	2	-28.41	0	29.88	< 2.2e-16 ***