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# PILOT STUDY OF AN ELECTRONIC MONITORING SYSTEM ON A TROPICAL TUNA PURSE SEINE VESSEL IN THE ATLANTIC OCEAN

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*SUMMARY*

*The data collected by onboard observers during tropical tuna purse seine fishing operations are commonly used for management purposes. For some types of data, such as discards, observer programs can be the most reliable, and sometimes the only source of information available for management of the fishery. Electronic monitoring (EM) systems are being used in some fisheries as an alternative, or a complement to human observers. The overall objective of this study was to test the use of EM on a tropical tuna purse seiner in the Atlantic Ocean. This objective was split into two main goals: (1) make comparisons between data collected using EM and observers to determine if EM can reliably document fishing (effort, set-type, catch, and by-catch) on the tuna purse seine fishery, and (2) to evaluate the operational aspects of using EM to monitor the tuna purse seine fishery. To achieve these objectives, EM was deployed on the Playa de Bakio, based out of Abidjan, Ivory Coast for three commercial fishing trips between November 28, 2011 and March 27, 2012. During these three trips, 61 sets were monitored using EM systems and by observers. Set-type was correctly identified using EM for 60 of the 61 sets. Tuna catch per set was not significantly different between EM and observer data sets, however, for larger volume sets, EM underestimated tuna catch. Catch composition matched well between EM and observers. However, in sets that were mainly comprised of skipjack, yellowfin tuna were underestimated. Overall, by-catch species were underestimated by EM, but large bodied species such as billfishes were well documented. Based on this research, EM is a viable tool for monitoring effort, set-type, tuna catch, and some types of by-catch within the tropical tuna purse seine fishery. Operational aspects that need to be considered for an EM program to be implemented include defining monitoring objectives, standardising installation and onboard catch handling methodology, and developing data and field service provision frameworks to support the program.*

*RÉSUMÉ*

*Les données recueillies par les observateurs embarqués pendant les opérations de pêche à la senne des thonidés tropicaux sont communément utilisées à des fins de gestion. Pour certains types de données, tels que les rejets, les programmes d'observateurs peuvent s'avérer les plus fiables et parfois ils constituent la seule source d'information disponible pour la gestion de la pêcherie. Les systèmes de suivi électronique sont utilisés dans certaines pêcheries à titre alternatif ou comme complément aux observateurs humains. L'objectif général de la présente étude est de tester l'utilisation du suivi électronique sur un senneur de thonidés tropicaux dans l'océan Atlantique. Cet objectif a été scindé en deux objectifs principaux : (1) Établir des comparaisons entre les données recueillies à l'aide du suivi électronique et celles collectées par les observateurs afin de déterminer si le suivi électronique peut documenter la pêche de façon fiable (effort, type d'opérations, prise et prise accessoire) dans le cadre de la pêcherie de senneurs thoniers ; et (2) évaluer les aspects opérationnels de l'emploi du suivi électronique pour effectuer un suivi de la pêcherie de senneurs thoniers. Afin d'atteindre ces objectifs, un système de suivi électronique a été mis en place à bord du navire Playa de Bakio, dont le port d'attache est Abidjan (Côte d'Ivoire), pour trois sorties de pêche commerciale, entre le 28 novembre 2011 et le 27 mars 2012. Au cours de ces trois sorties, 61 opérations ont fait l'objet d'un suivi à l'aide de systèmes de suivi électronique et d'observateurs. Le type d'opérations a été correctement identifié à l'aide du suivi électronique pour 60 des 61 opérations. La prise de thonidés par opération n'a guère été différente entre les jeux de données obtenus du suivi électronique et ceux des observateurs ; toutefois, pour des opérations de plus grand volume, le suivi électronique a sous-estimé la prise de thonidés. La composition de la capture obtenue du*

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*suivi électronique a coïncidé avec celle fournie par les observateurs. Toutefois, dans les opérations principalement composées de listao, l'albacore a été sous-estimé. Globalement, les espèces accessoires ont été sous-estimées par le suivi électronique, mais les espèces volumineuses, telles que les istiophoridés, ont été bien documentées. Sur la base de cette recherche, le suivi électronique s'avère un outil efficace pour le suivi de l'effort, du type d'opérations, la prise de thonidés et quelques types de prises accessoires au sein de la pêcherie de senneurs de thonidés tropicaux. Pour mettre en œuvre un programme de suivi électronique, il faudrait tenir compte des aspects opérationnels suivants : définir les objectifs de suivi, standardiser l'installation et la méthodologie de la manipulation de la capture à bord et élaborer des cadres de transmission des données et de fourniture de services sur le terrain afin d'appuyer le programme.*

*RESUMEN*

*Los datos recopilados por observadores a bordo durante las operaciones de pesca de los cerqueros de túnidos tropicales se utilizan generalmente con fines de ordenación. Para algunos tipos de datos, como los descartes, los programas de observadores pueden ser la fuente más fiable, y a veces la única, de información disponible para la ordenación de la pesquería. En algunas pesquerías se están utilizando sistemas de seguimiento electrónico (EM) a modo de alternativa o para complementar el trabajo de los observadores humanos. El objetivo general de este estudio es comprobar el uso de EM en un cerquero de pesca de túnidos tropicales en el océano Atlántico. Este objetivo se ha desglosado en dos objetivos principales: (1) realizar comparaciones entre los datos recopilados utilizando EM y los datos de los observadores para determinar si el EM puede documentar la pesca de un modo fiable (esfuerzo, tipo de lance, captura y captura fortuita) en la pesquería de cerco de túnidos, y (2) evaluar los aspectos operativos de la utilización de los EM para realizar un seguimiento de la pesquería de cerco de túnidos. Para alcanzar estos objetivos, se instaló un EM en el buque Playa de Bakio, con base en Abiyán, Côte d'Ivoire, durante tres mareas de pesca comerciales que tuvieron lugar entre el 28 de noviembre de 2011 y el 27 de marzo de 2012. Durante estas tres mareas, se realizó un seguimiento de 61 lances mediante sistemas EM y con observadores. El sistema EM identificó correctamente el tipo de lance en 60 de los 61 lances. La captura de túnidos por lance no presentaba diferencias significativas en los conjuntos de datos de EM y de los observadores. Sin embargo, para lances con volúmenes más elevados el sistema EM subestimó la captura de túnidos. La composición de la captura registrada por los observadores y la registrada mediante el sistema EM coincidían. Sin embargo, en los lances compuestos sobre todo de listado, se subestimaba el rabil. En general, el sistema EM subestimó las especies de captura fortuita, pero las especies grandes como los istiofóridos estaban bien documentadas. De esta investigación se deduce que el sistema EM es una herramienta viable para hacer un seguimiento del esfuerzo, del tipo de lance de la captura de túnidos y de algunos tipos de captura fortuita en la pesquería de cerco de túnidos tropicales. Los aspectos operativos que tienen que considerarse a la hora de implementar un programa EM son: la definición de los objetivos de seguimiento, la estandarización de la instalación y la metodología de manipulación de la captura a bordo, así como el desarrollo de marcos de provisión de servicios y datos en el terreno, con el fin de que puedan servir de respaldo al programa.*

*KEYWORDS*

*Tropical tunas, purse seine, electronic monitoring*

## 1. Introduction

### *1.1 Background*

The data collected by independent observers during fishing operations are commonly used to complement other data, such as those from port sampling or skippers' logbooks. For some types of data, such as discards, observer programs can be the most reliable, and sometimes the only source of information available for management of the fishery.

Observer programs are becoming an increasingly important tool to monitor tropical tuna fisheries. Under the IATTC and WCPFC regulations, there is a requirement for 100% observer coverage of large-scale purse seiners. Under the ICCAT and IOTC regulations, there is a recommendation of 5% coverage for large fishing vessels

(ICCAT, 2010 & IOTC, 2010). The ICCAT requirement increases to 100% for purse seiners during a two-month prohibition on FAD fishing in an area off western Africa (ICCAT Rec. 11-01).

There are, however, several difficulties involved in placing observers onboard fishing vessels; these difficulties are usually related to the high costs involved in observer placement, debriefing and data handling, and the limited availability of space to accommodate observers onboard vessels. In some cases, such as in the western equatorial Indian Ocean, problems such as piracy make it extremely difficult, dangerous, or impossible to place human observers onboard.

Electronic monitoring (EM) systems are being used in some fisheries as an alternative and/or a complement to human observers onboard (McElderry, 2008). Archipelago Marine Research Ltd. (Archipelago) has developed an EM system that has been used in a wide variety of applications for monitoring fishing and collecting fisheries related data (McElderry, 2008). The EM systems consist of a centralized computer combined with several sensors and cameras, that records the key aspects of the fishing operations such as vessel location, vessel speed, and equipment activity. The International Sustainable Seafood Foundation (ISSF) worked with Azti-Tecnalia, Pevasa (Pesquería Vasco Montañesa S.A.), and Archipelago to complete this study examining the possibility of using EM to monitor the commercial tropical tuna purse seine fishery.

### *1.2 Objectives*

The purpose of this study was to test the use of an EM system on a tropical tuna purse seine vessel during three fishing trips in the Atlantic Ocean, with a view to examining the possibility of effectively implementing EM in tropical tuna purse seine fisheries. The two main objectives of this study are to:

i) Compare the data collected using EM to the data collected by observers to determine if EM systems can be used to reliably collect unbiased data on commercial purse seine vessels. This main objective was divided into three specific objectives:
   a) Evaluate the reliability and functionality of EM to monitor fishing operations including set locations and set-type.
   b) Evaluate the reliability and functionality of EM to estimate tuna catches by species, both for the retained and for the discarded components.
   c) Evaluate the reliability and functionality of EM to estimate bycatch such as sharks, billfishes, turtles and other bony fish.

ii) Evaluate the operational aspects of the implementation of EM systems for monitoring fishing activity from the perspective of scientists, managers and fishers.

### *1.3 Description of the tuna purse seine fishery*

Tuna and tuna-like species are important socio-economic resources as well as a significant source of protein for society (Majkowski *et al*., 2011). Among the most commercially important tuna species are the three tropical tuna species: bigeye (*Thunnus obesus,* BET), skipjack (*Katsuwonus pelamis,* SKJ), and yellowfin (*Thunnus albacares,* YFT). These species are caught by several industrial fleets of different countries, as well as by artisanal fleets of coastal states, landed and processed in many locations around the world, traded in a global market, and finally consumed worldwide (Majkowski *et al.,* 2011).

For management purposes, there are 12 stocks of tropical tuna species. For both bigeye and yellowfin tunas, there are two stocks in the Pacific Ocean (the Eastern and Western stocks, respectively), while a there is a single stock in each of the Atlantic and Indian oceans. Regarding skipjack tuna, there are two stocks in both the Pacific and Atlantic oceans (the Eastern and Western stocks, respectively), while there is a single stock in the Indian Ocean.

Each stock is managed by the respective tuna Regional Fishery Management Organization (RFMO). These include the International Commission for the Conservation of Atlantic Tunas (ICCAT, www.iccat.int), the Indian Ocean Tuna Commission (IOTC, www.iotc.org), the Western and Central Pacific Fisheries Commission (WCPFC, www.wcpfc.int), and the Inter-American Tropical Tuna Commission (IATTC, www.iattc.org). The different tuna RFMOs are faced with similar management problems; for example, in relation to data collection and observer programs, and they have recently started to cooperate through information sharing and common discussion through the so-called Kobe meeting process (see Kobe I and Kobe II reports at www.tuna-org.org). Among other things, they have discussed the necessity of creating standardized data collection and observer programs, as well as increasing the observer coverage to improve catch and discard monitoring for tuna fisheries.

The total catch of tropical tuna species has increased continuously from 1950 to 2010, with the highest level, around 4.2 million tonnes, observed in 2005 (**Figure 1**). In 2010, global catch of tropical tunas was around four million tonnes, which represents around 60% of the total catch of all tuna and tuna-like species. The individual species' contribution to total catch of principal commercial tropical tuna species in 2010 was around 60 per cent for skipjack, around 31 percent for yellowfin, and 9% for bigeye tuna.

In the Atlantic Ocean, most of the catches consisted mainly of yellowfin followed by skipjack and bigeye up to 1976 (**Figure 2**); since then, the majority of catches were yellowfin and skipjack (around 40% each) followed by bigeye (20%). Currently, the relative contribution of skipjack has been greater than yellowfin, comprising the 50% of catches in comparison to 30% of catches of yellowfin in 2010 (**Figure 2**).

Purse seine is the surface gear that contributes most to the catch of yellowfin and skipjack globally (Majkowski *et al.,* 2011). In the purse seine fishery, three main fishing strategies are used to capture tunas: (1) targeting fish swimming in free schools, (2) targeting fish swimming around drifting objects, (3) targeting fish associated with dolphins (only in the particular case of Eastern Pacific Ocean), and in some isolated cases associated with whales or whale sharks. In the first approach, called a free-school set, a school of fish is identified from evidence in the water's surface, and is captured by encircling it. In the second approach, a drifting object where fish are aggregated is encircled with the net. Within this second strategy, there are a subset of techniques including sets on encountered "natural" floating objects ("log sets"), and sets on fish aggregating devices (FADs). FADs are floating objects that have been modified and placed in the fishing areas by the fishers to attract fish, and to facilitate their aggregation and capture. Additionally, FADs are often outfitted with a buoy to help fishers locate them. The strategy of using FADs was developed in the 1980s, but greatly increased in use during the 1990s, and is currently responsible of the major component of the purse seine bycatch and discards (Amande *et al*., 2010).

Tuna purse seining generates low levels of bycatch relative to the total catch (Amande *et al*., 2010). In the Atlantic Ocean, annual average bycatch for the European Union (EU) tropical tuna purse seine fleet is estimated at 7.5% of the total catch, with tunas representing 83% (67.2 t/1000 t) of the total bycatch, followed by other bony fishes (10%, 7.8 t/1000 t), billfishes (5%, 4.0 t/1000 t), sharks (1%, 0.9 t/1000 t) and rays (1%, 0.9 t/1000 t) (Amande *et al.,* 2010).

The most discarded tuna species is the skipjack, followed by little tunny (*Euthynnus alletteratus*) and bullet tuna (*Auxis rochei*). Atlantic sailfish (*Istiophorus albicans*) and blue marlin (*Makaira nigricans*) are the most caught billfishes, Atlantic sailfish are more frequently associated with free schools, and the blue marlin are more frequently associated with FAD sets. In relation with other bony fishes, more than 97% of this group bycatch is caught during FAD-sets, and the dominant bycatch species are triggerfish (*Balistidae*) and rainbow runner (*Elegatis bipinnulata*). Silky shark (*Carcharhinus falciformis*) is the most frequently captured shark, and represents more than 50% of the total shark bycatch in the fishery. Occasionally some turtle and mammal bycatch can occur (Amande *et al.,* 2010). The handling of some bycatch species, including turtles and most sharks, is control by ICCAT regulations stating that they must be discarded (ICCAT Recs. 11-08 and 10-08).

## 2. Materials and Methods

### *2.1 Data Collection*

#### *2.1.1 Survey Plan*

The installation of the equipment took place in Abidjan, Ivory Coast, during three days, between 26th and 28th November, 2012. EM equipment was installed by Archipelago and Azti-Tecnalia staff. On November 28th the vessel went to the sea, and during the next three trips, data were collected simultaneously using EM and by the at-sea observer. The initial plan was to sample two fishing trips, but the duration of the second trip was too short and a third was sampled **(Table 1**).

During the first trip, some adjustments were made by the at-sea observer to the EM system installation to ensure that data collection met the monitoring objectives, and that the system functioned well. Information collected by observers was stored in the Azti-Tecnalia fisheries database, and EM data were stored on hard disks.

#### *2.1.2 Vessel details*

A vessel owned by Pesquería Vasco Montañesa, S.A. (PEVASA), the *Playa de Bakio* (**Figure 3**) was selected to take part in the pilot study. The *Playa de Bakio* is a 75.6 m tuna purse seine vessel based in Abidjan, Ivory Coast (**Table 2**).

#### *2.1.3 Electronic Monitoring System*

The EM systems used for this project were manufactured by Archipelago in Victoria, Canada and are designed for the collection of fisheries data. EM systems have been installed on a variety of fishing gear types and boats around the world, and have been in use as a key source of fishery data in the British Columbia Groundfish Fishery since 2006 (McElderry, 2008; Stanley *et al.*, 2011). The EM Observe$^{TM}$ v4.2 system is comprised of a system control centre, up to four closed circuit television cameras, a GPS receiver, a hydraulic pressure sensor, rotational sensor, and a satellite modem transceiver (**Figure 4**). The EM system collects high-frequency sensor data throughout the entire trip, and records imagery only when triggered by fishing activity. Imagery and sensor data are stored digitally on a removable hard drive that can be exchanged when it reaches it storage capacity.

The EM system software, called EM Record$^{TM}$, is installed on the control centre and has numerous settings that can be modified to accommodate the data collection objectives, and the vessel-specific installation. The adjustments that can be made to the software settings include:

- Triggers for imagery recording (pressure, speed, rotation, geographic area);
- Imagery recording run-on time, or the amount of time that imagery was recorded after fishing was finished;
- Sensor data sample rate; and
- Imagery frame rate for each camera.

Using the various options for the software settings, the technician limited the imagery recorded to periods of time for which fishing equipment was in use, thus ensuring that pertinent data are recorded, and non-pertinent activities are not.

At the outset of this project, it was recognized that the catch handling of fish onboard was highly complex and would require more than one system. As a result, two four-camera EM systems were used to monitor the vessel during the study period in order to effectively record all fishing activities. A system installed above deck was set to record the capture of fish and general fishing activity, including setting, pursing, brailing, and some discarding. A system installed below deck was set to capture movement of fish below deck along the sorting conveyor belt.

The technicians installed the systems to monitor and record as much of the fishing activity as possible. During the installation, the Archipelago technician spoke with officers, crew and the observer to gather information and design the most effective EM system installation. The Archipelago technician installed the systems to monitor as many catch handling control points as possible; a control point is an area where catch is handled, and then it is either retained or discarded in an obvious way. Identifying control points is very important for properly installing an EM system because they can be used to track the key movements of fish throughout the vessel.

Fishing activity on the *Playa de Bakio* occurs in the same way during each set; the set begins when the net boat enters the water and begins to pull the net to encircle the school. All fishing activity occurs on the port side of the vessel where the net is set, pursed, sacked and then the fish are brailed aboard. While fish are being sorted the crew removes some of the large bodied bycatch such as billfishes, sharks, and turtles from the brailer. Large bodied bycatch species, including sharks and turtles, are discarded on the starboard side after being measured and handled by the observer. The bulk of the fish are then transferred through the hatch to the below-deck area. Once in the below-deck area, fish are sorted on the conveyor and placed into storage holds.

Activities in the below-deck area presented significant difficulties for monitoring with EM; the conveyor can be moved in either direction to transport fish to the storage wells. For the most part, fish are transferred direclty from the conveyor at several points and transferred directly into one of the 18 brine wells. In addition, bycatch was removed either from the conveyor, or left on the conveyor and to be deposited on a net at the end of the conveyor belt for later discarding.

The highly complex discard handling method and multiple control points made monitoring the below-deck catch handling with EM challenging. On the Playa de Bakio, there are 21 main control points (one brailer, one large bycatch handling area, 18 wells, and one discard pile), however, fish are also removed for discarding at other points in the vessel. This high number of control points is the primary reason that two four-camera systems were chosen to monitor the vessel from the outset of the project, and it was recognized that not all control points could be monitored completely.

The control centre for the above-deck system was initially installed in a small office near the wheelhouse; other components of the system and their objectives were:

- Four cameras (**Figure 5**):
    - two views from the port side of the vessel to record gear setting and hauling;

- two views of the deck activity and brailing of fish into the hold

- Satellite modem – transmitted an hourly synoptic data report, called a Health Statement to an FTP site;
- Hydraulic sensor – determined when gear is in use, and triggers imagery recording;
- GPS – determined vessel location and speed;

The control centre for the below-deck system was installed in the machine shop below deck; other components of the system and their objectives were:

- Four cameras (**Figure 5**):
  - Two views of the point where catch enters the conveyor;
  - Two overlapping views of the end of the conveyor belt and discard pile.
- Conveyor belt motion sensor – determined when conveyor belt is in use and triggers imagery recording;
- GPS – determined vessel location and speed.

Each system was operated independently, and recorded imagery only when triggered by the control centre. The above-deck system was set to record imagery when there was hydraulic activity onboard because the brailer and winch use hydraulics for operations, and continue for 30 minutes after hydraulic activity had stopped. This ensured that at a minimum, the setting, pursing, and brailing of the net were recorded. The below-deck system was set to record imagery when the conveyor belt was active and was triggered by the motion detector; this setting ensured that at a minimum, imagery was recorded when the fish were being transported to storage wells below deck.

#### *2.1.4 Adjustments to the System*

During the first trip, several changes to the EM system were made by the observer in order to improve the data collection and camera views. These changes included:

- replacing the below-deck EM control centre with the spare;
- replacing the proximity sensor from the conveyor belt with a rotational sensor to improve motion detection on the conveyor belt;
- repositioning two of the cameras installed half-way up the mast to the hydraulic control desk for a better view of the brailer; and
- repositioning Camera 3 connected to the below-deck system to the large discards are above deck.

These changes improved the data collection and focused the imagery on the key fishing activities.

In addition to the changes made by the observer, the Archipelago technician met the boat between the first and second trips to provide service and make the necessary adjustments. The trip primarily involved:

- reviewing imagery and making minor adjustments to the camera views
- changing the power supply of the below-deck system (to fix the problems with Camera 3)

The combination of these changes and troubleshooting resulted in the data set from the second and third trip being more reliable, with better views of key activities (**Figure 6** and **Figure 7**) and fewer data gaps.

#### *2.1.5 Health Statements*

The above-deck EM system included a satellite modem transceiver that transmitted an hourly summary of data to a secure FTP site that was maintained by Archipelago. The Health Statements contained a summary of sensor data from the previous hour; this summary included:

- set indicators:
  - vessel location, and direction,
  - average vessel speed,
  - hydraulic activity (as a percentage of time over threshold), and
  - imagery recording on/off;
- general information:
  - date, time,
  - system on/off ,
  - power failure or low voltage events (if any),
  - percentage of time that imagery was recording,
  - percentage of time that the EM system was operating, and
  - remaining hard drive storage space.

The Health Statements were regularly examined by Archipelago staff. Health statements were used to monitor system performance and determine if any communication with the vessel was required. Archipelago also examined the Health Statement data to determine if it could be used to monitor and track the number of sets on an hourly basis while the fishing vessel is at-sea.

### *2.1.6 EU Observer Program*

Since 2003, Azti-Technalia in collaboration with IEO (Spanish Oceanography Institute) and IRD (Institute de Recherche pour le Développement), have been conducting a coordinated observer program as part of the Spanish and French National Programs for the Data Collection in the Fisheries sector established according to the European Regulations (Commission Regulation (EC) No. 665/2008). This sampling program provides information about the commercial and non-commercial species that are in the catch and frequently discarded, which allows studying the biodiversity of the exploited resources. During the first years, this sampling program only covered around 2% of the total trips, however, this coverage increased up to values exceeding 10% in 2010. Observers for this study used the standard methods used in the EU observer program. During these trips, observers filled in five different data sheets (Delgado de Molina, 1997), where information about tuna species, bycatch species and Fish Aggregating Devices (FADs) is collected. Data on these sheets include the following:

- **Data sheet 1 -** Route data and environmental parameters:
    - bridge data (position per hour, etc.),
    - environmental data (wind speed, water temperature, etc.), and
    - information about systems associated with tuna schools (i.e., birds, FAD, etc.).

- **Data sheet 2 -** Fishing operation parameters and catch data:
    - characteristics of the set (shooting hour, rings up hour, etc), and
    - total catch, both target species and bycatch species catches and fates.

- **Data sheet 3** -Size sampling for tunas:
    - size sampling for tuna species is collected in these data sheets.

- **Data sheet 4** - Size sampling for accompanying fauna:
    - size sampling for bycatch species is collected in these data sheets.
    - sampling size by sex when possible for rays, sharks, cetaceans and tortoises.

- **Data sheet 5 -** Fishing Aggregator Device (FAD) monitoring:
    - FAD type, satellite buoy data or fate.

Observers collected route data every hour, and all the fishing operations are sampled throughout the trips. Within each set, the priority of sampling for the observer was (1) estimating discarded tunas and measuring a subsample, (2) measuring sharks, billfishes and turtles, (3) estimating the number or weight of smaller bycatch species, measuring a subsample. Retained tuna catch information was recorded directly from the fishing logbook, and logbook information is based on a visual estimate made by the crew. However, in some cases, when small tunas that were not included in the logbook, but were identified by the observer, the total was estimated and recorded by the observer.

## ***2.2 EM Data Review***

The data collected using the EM systems were reviewed using the Archipelago EM Interpret$^{TM}$ software (www.archipelago.ca). EM Interpret is a software package that integrates and displays EM sensor and imagery data for review. The data display includes line graphs of the high-frequency sensor data, a map of the vessel track throughout the trip, and imagery which is linked to sensor data. The software allows the user to efficiently review and annotate the fishing trip, highlight fishing activity and record catch and bycatch. Annotations are used to identify key moments or periods of time in the data set and define the fishing activity. In other words, annotations act as a bookmark within the synchronized data time series to identify components of a set.

In consultation with Azti-Tecnalia, Archipelago created a custom annotation configuration of EM Interpret$^{TM}$ for the tuna purse seine fishery. The custom configuration of EM Interpret included a fishery-specific species list and set of annotations (start pursing, rings up, FAD seen, etc).

The EM data were reviewed by Azti-Tecnalia staff using EM Interpret$^{TM}$ at the end of each fishing trip. In an effort to match the observer data that are typically collected on such sets, reviewers used EM Interpret to create annotations to identify a number of variables including:

- set location (start/end),
- set time (start/end),
- fishing effort,
- time of several events (start pursing, rings up, start brailing).
- set-type (to identify if FAD was seen),
- retained and released catch, and

The EM reviewer used EM Interpret to watch the imagery and identify all of the key components of the set, and created annotations at the appropriate point in the data set. During the review, the viewer added the appropriate annotation at each point in time when the associated action or object was seen. The stages in the EM data review involved:

1. Adding Event start/end annotations (time, location),
2. Adding Video Review start/end annotations (time, location),
3. Watching imagery from the beginning of event,
4. Adding start pursing annotation (time, location),
5. If FAD was visible, adding FAD annotation (time, location),
6. Adding rings up annotation (time, location),

The annotations used to document catch items include the Brailer, Individual Catch Item, Multiple Catch Item, and Gilled Fish annotations. To document catch, the reviewer added annotations while watching the imagery of the set. The reviewer documented each time that a brailer was seen moving fish from the net to the hatch. For each brailer annotation, the reviewer recorded the brailer fullness, species, and species composition (based on below-deck imagery). If fish were observed caught within the netting, the reviewer recorded these as Gilled Fish, and recorded the species, estimated number, and fate (discarded or retained).

As the brailer was moved to the hatch area from the net, the reviewer documented when a large bycatch item (such as a billfish, shark, or turtle) was removed from the brailer. This annotation included the fate of the fish (discarded or retained), the species, and the estimated length and weight.

For all other catch items, including small sharks, and other bony fishes, the reviewer documented them from the below-deck imagery collected along the conveyor belt when they were visible. The reviewer would either add an annotation for an individual catch item, or for multiple catch items based on what was visible in the imagery.
After the review process was complete, annotations were saved in EM Interpret and exported to MS Access for further analysis

*2.2.1 Estimating Tuna Catch from EM*

The EM data outputs quantified the number of trips, sets, and brailers per set which were then used to estimate the tuna catch. Each brailer annotation required the reviewer to enter the "brailer fullness", species, and species composition percentage. This information was then used to estimate the total weight of tuna that were retained according equation (1):

(1) Tuna species weight = full brailer weight * brailer fullness * species percentage

The "full brailer weight" (10 tons) was provided by the observer, and used for each of the brailers for this study (note: this value is dependent on the vessel's gear). The relationship between brailer fullness and brailer weight was assumed to be linear, therefore the same full brailer weight was used for each calculation.

### *2.3 Image Quality*

The EM reviewer recorded the image quality as high, medium or low, based on a qualitative assessment of the imagery. The classification of image quality was based on the reviewer's qualitative assessment of their ability to achieve the objectives using the available imagery. For example, while viewing the imagery of the brailer, the imagery was classified as high quality when the reviewer was able to clearly see the brailer, and brailer fullness. For the brailer view, imagery was classified as low quality imagery if the reviewer had a poor view of the brailer, and had difficulty assessing the brailer fullness. Variables that typically affect imagery quality are things such as water or dirt on the camera dome, lighting, weather (e.g., rain or fog), and whether or not the view was obstructed.

### *2.4 Review Time*

During the review process, the EM reviewer recorded the amount of time it took to completely review each set. Review time was recorded because it is a useful indicator for planning an operational program, and is presented in the results.

### *2.5 Data Capture Success*

Data capture success is defined by two key components including: overall sensor data, and overall imagery data. These metrics are useful in assessing the success of the EM system for collecting data at-sea, and usefulness for achieving the monitoring objectives.

Overall sensor data success is defined as the amount of time for which the EM system was running and collecting sensor data (i.e., GPS, hydraulic pressure, rotational data). This metric reflects when the EM system was functioning normally. Sensor data success can also be defined as the time when the system was collecting data, even if one component of the system was not working properly. Incomplete data success can be caused by a variety of factors related to either the system itself (system error or lockup) or vessel and crew behaviour (system powered off, or power loss). A complete data set (100%) is expected for each of the systems, and would include continuous sensor data collection from the time the vessel left port to the time the vessel returned to port.

In addition, the overall imagery success, which is defined as the amount of time for which the systems were collecting imagery data is summarised. Imagery success of 100% indicates that for all sets, there is imagery collected when it was expected. Imagery success rate only reflects when images was recorded, and does not include a measure of image quality or usefulness.

### *2.6 Classification of Set-types*

In the tropical tuna purse seine fishery, set-type is a crucial element of the monitoring program, and helps to define the fishing effort of the fleet. During the EM data review process the reviewer identified each set as one of the following: fishing on a FAD or free-school based on imagery review. Sensor data (i.e., speed, location, hydraulic pressure) were also examined to determine if it is possible to determine set-type from sensor data alone.

### *2.7 Statistical Analysis*

The data collected by both observers, and using EM were compared for three main categories: tuna catch, large bycatch, and other bony fishes. In the case of tunas, discarded and retained fractions of catch were analysed separately, while for the bycatch all the caught individuals were compared, without taking into account if they were retained or discarded. The following analyses were conducted on the three groups in order to evaluate the use of EM to estimate the different components of the catch. All statistical analyses and comparisons were performed by Azti-Tecnalia.

#### *2.7.1 Tuna Catch Comparison*

*Analysis of tuna catch*

First, total tuna catch per set was compared between EM and observer records for each set. A Wilcoxon signed-rank test was used to compare the tuna catch data estimated per set by both monitoring methods; this is a nonparametric test that takes into account the sign and magnitude of the paired differences between data sets. The null hypothesis compares the estimated median weight of retained tuna species from EM and observer records. This method is the analog nonparametric test of the paired sample t-test, and it was selected due to the non-normal distribution of the data. We also studied if the differences between the estimates made by EM or observer were dependent on the total quantities of tuna catch. We divided the weight of retained tuna estimated per set from observers into three classes: [0,9 ton], (9,20 ton] and (20, 150 ton], which represent low, medium and high weights of catch per set respectively. We then calculated the differences between the estimated weight from EM and observers at each class, and compared the medians between classes using Mann-Whitney U test.

*Analysis of tuna estimates by species*

We used a Wilcoxon signed-rank test in order to compare the proportion of weight for each tuna species estimated by set with both monitoring methods. We also calculated a correlation matrix of the differences between the estimates for each species in order to study possible relations between them.

We divided the estimated weight by set from observers into three classes of similar size, which represent low, medium and large set weight (as defined above) and we did a Mann-Whitney U test, in order to study the differences on the estimates for each species depending on the total catch per set. We also studied the differences between the estimated proportions of weight of YFT by both fishing methods (FAD and free school). We limited the examination to the differences for YFT, because YFT is the main caught species within free-school sets.

For discarded tuna, no analyses were preformed due to the limited data, however, a summary of the discards recorded by EM and the observer are presented.

*2.7.2 Bycatch Estimation*

***Sharks and Billfishes***

*Analysis of sharks and billfishes species together*

In the case of sharks and billfishes, we did a Wilcoxon signed-rank test to compare the total number of captured individuals estimated from both monitoring methods.

*Analysis of sharks and billfishes by species*

We analyzed if there were significant differences between the estimates by species with both monitoring methods, however, some of the species were absent or not observed in a large proportion of sets, or very low number of individuals were present. The focus was on the differences in the presence, without taking into account the magnitude of the differences in the estimates. Therefore, we transformed the data into presence/absence data and we used a McNemar's test, to compare the proportion of data with presence estimated with both methods (Zar, 1999).

**Other Bony Fishes**

*Analysis of other bony fishes, all species together*

For other bony fishes, we performed a Wilcoxon signed-rank test to compare the total number of other bony fishes estimated (without taking into account different species) from both monitoring methods.

*Analysis of other bony fishes by species*

We also used the Wilcoxon signed-rank test to compare the estimates of numbers of other bony fish bycatch by species. Nevertheless, these analyses were limited to those species for which the incidence of occurrence was 75% or more of total sets. With the rest of the species, data were transformed to presence/absence, and a McNemar's test was used to compare the proportions of presence estimated with both methods.

## 3. Results

### *3.1 System Performance*

All of the problems that were encountered were on the below-deck system, and during the first fishing trip. The major problems encountered included:

- The below-deck control centre was not reading the GPS
- The first motion sensor (a proximity sensor) did not function as expected, and
- Camera 3 (below deck) did not record after being repositioned due to a problem with the power source.

Early in the first trip, the below-deck system had an intermittent GPS signal; the observer moved the GPS to several locations to try to improve the signal. This approach did not resolve the problem, so the control centre was replaced with the spare, which resolved the problem. The impact of this was that the below-deck system had unreliable GPS data from the departure (November 28, 2011) to January 13, 2012, however this data was not used in the final review because the above-deck data set was complete.

The proximity sensor on the conveyor belt below deck did not function as expected, and as a result, the observer replaced it with a laser sensor to detect movement of the conveyor. The impact on data collection was minimal because prior to changing the sensor, the observer was able to record sets by manually triggering imagery recording.

During the first trip, Camera 3 in the below-deck system had a problem with the power connection causing it to fail after being repositioned from to view the discard handling area above-deck. The problem was fixed between trips by the Archipelago technician, and the camera functioned normally during the second and third trips.

### *3.2 EM Data Collection Success*

The *Playa de Bakio* carried EM equipment for monitoring fishing from November 29, 2011 to March 26 2012, and three trips were monitored successfully and collected a total of 1587 hours of sensor data across all three trips (**Table 3**). The mean data success rate for all three trips was 95.1%. Two notable gaps occurred; the first occurred during the first trip (77.7 hours total), and the reasons are not known. The second gap occurred during the third trip when the above-deck control centre was powered off by the observer from 12:14 on March 24 to 6:46 on March 25. This was done because the hydraulics were being used, but there was no fishing occurring.

Across the three trips, a total of 61 sets were recorded using the EM systems, and reviewed by an EM reviewer (**Table 4**). For all sets, 156 hours of video imagery were collected, resulting in an imagery success rate of 99.8% for all three trips.

The overall data capture success rate for the below-deck system was lower than the above-deck system with 89.5% during the first trip, 100% during the second trip, and 89.5% during third trip (**Table 5**). The missing data collection on the first trip was caused by problems with the control centre, which was replaced mid-way through the first trip. During the third trip, the below-deck control centre was powered off from 12:00 March 10 to March 14 at around 12:00, resulting in missed data collection; reasons for this power-down were not known.

### *3.3 Image Quality*

Free school sets had a greater number of sets with imagery classified as "high", while FAD sets more “medium” and “low” scores were present (**Table 6**). This is likely related to the fact that the species documentation for free school sets could be more easily achieved due to the mono-specific nature of the sets. Trip one was excluded from this analysis because changes to the camera views and locations were made during trip one

### *3.4 Imagery Review Time*

The summary of review times by set-type for trip two and three indicate that FAD sets were more time consuming to review than free school sets (**Table 7**); for FAD sets, the EM reviewer spent an average of 68.13 minutes per event (most events lasted around three hours in real time). During FAD sets, catch is composed of various sizes and mixed species with a higher abundance of small bycatch than is seen in free school sets. On the other hand, free school sets are mostly mono-specific, with large tunas and few small bycatch species, thus simplifying the review process, and decreasing the average review time to 48.5 minutes. Finally, in null sets, where no fish were caught, the review time was reduced to 23.83 minutes. Across set-types, the mean review time was 54.84 minutes per set for the second and third trips.

### *3.5 Classification of Sets*

#### *3.5.1 Fishing Characteristics*

A comparison between the EM data and the observer data revealed that there is a standardized and typical signature visible in the EM sensor data for this vessel during fishing. The pattern is as follows: the start of a set was identified by high vessel speed (steaming to a location) followed by a short period of low speed (2-5 knots), then high speed (>9 knots). This period indicated that the crew was setting the net and encircling the tuna. After setting, the sensor data typically showed high pressure followed by several hours (~3) of low speed (<1 knots), while the net was being pursed, and the fish were brailed (**Figure 8**). When the vessel was not taking part in fishing operations, the typical cruising speed was around 11-12 knots. Additionally, the vessel speed usually dropped to less than 1 knot between the evening and morning (about 18:00 to 06:00).

In addition to line graphs, an EM Interpret map displaying the vessel cruise track can be used to help identify sets; the distinct combination of speed and direction indicates where a set has taken place. In this study, the cruise track indicated that the vessel typically approached and encircled the fish, and then drifted for several hours while fish were brailed (**Figure 9**).
**Figure**
*3.5.2 Determining Set-Type Using EM*

Both EM and observer records indicate the set-type for each fishing event; 60 of the 61 (98%) monitored sets were correctly identified using EM (**Annex 1, Table 1**). Of those 61 sets, the observer records shows that 23 were free school sets, and 38 were FAD sets. The EM reviewer identified one set (January 9, 2012) during the first trip as a FAD set based on imagery review, while the observer classified it as a free-school set.

For FAD sets, the imagery commonly showed a the FAD being towed by the speedboat during within camera view (**Figure 10**), however, it would be very easy for this to take place outside of the camera view, or for the EM reviewer to miss it with a minor change in vessel behavior. On the other hand, during free-school sets, the imagery show both the skiff and the speedboat moving in circles until the rings were up to avoid fish escaping while the net is not completely closed.

The EM sensor data was not used as the main method of determining set-type (only video data were used), however, based on a qualitative assessment, sensor data do appear to be indicative of set-type. There is a difference in fishing behaviour between free-school and non-free-school sets that is obvious from the combination of speed, and hydraulic pressure records. During the documented FAD sets, the vessel tended to approach the fishing area with constant speed, then slow down, then return to full speed immediately before the shooting operation (**Figure 11**). Alternatively, during free-school sets (as confirmed by the observer data), the EM data showed that the speed prior to setting was more variable while the vessel followed the school, and did not drop as low as during FAD sets (**Figure 12**). Similar to FAD sets, during free-school sets, the vessel speed dropped to nearly 0 knots for pursing, sacking, and brailing activities.

*3.5.3 EM Health Statements*

The data from the Health Statements was very useful for allowing near-real time monitoring of fishing activity. Across all three trips, only three sets were not identified by the Archipelago reviewer using the Health Statement viewer. The sets that were not identified occurred on days with multiple sets (**Figure 13** and **Figure 14**), and the scale of data was too coarse to define obvious breaks between sets. Using the Health Statement viewer, the reviewer identified two periods of time on December 10 as fishing that were in fact null events (i.e., no fish were caught).

### *3.6 Tuna catch Estimation*

*3.6.1 Retained Tuna*

The results of a Wilcoxon signed-rank test comparing the estimated median weight of retained tuna per set from EM and observer data indicate that there is no significant difference ($n$=61, $V$ = 677.5, *p-value* = 0.9202>0.05). This result suggests that EM and observer data were equally reliable methods for estimating total catch per set.

A Mann-Whitney U test comparing catch estimates between EM and observer data shows that the median of the estimated weight distribution made by observers is significantly higher than the median estimated weight distribution made by EM, when estimated total weight is high, (20 to 150 ton]) in comparison to catches with low or medium weight class (**Figure 15**). This indicates that EM and observer data were not significantly different; however, when the total catch is high, EM underestimates the total catch relative to observers.

The EM reviewer was able to reliably record the main tuna species that were caught. Five tuna species were identified using observer and EM data: *Katsuwonus pelamis* (SKJ), *Thunnus albacares* (YFT), *Auxis spp*. (AUX), *Thunus obesus* (BET) and *Euthynus alleteratus* (LTA). In addition, the observer identified the species *Thunnus alalunga* (ALB) in one set, where EM did not have a record of that species. **Table 2** in **Annex 1** shows the tuna catch estimates made by the observers and by using EM.

A Wilcoxon signed-rank test was used to compare the estimated proportion of weight for each tuna species from both sampling methods. The median of the estimated proportion of weight from EM is significantly different than that estimated from observers for SKJ and YFT tuna species (**Table 8** and **Figure 16**; **Annex 1-Figure 3**). Nevertheless, there were no significant differences in the estimated proportions between both methods for the other tuna species.

The results of a Mann-Whitney U test comparing the tuna catch quantities between EM and observers suggests that at high catch quantities, the estimates of SKJ were overestimated with EM while the estimates of YFT were underestimated (**Annex 1, Table 4 & Figure 5**).

A correlation matrix of the differences between the estimated proportions of weight from EM and observer data indicates that there is a negative correlation between the differences of the estimates of SKJ with BET and YFT (**Annex 1, Table 3**). Nevertheless, as it has been mentioned before, there is no significant difference in the estimates of BET (**Table 6**), thus, this suggests that the underestimation of YFT could be due to an overestimation of SKJ (**Annex 1, Figure 4**).

For the differences between the estimated proportions of tuna weight from both sampling methods by species at different total weight classes, Mann-Whitney U test results show that when total weight is high, the estimated proportions of weight of YFT from observers were significantly higher than EM (**Annex 1, Table 4**). However, it is important to mention that sets with higher total catch were FAD sets (**Figure 17**); that is, there were significant differences between the estimated proportions of YFT tuna weight from observer and EM in FAD sets, when YFT was a minority species, but there were no differences in free school sets (**Annex 1, Table 5**).

*3.6.2 Discarded tuna*

Discarded tuna quantities were low during the three trips that were monitored. Discarded tuna catch was limited to some gilled and damaged small-size fish. There was only one set where discarded tuna weight was larger than one ton (**Table 9**). This discarded catch was identified both by observer (2.5 Ton) and by EM (0.5 Ton), although the EM-based discard estimate was lower.

### *3.7 Bycatch Estimation*

*3.7.1 Large Bycatch*

The result of the Wilcoxon signed-rank test comparing EM and observer records of captured sharks and billfishes shows that the estimated median number of individuals of sharks were significantly lower from EM than from observers ($V = 4$, *p-value* $= 0.0002927 < 0.05$), but in the case of billfish, there were no significant differences between the median from both methods results ($V = 6$, *p-value* $= 0.1883 > 0.05$).

The observer registered 109 sharks and 29 billfishes, while the EM data only contained records of 58 sharks and 20 billfishes (**Annex 1, Table 6**). The most frequently captured species of sharks and billfishes were observed from both monitoring methods at least in some sets. Main species were distinguished from both methods: *Makaira nigricans* (BUM), *Carcharhinus falciformis* (CFA), *Istiophorus albicans* (SAI), and *Sphyrna lewini* (SLE). Nevertheless, in some cases, with the EM method, the taxonomic identification only reached the family level; some CFA were only identified as *Carcharhinidae* (FCA) and some SLE were only identified as *Sphyrnidae* (FSP).

Some less captured species were only recorded from one of the methods; one *Isurus oxyrinchus* (IOX) and one *Carcharhinus longimanus* (CLO) were only recorded by the observer. The EM data contained one *Mobula spp*. (RMV) that was not found in the observer data. During the third trip, two *Tetrapterus albidus* (WHM) individuals where identified only using EM, but based on comparisons with observer data they correspond to *Istiophorus albicans* (SAI) individuals (**Annex 1, Table 6**), so were likely identified incorrectly using EM.

McNemar's test was used to compare the estimates of presence/absence from both methods for some species (**Table 10**). The estimate of presence of *Carcharinidae* (CFA and FCA) species is significantly lower from EM than from observer data. For the other species, *Makaira nigricans* (BUM) and *Istiophorus albicans* (SAI) there is no significant difference between the EM and observer data. *Sphyrnidae* presence/absence data from EM and observer data were exactly the same; therefore those species were not compared using statistical tests.

In the case of turtles, only two individuals were caught (and released alive) and identified by the observer within the three trips, one *Lepidochelys olivacea* and one *Chelonia mydas*. These turtles were also recorded using EM prior to their release; however, it was impossible to identify the species in both cases.

### *3.7.2 Small Species (other bony fishes)*

The Wilcoxon signed-rank test results show that the estimated total number of other bony fishes were significantly lower in EM than in observers data ($V$ = 57.5, $p$ = 5.404e-07<0.05) (**Figure 18**). The observer estimated that 15,007 small bony fish were caught during the three trips while only 3,801 individuals were estimated using EM. Based on the observer estimates, only 25.3% of the total small bony fishes bycatch was registered using EM.

Although some minority bony fish species were never observed or identified using EM, the main species within these trips were observed by both methods. Main species include the following: *Canthidermis maculatus* (BCM), *Caranx crysos* (CRY), *Elegatis bipinnulata* (ELP), *Acanthocybium solandri* (WAH), *Coryphaena hippurus* (COH), *Kyphosus spectator* (KPS), *Lobotes surinamensis* (LOB), *Seriola rivoleana* (SER), *Balistidae* (FBA).

We used the Wilcoxon signed-rank test, to compare the number of other bony fish species from both methods only for species for incidence was more than 75%, these include BCM, CRY, WAH, COH, ELP. We used McNemar's test with the other species after transforming the data to presence/absence. The results show that the median of the estimated individuals from EM is significantly lower for all the analyzed species; BCM, CRY, WAH, COH, ELP (**Table 12**). In addition, the estimated presence of KPS, LOB and SER from EM is also significantly lower than from observers (**Table 11**).

## 4. Discussion: Technical Assessment

### *4.1 Overall System Performance*

As described in the Methods section, some changes were made by the observer while the vessel was at-sea, and during the inter-trip service by the Archipelago technician. The majority of the technical issues occurred during the first fishing trip; given that this was the first time that EM was deployed on this gear type and vessel, some adjustments and technical challenges were anticipated. The problems encountered were fixed either by the Azti-Tecnalia observer during the first trip, or during the inter-trip service by the Archipelago technician, and had limited impact in the overall data collection.

### *4.2 EM Data Collection Success*

The data collection success rate for this project was very high (nearly 100% for data and 99% for video), especially for the first installation on this gear type. Typically, a lower data capture success rate is expected on the first deployment of EM, while high success rates (near 100%) have been achieved in operational programs. The high success rate in this project is due to the reliable power available on the *Playa de Bakio*, as well as having an observer onboard who was able to oversee the system and fix any issues at sea.

### *4.3 Image Quality*

In relation to image quality, overall the image quality was sufficient, and the bulk of reviewer assessments were medium or high quality. There are several factors that can improve the reviewer's ability to meet the monitoring objectives through improved image quality. Non-system related factors (such as backlighting, fish scales or water droplets on the cameras) can reduce the image quality, and in some cases, can make the imagery virtually unusable. In this study, the observer was responsible for cleaning cameras and ensuring that the views were unobstructed, which likely had a positive effect on image quality.

This study used analog cameras to record imagery to the hard drives; Archipelago is currently developing a system that uses Internet Protocol (IP) cameras with a much higher resolution. It is important to note that camera type and resolution are only two factors that can affect the quality and usefulness of imagery, and external factors such lighting, distance from target, and weather can be equally important to image quality as the type of camera being used.

### *4.4 Imagery Review Time*

Reduction of cost whilst maintaining high quality data collection for managers is one of the main aims of electronic monitoring, and the imagery reviewing time could be one of the key points on this issue (see Stanley et al., 2011 for more discussion on variables affecting program cost). The EM system collected nearly 1600 hours of sensor data, and 160 hours of imagery over the three monitored trips, and all of the imagery was reviewed in 31 hours of reviewer time. Relative to the total length of all three trips, 31 hours of review time is a highly efficient method of monitoring a trip. Moreover, when compared to the effort involved in deploying an observer to collect about data for roughly 3 hours per set, EM may provide an efficient monitoring tool to collect some types of data.

This pilot study on a tuna purse seiner has shown that the average review time per set depends on different factors, mainly set-type and total amount of catch. The review of EM data in the project was done by recently trained AZTI-Technalia staff, who had extensive experience as observers, but no previous experience with EM. Although viewer experience was not tested in this project, it is a third factor that likely affects review time. In any case, the mean review time per set did not exceed 1.25 hrs for any sets, suggesting that EM may be an economical monitoring method, provided that high quality data are collected.

### *4.5 Set Type Classification*

The approach used in this research to identify FADs sets from imagery and sensor data signatures appears to be effective for the *Playa de Bakio* fishing techniques, and was able to correctly identify 60 of the 61 sets. It is important to note that the usefulness of this method is limited to vessels with similar fishing behaviour (may include the entire Spanish fleet). Future research should focus on confirming and expanding the methods for identifying set-type independent of observer and fishing logbooks. Ongoing research on other tropical tuna purse seine vessels focuses on the use of similar approaches, as well as testing various camera views facing toward the fishing area on the port side. This “out-to-sea” view will likely require slight modifications based on vessel-specific gear setting and hauling.

While this study used imagery to determine set-type, the use of only EM sensor data is a very promising method as well. The differences in how vessels approach and begin fishing on either FAD or free-school sets are obvious in the EM sensor data, and appear to be fairly consistent. For example, on January 9, 2012 a set was classified as a FAD set based on imagery review but it was in fact a free-school set. When the sensor data for this set are examined, this set is consistent with sensor data collected for free-school sets (**Figure 19**), so could have been identified as such, if imagery and sensor data were both used to identify set-type. Examination of EM data collected on more vessels should focus on clarifying the differences between FAD and free-school EM sensor data.

### *4.6 Health Statements*

The synoptic hourly data summary reports provided via satellite modem (Health Statements) are a useful tool for monitoring fishing activity in near real-time, although they do not provide the ability to determine catch while the vessel is at sea. The addition of a rotational sensor on the main winch could help to clarify when fishing events are occurring and differentiate between non-fishing related hydraulic activity and fishing.

### *4.7 Tuna Catch Estimation*

In general terms, as results show, total tuna catch can be accurately estimated using EM because observer and EM system estimates of total retained catch per set were not significantly different, however, for high volume sets, total catch is underestimated with the methods that were used here. It is important to note that the observer did not rely on brailer count and brailer fullness to estimate the tuna catch in the same way that EM did, and as such the differences in EM and observer data may be related to the different estimation methods used by each.

Both monitoring methods were able to identify the same tuna species for all sets with the exception of one set in which the observer recorded several albacore (*Thunnus alalunga*) that were not recorded by the EM imagery reviewer. Compared to the observer records, the use of EM was able to reliably estimate the proportion of each tuna species per set, although in some cases the species that were in small quantity in set were underestimated when using EM. Of particular importance to catch monitoring is the example of sets where skipjack were the main species, and yellowfin were underestimated and attributed to skipjack.

In terms of identifying all species within a set, the main challenge is the large volume of fish that enter the conveyor at once, thus hiding a large portion of the fish under the top layer. Given the combination of the camera views (see **Figure 5**), and a known brail volume or weight, it is feasible to accurately estimate the total catch using Equation (1). Some mechanism to organize or manage the volume of fish and to allow the EM system to record imagery of the catch on the conveyor belt would facilitate this work. In this respect, it is important to note that the elapsed time between brailing and freezing in the wells is critical to tuna product quality, since the lower this time, the higher the quality of the fish. Some mechanism to manage high volume of fish without increasing the time before freezing will help to improve the EM-based estimate without compromising the quality of fish.

### *4.8 Bycatch Estimation*

In general terms, using the observer data as the baseline, the use of EM on the *Playa de Bakio* was able to reliably estimate and identify billfish catch based on these analyses, but underestimated the bycatch for some small sharks and small bony fishes. This result is influenced to a large degree by the methods used to handle catch on the *Playa de Bakio* which allow for easy identification of large bycatch, but make it very difficult to track and identify small bycatch mixed in with tuna.

Large bycatch species (billfishes, *and large size sharks*) were well documented by EM, because the visible catch handling of the fish was easily observed by the reviewer. These bycatch were normally sorted from the brailer in the above-deck area because they are too big to go directly though the hatch to the below-deck area. During brailing, the observer usually worked in the below-deck area, and the collaboration of the crew was necessary to alert the observer when bycatch was being sorted above deck. The EM systems allow for analysis of both the above- and below-deck areas at the same time, without the need for crew collaboration. An example of when this might have affected the observer's ability to document catch is the *Mobula spp* (devil ray) that was unaccounted for by the observer (trip 3, set nº 12) but was observed by EM reviewers. Overall, EM was able to fully document large bycatch species that were handled in the above-deck area.

For large bycatch species, taxonomic identification has been identified as another clear difference between the two monitoring methods. In the EM data, 23% of the *Charcharinidae* sharks and 100% of the hammerhead sharks (*Sphyrnidae*) were identified to the family level, while the observer identified each of them to the species level. Additionally, during the study period, two turtles were caught and released alive, and although all of them were documented by the EM reviewers, it was impossible to determine the species from the imagery. Furthermore, two sailfishes were wrongly identified by EM reviewers. For species with small distinctive identifying characteristics, it seems that the camera views did not allow for images that were clear enough to distinguish to species level. Each of these examples highlights the importance of matching catching handling to EM installation and monitoring objectives, but may also be improved with increased imagery resolution and frame rate.

In the case of other bony fishes and smaller bycatch, these species were generally underestimated by EM, but their presence was well documented. During fishing, these individuals pass directly through the hatch with the rest of the catch, making their observation and identification very difficult. The catch handling methods that were used resulted in a large portion of the bony fishes and small sharks being missed by the EM review process. In most cases, bonny fishes were retained and they were not sorted by crew, and in the case of the small sharks sorting and discarding was done in many different control points. Due to this catch handling method, it was very difficult to accurately estimate the total bycatch by species using EM. In some cases, unwanted fish were discarded with a net at the end of the belt, and were easily monitored with EM. For example, in set number 11 during the second trip, the discard pile was used, and EM based estimates were more accurate than in the other sets. These issues highlight the importance of using standardized catching handling methods onboard in conjunction with EM to ensure complete data capture.

Similar to the challenge of estimating mixed tuna species composition, the high concentration of fish being processed on the conveyor belt presents the biggest challenge for the use of EM, and is one factor complicating the estimation of bycatch in the below-deck area. Some mechanism to organize or manage the volume of fish and to allow the EM system to record the catch in an orderly manner would facilitate the use of EM to document bycatch. A second, and equally important, factor in the underestimation of bycatch by EM is the complex catch handling methods used on the *Playa de Bakio*, given the limited number of cameras on the current EM system, and high number of control points, the monitoring bycatch with EM will be difficult until either more cameras are installed, or fewer control points are used.

### *4.9 Why Where Observer & EM Estimates Different?*

The differences observed in this study are the result of a few factors and a function of the application of the technology as well as the technology itself. In this type of study it is important to recognize that both observer and EM results are estimates; there is no precise benchmark from which to measure EM data accuracy. Observers prioritize their efforts across a range of duties, and some of their results are not direct measurements, but estimates, or are estimates made by others (i.e., taken from the fishing logbook). During brailing, the observer usually worked in the below-deck area, and the collaboration of the crew was necessary to alert the observer when bycatch was being sorted above deck. Since the accuracy of observer estimates are not known, relative differences between the two methods can be due to imprecision with both.

Despite the potential uncertainty, the observer estimates provided a more comprehensive assessment of catch than EM estimates. The EM-based estimates depend on camera imagery from a number of vantage points and it is difficult to cover all areas of catch handling on a tuna purse seiner. The above deck operations were generally well covered and reviewers were able to make basic determinations of target catch volume. As well, large bycatch species could also be assessed if they were handled on the fishing deck; gilled fish were more problematic to view simply because of their small size and limited ability to resolve clearly in the imagery. After the catch was brailed aboard and transferred to the below deck conveyor, imagery reviewers could identify the major species, but with many fish on the conveyor at once, it was difficult to estimate their composition. The high concentration of fish being handled on the conveyor belt presents the biggest challenge for the use of EM, and is one factor complicating the estimation of bycatch in the below-deck area. Some means to organize or manage the volume of fish and to allow the EM system to record the catch in an orderly manner would facilitate the use of EM to document bycatch. The low ceiling height and narrow clearance between the conveyor and ceiling also made it difficult to install cameras with a good vantage point. More cameras would have been an improvement, but the best vantage point for retained catch would be a clear view as the fish are transferred from the conveyor to the well itself. Such a configuration would require many more cameras than were used in this study.

In terms of non-target catch (i.e., catch not placed in the fish wells) there were different catch handling methods used: fish were basketed on deck, placed in baskets from the conveyor, and deposited onto a cargo net at the end of the conveyor. Except for the last, there were too many places where bycatch handling occurred and these locations did not correspond with CCTV camera placements. Consequently, a large portion of the bony fishes were missed by the EM review process. In most cases, these species were retained for crew use or consumption aboard. Due to this catch handling method, it was very difficult to accurately estimate the total bycatch by species using EM. In the instances where bycatch was deposited onto the cargo net at the end of the conveyor belt the EM-based estimate more closely agreed with the observer estimate than in the other sets.

Finally, the EM-based catch assessment was also limited by the quality of imagery itself. The current EM system uses analog CCTV cameras because they are economical, reliable, and quite durable for fishing deck conditions. The lower resolution (about 0.33 megapixels per image) has generally been addressed by setting the field of view of each camera to the desired objective. When there are many activities occurring, more analog cameras are needed to cover the resolution needs properly. Digital cameras are rapidly overtaking the analog camera market with models that are comparable in cost and durability. Digital cameras have much higher image resolution and frame rates and will dramatically improve the ability to make catch assessments. Digital cameras come at a high data storage cost and the challenge of balancing resolution needs with data storage duration becomes more difficult, especially on vessels with 6-8 week fishing trips. With image recording limited to catch processing times, the 1,600 hours of time at sea over three fishing trips resulted in about 160 hours of catch handling time. With this pattern of effort, it would seem that significant improvements in imagery could be achieved without a burdensome addition to data storage.

Potentially the most influential factor in the difference between EM-based and observer estimates was highly distributed catch handling on the vessel. **Figure 20** provides a schematic of catch handling processes aboard the Playa de Bakio, with an assessment of how well the EM imagery could estimate catch. Most areas where catch is handled were moderately or poorly covered by EM cameras. Ideally, catch processing would occur at designated points (‘control points’) and camera placements would align with these activities. Given the limited number of cameras and lack of control points, it is not surprising that detailed catch assessment was difficult. Improvements will be difficult to achieve without more cameras, more structured catch handling (i.e., fewer control points), or both. Thus, we believe that the limited ability to assess catch by EM technology is not just the technology but the application of the technology.

## 5. Conclusion and Recommendations

### *5.1 Conclusion: Feasibility of the EM System*

The two main objectives of this study were (i) to compare the data collected using EM to the data collected by observer to determine if EM systems can be used to reliably collect unbiased data on commercial purse seine vessels, and (ii) to evaluate the operational aspects of the implementation of EM systems for monitoring fishing activity from the perspective of scientists, managers, and fishers. Regarding the first objective, the analyses in this study showed that EM can be used to determine the fishing effort (number of sets), set-type, and total tuna catch as reliably as observers can. In order to be fully comparable with observer data, improvements for accurately estimating the bycatch will need to be developed in the EM system, installation, or review process.

Despite some of the limitations, the EM system, in conjunction with port sampling for species identification and confirmation, will be valuable to gather target species catch statistics when these data are not, or are poorly, collected. For bycatch investigation, the use of EM could be a complementary tool to observers during the data collection process. EM is a useful alternative that could significantly increase the sampling coverage, even if the EM data were limited to effort, location, set-type and tuna catch. There are many cases where full monitoring coverage is demanded for various reasons, mainly due to control and enforcement reasons or objectives. For example, the case of the ICCAT requirement to increase to 100% for purse seiners during a two-month prohibition on FAD fishing in an area off western Africa (ICCAT Rec. 11-01) or for companies seeking “eco label” certification (e.g., Friend of the Sea) which required 100% observer coverage. In cases such as these, EM could function as a useful tool for monitoring fishing.

### *5.2 Recommendations for an Operational Program*

For the second objective of this project, and from an operational perspective, the adoption of EM presents some major challenges given the size of the fleet with different levels of development in various regions, number of countries and companies involved in this fishery, and the complexity of the RFMO decision making processes.

There are several areas of monitoring that will need to be addressed in the future if EM becomes an operational monitoring tool within the tropical tuna purse seine fishery. The first includes the specific aspects relating to the application of the technology including defining the monitoring objectives, installation specifications, data collection specifications, onboard methodology, and data analysis requirements. These elements require careful planning to ensure that the desired data collection objectives are achieved. The second operational element concerns the monitoring program itself; this part specifies how all the operational elements of the program come together in the most efficient and cost effective fashion. Each area presents unique challenges that should be considered as EM is explored as a monitoring tool for deployment on a larger scale.

#### *5.2.1 Monitoring Objectives*

To be effective, monitoring programs must have clear objectives, as defined by the science and management data needs (Zollett *et al.*, 2011). EM shows great promise as a potential tool for monitoring tuna catch, but it is limited in some aspects, and cannot be a “plug-and-play” alternative to observers. As such, industry, managers, and scientists will need to discuss how EM can fit into the overall monitoring program - as a compliment to observers or fishing logbooks, or as a tool for when observers are not an option - each of these presents a variety of possible ways to use EM, and should be considered fully. The development of an EM program would require a set of monitoring objectives that are based on the capabilities and limitations of the technology.

#### *5.2.2 EM Installation*

A fully-implemented EM program would require that RFMOs outline the specific requirements of the EM system and the installation methods. This research suggests that the installation used is sufficient for achieving some monitoring objectives, but refinement of the placement and techniques could further improve the overall data collection. At a minimum, the system should include the ability to capture:

- vessel cruise track,
- set location and set-type,
- equipment activity (i.e., use of hydraulics, winches, etc),
- camera views of:
    - o the brailer coming onboard,

- o the net in the water,
- o all discard handling areas and control points,
- o overview of deck activity,
- o conveyor belt close-up,
- o views of activity below deck (still to be refined),
- o out-to-sea view (for identifying set-type)

These standards will continue to evolve with ongoing research, helping to refine the requirements of the monitoring program.

*5.2.3 Data Specifications and Quality Standards*

In order to ensure that the various components of EM can function efficiently together, there are minimum data standards that need to be maintained by the vessel; these data standards incorporate both sensor and imagery data quality, including:

- EM system is turned on before leaving port/national waters,
- EM system remains powered on for entire trip, until return to port,
- GPS data is continuous throughout the trip,
- Satellite modem transceivers send Health Statement data throughout the trip,
- Cameras are cleaned regularly, and
- Cameras are focused and aimed correctly.

These data quality steps will help to ensure that all of the data that are collected are useful to meeting the monitoring objectives.

*5.2.4 Onboard Methodology*

The success of an EM program would require that the vessel owners and crew understand the importance of standardized catch handling and control points. EM systems are designed to be flexible enough to accommodate a variety of catch handling methods, but handling must be consistent and standardized in order to collect reliable data. For example, if a camera is installed above the discard handling area, and discarding handling is moved to another area of the vessel, the camera view will no longer capture discarding events. This example illustrates the importance of having strong support from the vessel owners, officers and crew to achieve monitoring objectives.

While installing the EM systems, the technician requires a detailed knowledge of the fishing operations to ensure that the system captures imagery of all pertinent events. In an operational program, Vessel Monitoring Plans (VMPs) can be used to ensure that the vessel officers and crew understand and comply with all of the requirements of the use of the EM system. It is important that the program is designed to hold captains and crew accountable for any changes in the catch handling methods that could decrease the effectiveness of EM. The effective use of EM requires that several processes and standards to be put in place (and enforced) in order to successfully achieve the monitoring objectives. In an EM program, the VMP could be used to document changes to catch handling or installation requirements, thus ensuring that objectives are recorded, and met.

*5.2.5 Operational Design of an EM Program*

In addition to the issues outlined above, the overall design of the program is important. While much of the design process can become preoccupied with the choice of technology itself, an EM-based monitoring program design also requires the consideration of the other large service elements. These service elements can have labour cost requirements that are relatively large compared to the capital cost of equipment, and thus require careful design and planning. An operational program involves several groups, including: an EM technology provider, locally-based service providers, and the fishing authority. **Figure 21** provides a schematic diagram of an EM program deployment showing the responsibilities and services that must come from the involved parties during the program development process. There are many options for program design that must be built around the specific characteristics of the fishery.

The role of the technology provider is to provide hardware and software tools and the methodology for their use that can be implemented in a scalable fashion. This could be either a single organization or several, depending on the regulations set by the fishing authority.

The main role of the local service providers are to supply direct support to the fishery to ensure that the EM program operates efficiently and achieves the objectives that have been set out. Local services can be provided by the fisheries authority, one or more contracted service providers, or the technology provider (if they are locally based). The two main functions of local services are data and field services; data services involve tracking, reviewing and analyzing, and storing the data. Data services providers also fill an important communication role by providing feedback to the vessel operators and field service providers about any changes to the installation that are required. Field services involve the installation and maintenance of EM systems, requiring both a strong understanding of the monitoring objectives of the EM program as well as strong technical capabilities and experience working with the fisheries industry. The geographical footprint of the tropical tuna purse seine fishery can present a major logistical challenge for providing a timely response to issues on the fishing vessels with qualified technicians.

Finally, the role of the fisheries authority is to set the overall mandate for an EM program and to ensure that the program outputs are used to effectively manage the fishery. The fisheries authority is directly involved with the program design and working closely with the technology provider, the local services provider, and industry. There is usually a high level of interaction between these groups aimed at improving the quality of information, keeping the program aligned with the monitoring objectives, and making improvements to operational efficiencies to reduce cost and improve the program effectiveness. This overall framework is crucial to a successful EM program.

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**Table 1.** Dates and number (Nº) of fishing operations during the three sampled trips.

| *Trip* | *Departure* | *Return* | *No. of Sets* |
|---|---|---|---|
| 1 | 28/11/2011 | 25/01/2012 | 26 |
| 2 | 03/02/2012 | 14/02/2012 | 13 |
| 3 | 17/02/2012 | 27/03/2012 | 22 |

**Table 2.** *Playa de Bakio* details.

| *Identification* | *Dimensions* |
|---|---|
| **Flag**: Spanish | **Overall Length**: 75,60 M |
| **Year Built**: 1991, Spain | **LPP**: 67,92 M |
| **Registration Number**: Bi-2-1-91 | **Breadth**: 13,6 M |
| **IMO**: 9010345 | **Depth**: 9,05 M |
| **Call Sign**: EGWJ | **Draught**: 6,62 M |
| **Port of Registry**: Bermeo | **Hull Material**: Steel |
| **Operating Zone**: FAO Zone 34 | **Number Of Holds**: 18 |

**Table 3.** Summary of data capture success for the above-deck system. Time gaps are periods of time when the system was not running.

| *Trip* | *Trip (hrs)* | *Nº of Sets* | *Time Gaps* | *Time Gap (hrs)* | *Data Success (%)* | *Total GPS Gaps* | *GPS Gaps (hrs)* | *GPS Success (%)* |
|---|---|---|---|---|---|---|---|---|
| 1 | 1353.7 | 26 | 28 | 77.7 | 94.3 | 1 | 0.7 | 99.9 |
| 2 | 234.0 | 13 | 0 | 0.0 | 100.0 | 0 | 0.0 | 100.0 |
| 3 | 924.4 | 22 | 4 | 18.2 | 98.0 | 2 | 0.02 | 100.0 |
| | **1587.7** | **61** | **28** | **77.7** | **95.1** | **1** | **0.7** | **100.0** |

**Table 4.** Summary of imagery data success for the above-deck system. Imagery gaps are periods of time when and imagery was expected (i.e., during sets) but none was recorded.

| *Trip* | *Nº of Sets* | *Sets With Imagery Gaps* | *Total Set (hrs)* | *Imagery Gaps* | *Imagery Gap (hrs)* | *Imagery Success (%)* |
|---|---|---|---|---|---|---|
| 1 | 26 | 1 | 69.4 | 1 | 0.3 | 99.6% |
| 2 | 13 | 0 | 33.6 | 0 | 0 | 100.0% |
| 3 | 22 | 0 | 53.2 | 0 | 0 | 100.0% |
| | **61** | **1** | **156.2** | **1** | **0.3** | **99.8%** |

**Table 5.** Summary of data capture success for the below-deck system. Time gaps are periods of time when the system was not running.

| *Trip* | *Trip (hrs)* | *Time Gaps* | *Time Gap (hrs)* | *Data Success (%)* | *Total GPS Gaps* | *GPS Gaps (hrs)* | *GPS Success (%)* |
|---|---|---|---|---|---|---|---|
| 1 | 1362.8 | 198 | 143 | 89.5 | 129 | 592 | 56.6 |
| 2 | 234.0 | 0 | 0 | 100 | 0 | 0 | 100 |
| 3 | 924.4 | 2 | 96.7 | 89.5 | 0 | 0 | 100 |
| | **1596.8** | **198** | **143.0** | **91.0** | **129** | **592.0** | **62.9** |

**Table 6.** Summary of imagery quality for each set in trip 2 and 3. Each set had approximately two separate imagery files associated with it.

| *Set-type* | *Nº Sets* | *Nº Imagery Files* | *Image quality* | | |
|---|---|---|---|---|---|
| | | | *Low* | *Medium* | *High* |
| FAD | 15 | 30 | 7 | 13 | 10 |
| Free Sch | 17 | 34 | 2 | 10 | 22 |
| NULL | 3 | 4 | 0 | 0 | 4 |
| Total | 35 | 68 | 9 | 23 | 36 |

**Table 7.** Summary of review time (minutes), and mean review time/set (minutes) per set-type (FAD, free school, or null set) for trips 2 and 3.

| *Set-type* | *Nº of Sets* | *Total review time* | *Mean review time/set* |
|---|---|---|---|
| FAD | 15 | 1021.9 | 68.13 |
| Free Sch | 17 | 825 | 48.53 |
| NULL | 3 | 71.5 | 23.83 |
| **Total** | **35** | **1918.4** | **54.81** |

**Table 8.** Wilcoxon signed-rank test comparing the medians of the estimated proportion of weight from observers (Obs) and EM. $H_0$ is the hypothesis, and *V* and *p*-value are the results of the test.

| *Species* | *Ho* | *V* | *p-value* |
|---|---|---|---|
| SKJ | $m_{EM} \leq m_{Obs}$ | 456.5 | 0.02092* |
| YFT | $m_{EM} \geq m_{Obs}$ | 162 | 0.0105* |
| AUX | $m_{EM} = m_{Obs}$ | 31 | 0.05911 |
| BET | $m_{EM} = m_{Obs}$ | 87.5 | 0.5256 |
| LTA | $m_{EM} = m_{Obs}$ | 3 | 1 |

* p<0.05, significantly different
** Not enough data ≠0 to make the test (see **Table 1**)

**Table 9.** Discarded tuna estimated (tons) by observers and using EM for sets where tuna discards were recorded.

| | | *EM System estimates* | | | | *Observer estimates* | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *SET* | *SKJ* | *YFT* | *AUX* | *TOTAL* | *SKJ* | *YFT* | *AUX* | *TOTAL* |
| 1 | 19 | | | | 0.00 | 0.20 | | | 0.20 |
| 1 | 20 | | | | 0.00 | | 0.20 | | 0.20 |
| 2 | 9 | 0.50 | | | 0.50 | 2.00 | | 0.50 | 2.50 |
| 2 | 10 | 0.10 | | | 0.10 | | | | 0.00 |
| 3 | 2 | 0.20 | | | 0.20 | | | | 0.00 |

**Table 10.** McNemar’s test results comparing the estimated presence/absence data from EM and observers for *Makaira nigricans* (BUM), *Istiophorus albicans (*SAI) and *Carcharinidae* (CFA + FCA).

| | *BUM* | *SAI* | *CFA +FCA* |
|---|---|---|---|
| statistic.McNemar's chi-squared | 0.3333 | 3 | 6.4 |
| parameter.df | 1 | 1 | 1 |
| p.value | 0.5637 | 0.08326 | 0.01141* |

*p<0.05 significantly different

**Table 11.** Wilcoxon signed-rank test comparing the medians of the estimated weight from observers (Obs) and EM of other bony fishes. $H_0$ is the hypothesis and *V*, *p*-value the results of the test. *p<0.05 significantly different.

| *Species* | *Ho* | *V* | *p-value* |
|---|---|---|---|
| BCM | mEM≥ mObs | 27 | 7.714e-06* |
| CRY | mEM≥ mObs | 25 | 2.589e-06* |
| COH | mEM ≥mObs | 49.5 | 0.0006727* |
| WAH | mEM≥ mObs | 61 | 0.003192* |
| ELP | mEM≥ mObs | 120 | 0.001237* |

**Table 12.** McNemar’s test results (statistic.McNemar's chi-squared, parameter.df, *p*.value) when the estimated presence/absence data from EM and observers’ were compared. The analysis is done for KPS, LOB, SER and FBA bony fish species.

| | *KPS* | *LOB* | *SER* | *FBA* |
|---|---|---|---|---|
| Statistic.McNemar's chi-squared | 12 | 11 | 11 | 0.3333333 |
| Parameter.df | 1 | 1 | 1 | 1 |
| p.value | 0.00053201* | 0.00091112* | 0.00091112* | 0.5637029 |

*p<0.05 significantly different.

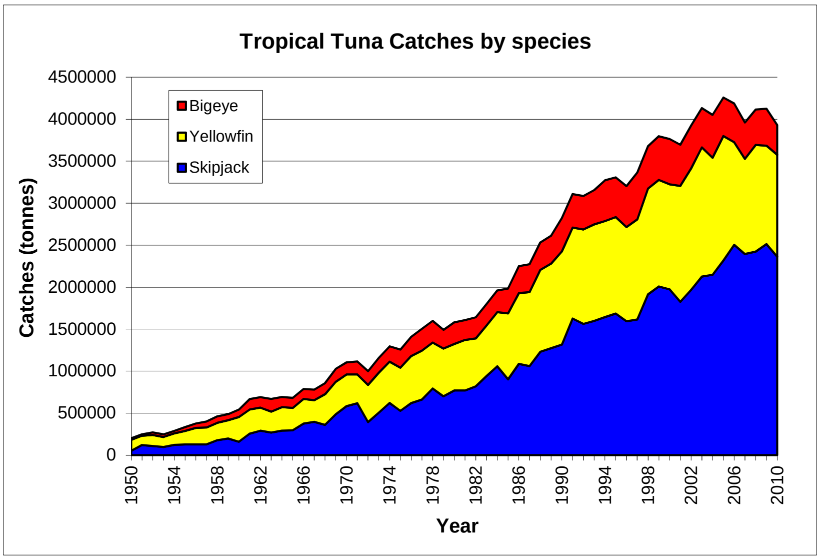



**Figure 1.** Global tropical tuna catch by species for skipjack, yellowfin and bigeye tuna from 1950 to 2012.

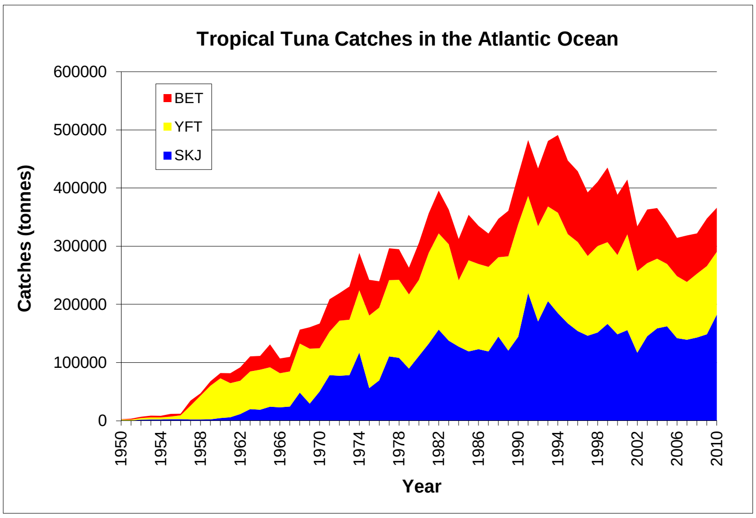



**Figure 2.** Tropical tuna catch in the Atlantic Ocean by species, including bigeye (BET), yellowfin (YFT), and skipjack (SKJ).

**Figure 3.** F/V *Playa de Bakio.*

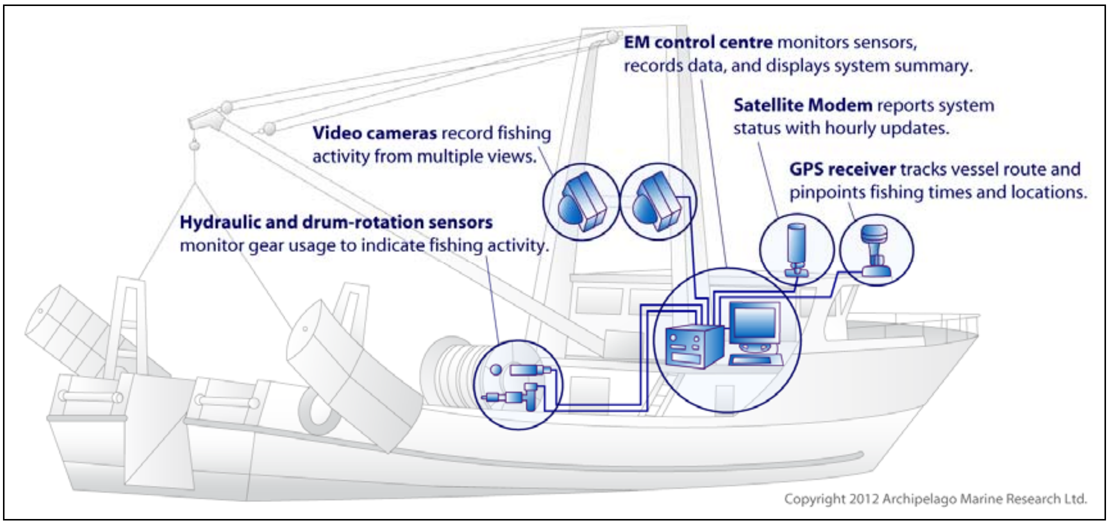



**Figure 4.** Schematic of a standard EM system.

**Figure 5.** Original camera views from the above-deck and below-deck EM system cameras as installed in November, 2012.

**Figure 6.** Camera views from the above-deck and below-deck EM system cameras after the inter-trip service in January, 2012.

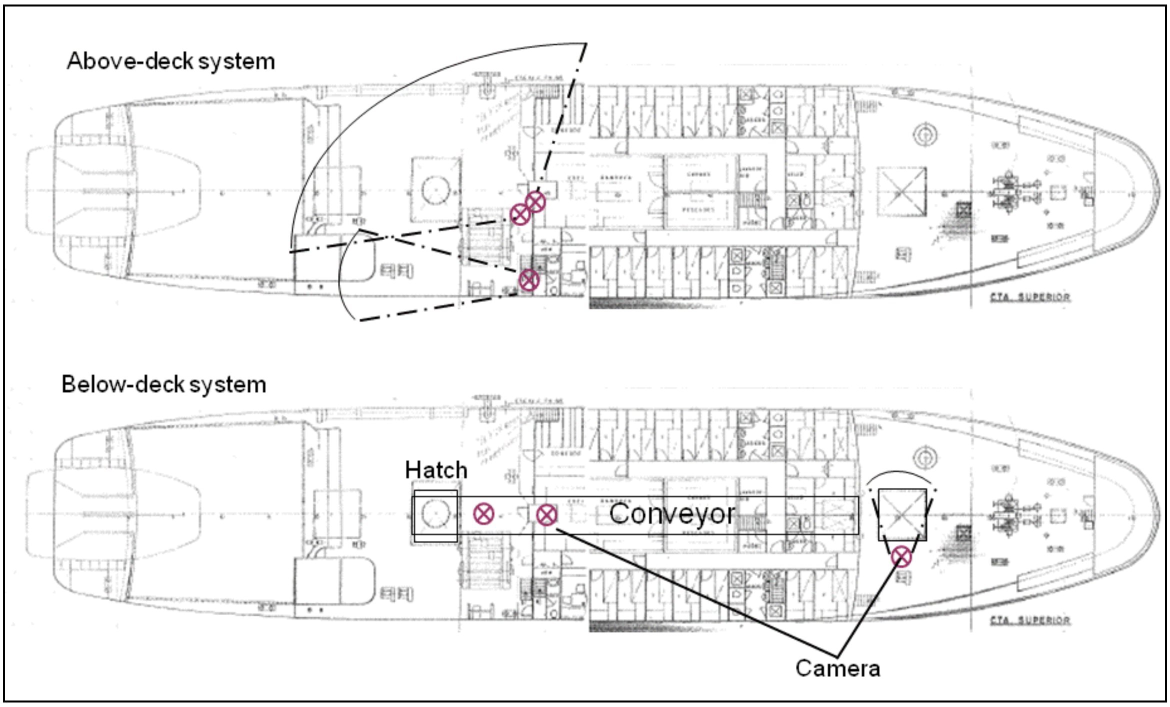



**Figure 7.** Final location and field of view for each of the cameras installed as part of the EM systems.

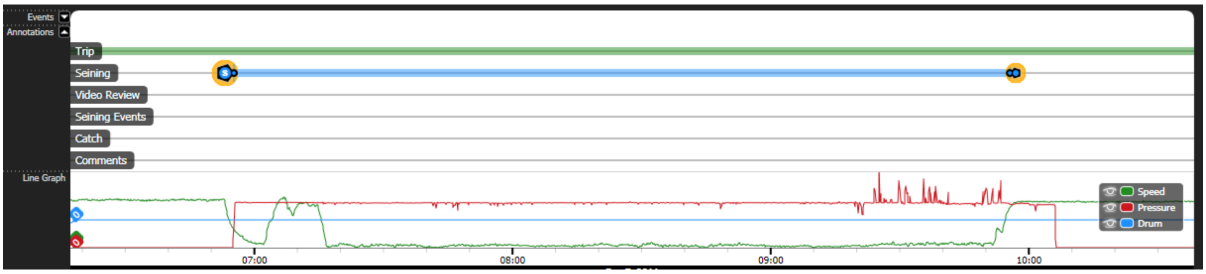



**Figure 8.** Example of EM sensor data collected for a typical purse seine set.

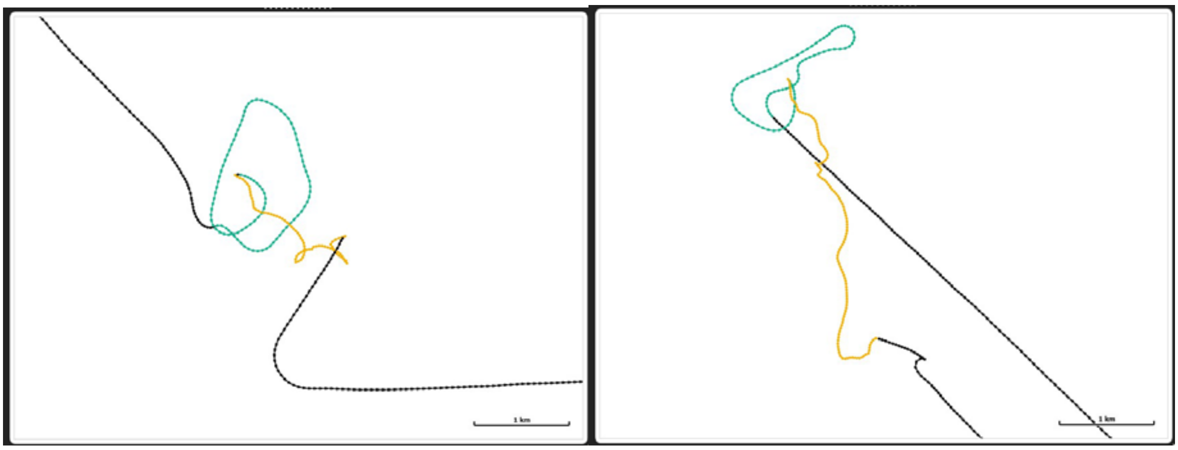



**Figure 9.** Examples of the cruise tracks for sets from January 2 (left) and January 19, 2012 (right). Blue-green indicates when the net was being set, and orange indicates when the net was being pursed, sacked and brailed.


**Figure 10.** Example of a FAD visible within camera view during a set.

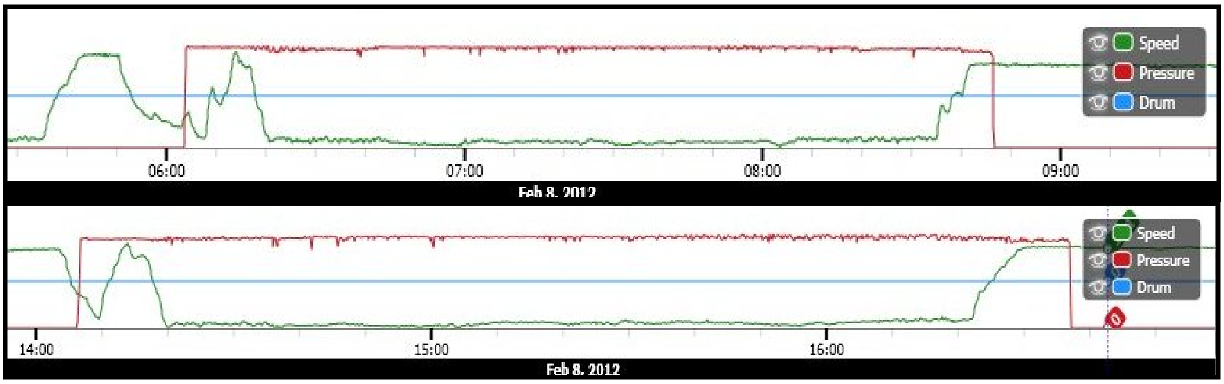



**Figure 11.** Examples of two typical sensor data sets for FAD fishing on the *Playa de Bakio*, February 8, 2012.

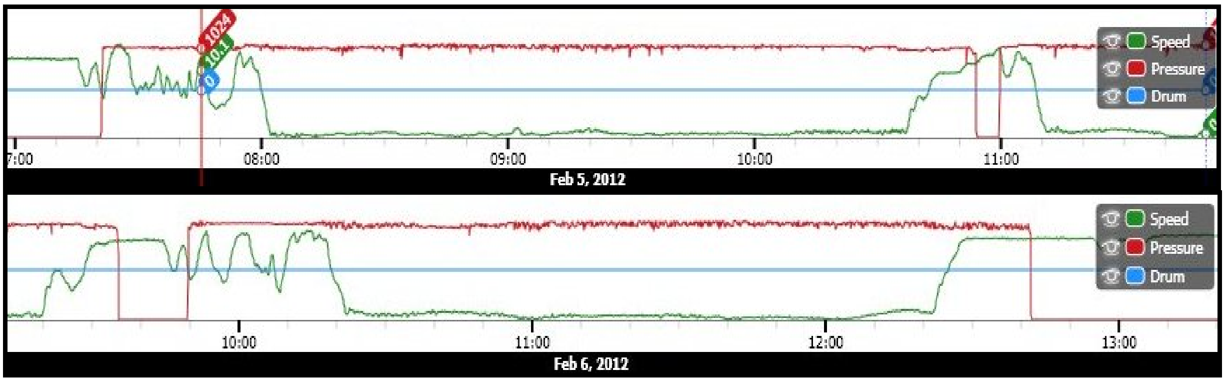



**Figure 12.** Example of two typical sensor data sets for free-school fishing on the *Playa de Bakio*, February 5 and 6, 2012.

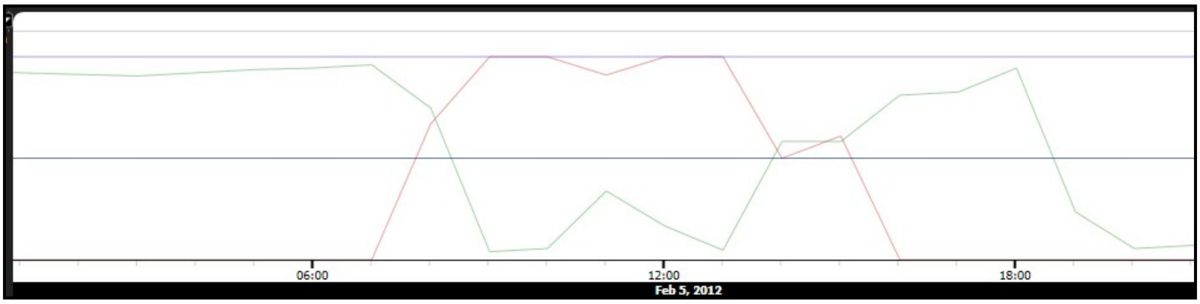



**Figure 13.** Health Statement viewer data for February 5, 2012. Two sets were fished, however, these sets were not easily identified using the Health Statements. The red line indicates the percentage of time that the hydraulic pressure was over the trigger value, and the green line indicates the mean vessel speed.

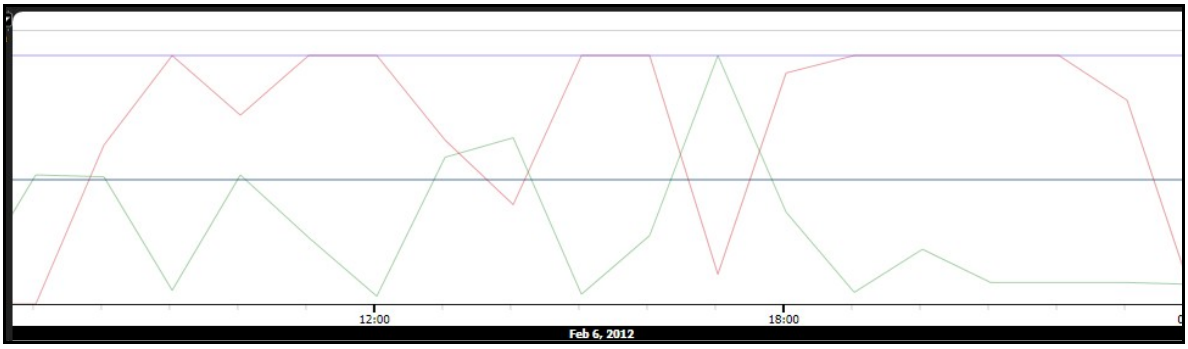



**Figure 14.** Health Statement viewer data for February 6, 2012. Four sets were fished, however, these set were not easily identified using the hourly Health Statements. The red line indicates the percentage of time that the hydraulic pressure was over the trigger value, and the green line indicates the mean vessel speed.

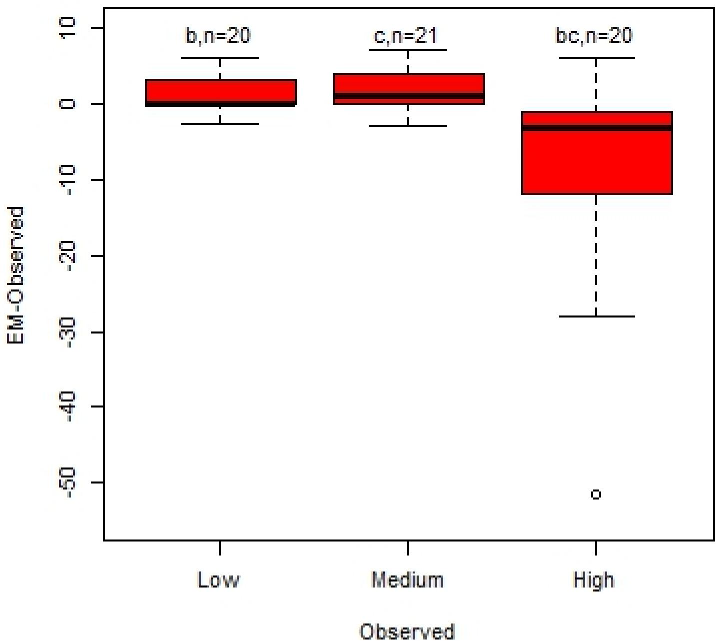



**Figure 15.** Boxplot of the differences between the tuna weight (tons) from EM and observers (y-axis) at three catch weight classes: low [0,9 ton], medium (9,20 ton], and high (20, 150 ton]. *b* means that the medians of the differences between the estimated total retained weights distributions by both methods were significantly different ($p<0.05$) when the estimated total catch weight is low or high (Mann-Whitney U test), and *c* when the estimated weight is medium (see **Annex 1, Table 4**,). *n* is the number of data points in each class.

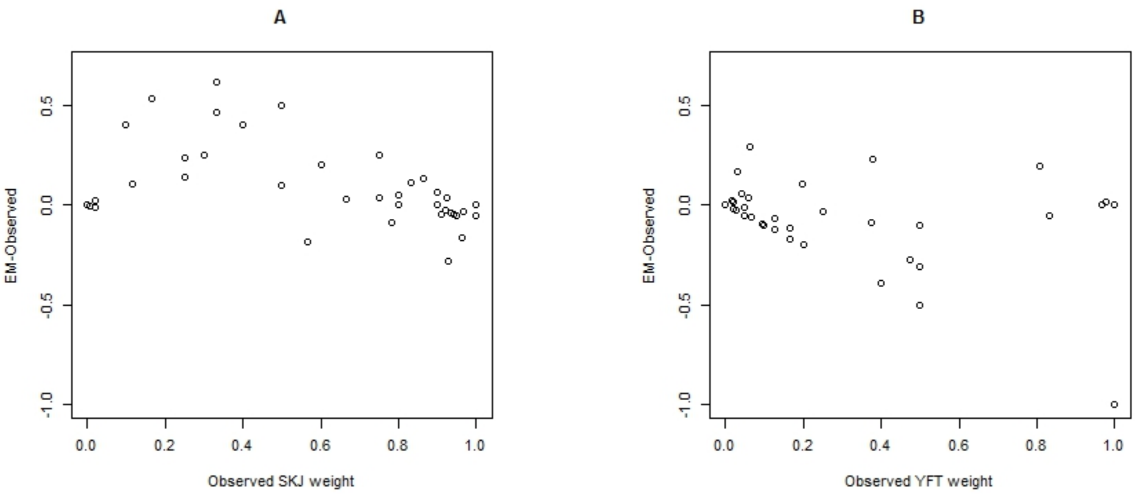



**Figure 16.** Plot of the differences between the estimated proportion of weight of SKJ (A) and YFT (B) tuna from EM (y-axis) and observer (x-axis) data at different proportions of weight of SKJ or YFT tuna estimated from observers.

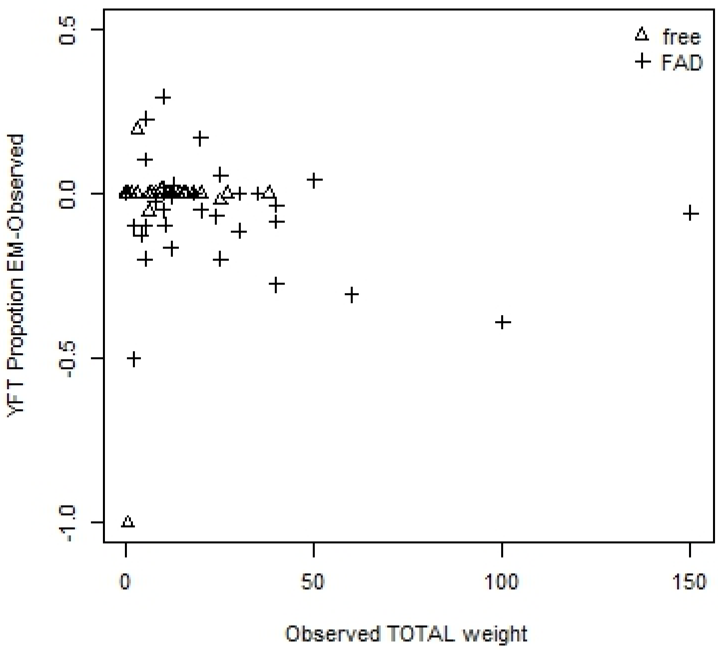



**Figure 17.** Plot of the differences between the estimated proportion of weight of YFT from EM and observers (y-axis) at different total weight per set estimated from observers (x-axis) for free school (triangles) and FAD sets (crosses).

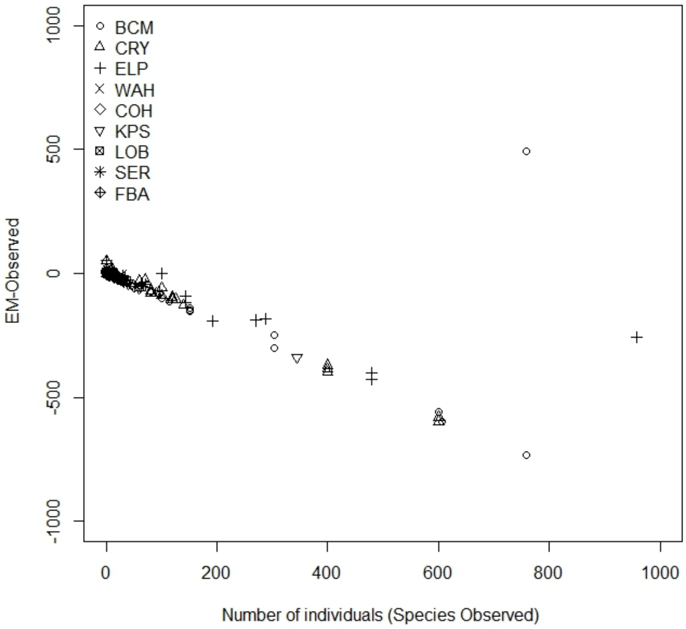



**Figure 18.** Plot of the differences between the estimated number of bony fishes from EM and observers (y-axis) at different number of individuals estimated by observer (x-axis).

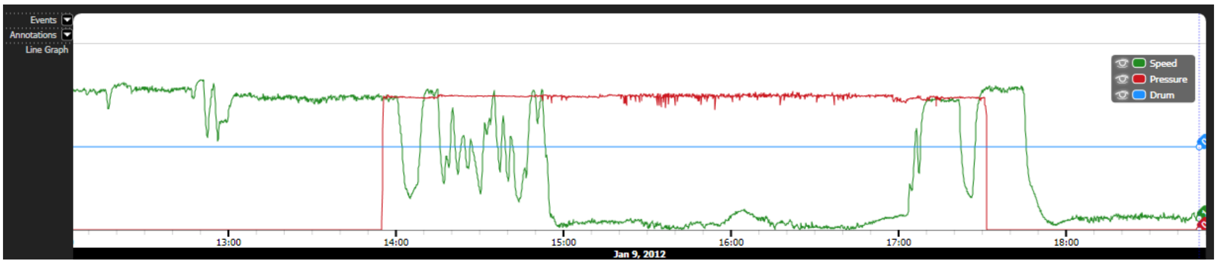



**Figure 19.** Sensor data for a set on January 9, 2012, which was wrongly identified from the imagery review as a FAD set. Sensor data is consistent with free-school set sensor data (i.e., highly variable speed at the beginning of the set).

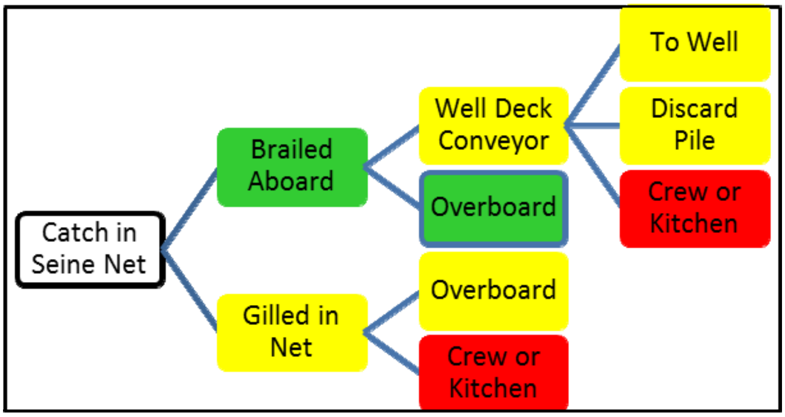



**Figure 20.** Schematic of catch handling processes aboard the Playa de Bakio. Green shows catch handling processes that were well covered by EM imagery, yellow shows moderate coverage, and red shows a low ability to monitor.

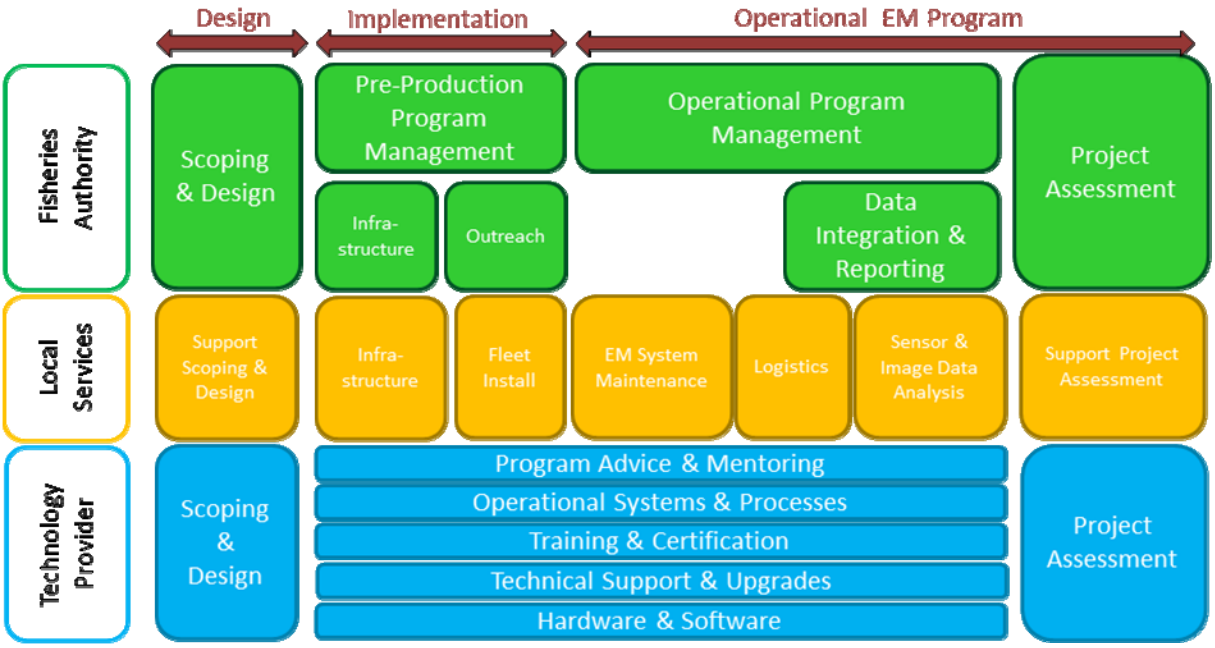



**Figure 21.** Schematic diagram of an operational EM program showing principle program elements by the technology provider, local services provider and the fisheries authority over the implementation cycle.

**Annex 1-Table 1.** Set-type as identified by the observer and by EM reviewer. Only one discrepancy exists between the two monitoring methods (Trip 1, Set 21).

| Trip | Set | Date | Set-type (observer) | Set-type (EM system) |
|---|---|---|---|---|
| 1 | 1 | 03-Dec-11 | FAD | FAD |
| 1 | 2 | 04-Dec-11 | FAD | FAD |
| 1 | 3 | 06-Dec-11 | FAD | FAD |
| 1 | 4 | 07-Dec-11 | FAD | FAD |
| 1 | 5 | 09-Dec-11 | FAD | FAD |
| 1 | 6 | 10-Dec-11 | FAD | FAD |
| 1 | 7 | 12-Dec-11 | FAD | FAD |
| 1 | 8 | 13-Dec-11 | FAD | FAD |
| 1 | 9 | 16-Dec-11 | FAD | FAD |
| 1 | 10 | 17-Dec-11 | FAD | FAD |
| 1 | 11 | 21-Dec-11 | FAD | FAD |
| 1 | 12 | 23-Dec-11 | FAD | FAD |
| 1 | 13 | 24-Dec-11 | FAD | FAD |
| 1 | 14 | 26-Dec-11 | FAD | FAD |
| 1 | 15 | 29-Dec-11 | FAD | FAD |
| 1 | 16 | 30-Dec-11 | FAD | FAD |
| 1 | 17 | 01-Jan-12 | FAD | FAD |
| 1 | 18 | 02-Jan-12 | FAD | FAD |
| 1 | 19 | 04-Jan-12 | FAD | FAD |
| 1 | 20 | 07-Jan-12 | FAD | FAD |
| 1 | 21 | 07-Jan-12 | FSC | FAD |
| 1 | 22 | 09-Jan-12 | FSC | FSC |
| 1 | 23 | 12-Jan-12 | FSC | FSC |
| 1 | 24 | 19-Jan-12 | FAD | FAD |
| 1 | 25 | 22-Jan-12 | FAD | FAD |
| 1 | 26 | 24-Jan-12 | FAD | FAD |
| 2 | 1 | 05-Feb-12 | FSC | FSC |
| 2 | 2 | 05-Feb-12 | FSC | FSC |
| 2 | 3 | 06-Feb-12 | FSC | FSC |
| 2 | 4 | 06-Feb-12 | FSC | FSC |
| 2 | 5 | 06-Feb-12 | FSC | FSC |
| 2 | 6 | 06-Feb-12 | FSC | FSC |
| 2 | 7 | 08-Feb-12 | FAD | FAD |
| 2 | 8 | 08-Feb-12 | FAD | FAD |
| 2 | 9 | 09-Feb-12 | FAD | FAD |
| 2 | 10 | 11-Feb-12 | FAD | FAD |
| 2 | 11 | 11-Feb-12 | FAD | FAD |
| 2 | 12 | 12-Feb-12 | FAD | FAD |
| 2 | 13 | 12-Feb-12 | FAD | FAD |
| 3 | 1 | 17-Feb-12 | FAD | FAD |
| 3 | 2 | 19-Feb-12 | FAD | FAD |
| 3 | 3 | 27-Feb-12 | FSC | FSC |
| 3 | 4 | 28-Feb-12 | FSC | FSC |
| 3 | 5 | 28-Feb-12 | FSC | FSC |
| 3 | 6 | 29-Feb-12 | FSC | FSC |
| 3 | 7 | 29-Feb-12 | FSC | FSC |
| 3 | 8 | 01-Mar-12 | FSC | FSC |
| 3 | 9 | 03-Mar-12 | FSC | FSC |
| 3 | 10 | 07-Mar-12 | FSC | FSC |
| 3 | 11 | 09-Mar-12 | FSC | FSC |
| 3 | 12 | 09-Mar-12 | FSC | FSC |
| 3 | 13 | 14-Mar-12 | FAD | FAD |
| 3 | 14 | 16-Mar-12 | FAD | FAD |
| 3 | 15 | 16-Mar-12 | FSC | FSC |
| 3 | 16 | 16-Mar-12 | FSC | FSC |
| 3 | 17 | 17-Mar-12 | FSC | FSC |
| 3 | 18 | 18-Mar-12 | FSC | FSC |
| 3 | 19 | 23-Mar-12 | FAD | FAD |
| 3 | 20 | 25-Mar-12 | FAD | FAD |
| 3 | 21 | 26-Mar-12 | FAD | FAD |
| 3 | 22 | 26-Mar-12 | FAD | FAD |

**Annex 1-Table 2.** Tuna catch estimates by species made by observer and using EM. During the first two sets, the below-deck system did not record images and it was impossible to estimate tuna catch by species.

| | | *EM-based Estimates* | | | | | | *Observer estimates* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *SET* | *BET* | *SKJ* | *YFT* | *AUX* | *LTA* | *TOTAL* | *BET* | *SKJ* | *YFT* | *AUX* | *LTA* | *ALB* | *TOTAL* |
| 1 | 1 | | | | | | **39.0** | 2.0 | 36.0 | 2.0 | 0.0 | 0.0 | 0.0 | **40.0** |
| 1 | 2 | | | | | | **68.0** | 0.0 | 95.0 | 1.0 | 0.0 | 0.0 | 0.0 | **96.0** |
| 1 | 3 | 0.8 | 15.2 | 0.0 | 0.0 | 0.0 | **16.0** | 0.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | **10.0** |
| 1 | 4 | 4.8 | 19.2 | 0.0 | 0.0 | 0.0 | **24.0** | 10.0 | 10.0 | 5.0 | 0.0 | 0.0 | 0.0 | **25.0** |
| 1 | 5 | 0.0 | 23.8 | 1.3 | 0.0 | 0.0 | **25.1** | 15.0 | 10.0 | 5.0 | 0.0 | 0.0 | 0.0 | **30.0** |
| 1 | 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| 1 | 7 | 5.1 | 11.9 | 0.0 | 0.0 | 0.0 | **17.0** | 15.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.0 | **18.0** |
| 1 | 8 | 11.0 | 13.2 | 9.9 | 0.0 | 0.0 | **34.1** | 15.0 | 10.0 | 15.0 | 0.0 | 0.0 | 0.0 | **40.0** |
| 1 | 9 | 3.9 | 9.1 | 0.0 | 0.0 | 0.0 | **13.0** | 2.0 | 8.0 | 2.0 | 0.0 | 0.0 | 0.0 | **12.0** |
| 1 | 10 | 0.8 | 4.3 | 0.0 | 0.0 | 0.0 | **5.0** | 0.5 | 4.0 | 0.5 | 0.0 | 0.0 | 0.0 | **5.0** |
| 1 | 11 | 3.2 | 28.8 | 0.0 | 0.0 | 0.0 | **32.0** | 0.0 | 33.0 | 0.0 | 2.0 | 0.0 | 0.0 | **35.0** |
| 1 | 12 | 9.4 | 88.2 | 0.8 | 0.0 | 0.0 | **98.4** | 0.0 | 140.0 | 10.0 | 0.0 | 0.0 | 0.0 | **150.0** |
| 1 | 13 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | **12.0** | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | 0.0 | **12.0** |
| 1 | 14 | 12.0 | 20.0 | 8.0 | 0.0 | 0.0 | **40.0** | 17.0 | 4.0 | 19.0 | 0.0 | 0.0 | 0.0 | **40.0** |
| 1 | 15 | 4.8 | 19.2 | 0.0 | 0.0 | 0.0 | **24.0** | 20.0 | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | **30.0** |
| 1 | 16 | 0.0 | 28.8 | 7.9 | 0.0 | 0.0 | **36.7** | 0.0 | 30.0 | 10.0 | 0.0 | 0.0 | 0.0 | **40.0** |
| 1 | 17 | 13.0 | 20.0 | 8.0 | 0.0 | 0.0 | **41.0** | 15.0 | 15.0 | 30.0 | 0.0 | 0.0 | 0.0 | **60.0** |
| 1 | 18 | 2.2 | 8.8 | 0.0 | 0.0 | 0.0 | **11.0** | 1.0 | 3.0 | 1.0 | 0.0 | 0.0 | 0.0 | **5.0** |
| 1 | 19 | 1.7 | 15.3 | 0.0 | 0.0 | 0.0 | **17.0** | 0.0 | 19.0 | 1.0 | 0.0 | 0.0 | 0.0 | **20.0** |
| 1 | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **20.0** | 0.0 | 19.0 | 0.0 | 0.5 | 0.0 | 0.0 | **19.5** |
| 1 | 21 | 0.0 | 0.0 | 27.0 | 0.0 | 0.0 | **27.0** | 0.0 | 0.0 | 35.0 | 0.0 | 0.0 | 0.0 | **35.0** |
| 1 | 22 | 0.0 | 0.0 | 7.0 | 0.0 | 0.0 | **7.0** | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 | 0.0 | **6.0** |
| 1 | 23 | 0.0 | 0.0 | 27.0 | 0.0 | 0.0 | **27.0** | 0.0 | 0.0 | 20.0 | 0.0 | 0.0 | 0.0 | **20.0** |
| 1 | 24 | 34.8 | 43.5 | 0.9 | 0.0 | 0.0 | **79.2** | 30.0 | 30.0 | 40.0 | 0.0 | 0.0 | 0.0 | **100.0** |
| 1 | 25 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **124.0** | 2.0 | 122.0 | 12.0 | 4.0 | 0.0 | 0.0 | **140.0** |
| 1 | 26 | 0.0 | 4.0 | 0.0 | 0.0 | 0.0 | **5.0** | 0.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | **2.0** |
| **1** | **Total** | **107.5** | **385.2** | **97.8** | **0.0** | **0.0** | **842.4** | **144.5** | **624.0** | **215.5** | **6.5** | **0.0** | **0.0** | **990.5** |
| 2 | 1 | 0.0 | 0.0 | 41.0 | 0.0 | 0.0 | **41.0** | 0.0 | 0.0 | 38.0 | 0.0 | 0.0 | 0.0 | **38.0** |
| 2 | 2 | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 | **18.0** | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 | 0.0 | **18.0** |
| 2 | 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | **0.3** |
| 2 | 4 | 0.0 | 0.0 | 17.0 | 0.0 | 0.0 | **17.0** | 0.0 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | **12.0** |
| 2 | 5 | 0.0 | 0.0 | 9.0 | 0.0 | 0.0 | **9.0** | 0.0 | 0.0 | 6.0 | 0.0 | 0.0 | 0.0 | **6.0** |
| 2 | 6 | 0.0 | 0.0 | 14.0 | 0.0 | 0.0 | **14.0** | 0.0 | 0.0 | 8.0 | 0.0 | 0.0 | 0.0 | **8.0** |
| 2 | 7 | 0.0 | 28.3 | 1.7 | 0.0 | 0.0 | **30.0** | 0.5 | 20.0 | 3.0 | 0.5 | 0.0 | 0.0 | **24.0** |
| 2 | 8 | 0.0 | 12.6 | 0.5 | 0.9 | 0.0 | **14.0** | 0.5 | 9.0 | 0.2 | 0.3 | 0.0 | 0.0 | **10.0** |
| 2 | 9 | 4.4 | 39.0 | 4.9 | 0.4 | 0.0 | **48.7** | 6.0 | 40.0 | 3.0 | 1.0 | 0.0 | 0.0 | **50.0** |
| 2 | 10 | 0.0 | 20.5 | 2.2 | 0.2 | 0.0 | **22.9** | 0.5 | 23.0 | 1.0 | 0.5 | 0.0 | 0.0 | **25.0** |
| 2 | 11 | 0.0 | 6.0 | 0.0 | 0.0 | 0.0 | **6.0** | 0.3 | 3.0 | 0.5 | 0.2 | 0.0 | 0.0 | **4.0** |
| 2 | 12 | 0.0 | 12.0 | 0.0 | 0.0 | 0.0 | **12.0** | 0.2 | 9.0 | 1.0 | 0.2 | 0.0 | 0.0 | **10.4** |

| | | *EM-based Estimates* | | | | | | *Observer estimates* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *SET* | *BET* | *SKJ* | *YFT* | *AUX* | *LTA* | *TOTAL* | *BET* | *SKJ* | *YFT* | *AUX* | *LTA* | *ALB* | *TOTAL* |
| 2 | 13 | 0.0 | 4.3 | 0.0 | 0.7 | 0.0 | **5.0** | 0.0 | 7.0 | 0.2 | 0.5 | 0.0 | 0.0 | **7.7** |
| **2** | **Total** | **4.4** | **122.7** | **108.3** | **2.2** | **0.0** | **237.6** | **8.0** | **111.0** | **91.2** | **3.2** | **0.0** | **0.0** | **213.4** |
| 3 | 1.0 | 0.0 | 1.9 | 3.0 | 0.1 | 0.0 | **5.0** | 0.0 | 3.0 | 2.0 | 0.3 | 0.0 | 0.0 | **5.3** |
| 3 | 2.0 | 0.0 | 4.2 | 1.8 | 0.0 | 0.0 | **6.0** | 0.0 | 4.0 | 1.0 | 0.1 | 0.0 | 0.0 | **5.1** |
| 3 | 3.0 | 0.0 | 0.0 | 14.0 | 0.0 | 0.0 | **14.0** | 0.0 | 0.0 | 14.0 | 0.0 | 0.0 | 0.0 | **14.0** |
| 3 | 4.0 | 0.0 | 0.0 | 0.4 | 0.0 | 0.0 | **0.4** | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | **0.3** |
| 3 | 5.0 | 0.0 | 0.0 | 10.0 | 0.0 | 0.0 | **10.0** | 0.0 | 0.0 | 7.0 | 0.0 | 0.0 | 0.0 | **7.0** |
| 3 | 6.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | **3.0** | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.6 | **3.1** |
| 3 | 7.0 | 0.0 | 0.0 | 24.0 | 0.0 | 0.0 | **24.0** | 0.0 | 0.0 | 27.0 | 0.0 | 0.0 | 0.0 | **27.0** |
| 3 | 8.0 | 0.0 | 0.0 | 15.0 | 0.0 | 0.0 | **15.0** | 0.0 | 0.0 | 16.0 | 0.0 | 0.0 | 0.0 | **16.0** |
| 3 | 9.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| 3 | 10.0 | 0.0 | 0.0 | 13.0 | 0.0 | 0.0 | **13.0** | 0.0 | 0.0 | 11.0 | 0.0 | 0.0 | 0.0 | **11.0** |
| 3 | 11.0 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | **1.0** | 0.0 | 0.0 | 1.2 | 0.0 | 0.0 | 0.0 | **1.2** |
| 3 | 12.0 | 0.0 | 0.1 | 12.9 | 0.0 | 0.0 | **13.0** | 0.0 | 0.2 | 9.0 | 0.0 | 0.0 | 0.0 | **9.2** |
| 3 | 13.0 | 0.0 | 0.6 | 0.4 | 0.0 | 0.0 | **1.0** | 0.0 | 1.0 | 1.0 | 0.0 | 0.0 | 0.0 | **2.0** |
| 3 | 14.0 | 0.0 | 13.9 | 0.0 | 0.2 | 0.3 | **14.4** | 0.0 | 9.0 | 0.5 | 0.3 | 0.2 | 0.0 | **10.0** |
| 3 | 15.0 | 0.0 | 2.2 | 7.8 | 0.0 | 0.0 | **10.0** | 0.0 | 0.7 | 5.0 | 0.0 | 0.3 | 0.0 | **6.0** |
| 3 | 16.0 | 0.0 | 0.0 | 19.2 | 0.0 | 0.6 | **19.8** | 0.0 | 0.1 | 15.0 | 0.1 | 0.3 | 0.0 | **15.5** |
| 3 | 17.0 | 0.0 | 1.0 | 0.0 | 0.0 | 24.0 | **25.0** | 0.0 | 0.5 | 0.5 | 0.0 | 24.0 | 0.0 | **25.0** |
| 3 | 18.0 | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | **3.0** | 0.0 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | **3.0** |
| 3 | 19.0 | 0.0 | 11.5 | 0.5 | 0.0 | 0.0 | **12.0** | 0.0 | 11.0 | 0.6 | 0.3 | 0.0 | 0.0 | **11.9** |
| 3 | 20.0 | 0.0 | 11.1 | 0.5 | 0.3 | 0.0 | **11.9** | 0.0 | 12.0 | 0.2 | 0.2 | 0.0 | 0.0 | **12.4** |
| 3 | 21.0 | 0.0 | 18.4 | 4.6 | 0.0 | 0.0 | **23.0** | 0.0 | 19.0 | 0.6 | 0.1 | 0.0 | 0.0 | **19.7** |
| 3 | 22.0 | 0.0 | 5.8 | 3.2 | 0.0 | 0.0 | **9.0** | 0.0 | 9.0 | 0.6 | 0.1 | 0.0 | 0.0 | **9.7** |
| **3** | **Total** | **0.0** | **70.7** | **137.3** | **0.6** | **24.9** | **233.5** | **0.0** | **69.5** | **118.0** | **1.5** | **24.8** | **0.6** | **214.4** |

**Annex 1-Table 3.** Mann-Whitney U test comparing the medians of the estimated proportion of weight from observers (Obs) and video monitoring (EM) for a given species at different weight levels of observed total weight: 1st class (low), 2nd class (medium), 3rd class (high). $H_0$ is the hypothesis and *Wa/Wb/Wc*, *pa/pb/pc* the results of each test. *b* when class1 vs. class 3 and *c* when class 2 vs. class 3.

| *Species* | *$H_0$* | *1st cl* | *2nd cl* | *3rd cl* | *Wa / Wb / Wc* | *Pa / Pb / Pc -value* | *Sig* |
|---|---|---|---|---|---|---|---|
| Total | $m_{EMi-Obsi,TOTAL} = m_{EMj-Obsj,TOTAL}$ i,j=1,2,3 j≠i | [0,9] | (9,20] | (20,150] | 184 / 344.5 / 367.5 | 0.504 / 0.000* / 0.000* | *b,c* |
| SKJ | $m_{EMi-Obsi,SKJ} = m_{EMj-Obsj,SKJ}$ i,j=1,2,3 j≠i | | | | 258 / 173.5 / 156 | 0.191 / 0.472 / 0.158 | |
| YFT | $m_{EMi-Obsi,YFT} = m_{EMj-Obsj,YFT}$ i,j=1,2,3 j≠i | | | | 167 / 237 / 303 | 0.242 / 0.312 **/ 0.013*** | *c* |
| AUX | $m_{EMi-Obsi,AUX} = m_{EMj-Obsj,AUX}$ i,j=1,2,3 j≠i | | | | 231 / 225 / 214 | 0.517 / 0.364 / 0.914 | |
| BET | $m_{EMi-Obsi,BET} = m_{EMj-Obsj,BET}$ i,j=1,2,3 j≠i | | | | 208 / 254 / 262.5 | 0.954 / 0.102 / 0.144 | |

**Annex 1-Table 4.** Wilcoxon signed-rank test comparing the medians of the estimated proportion of weight from observers (Obs) and video monitoring (EM) when free or FAD set occur. $H_0$ is the hypothesis and, *V* and *p*-value the results of the test.

| *Species* | *Set-type* | *Ho* | *V* | *p-value* |
|---|---|---|---|---|
| YFT | FAD | $m_{EM} = m_{Obs}$ | 121 | 0.006* |
| YFT | free | $m_{EM} = m_{Obs}$ | 7 | 0.5294 |

* p<0.05, significantly different.

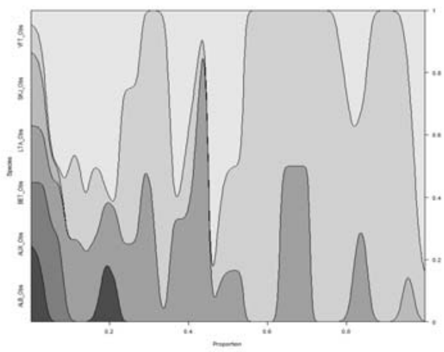
**Annex 1-Table 5.** Shark and billfish bycatch estimates (numbers) by set, made by observers and using EM. *Isurus oxyrinchus* (IOX), *Carcharhinus longimanus* (CLO), *Mobula spp.* (RMV), *Tetrapterus albidus* (WHM) *Istiophorus albicans* (SAI), *Makaira nigricans* (BUM), *Carcharhinus falciformis* (CFA), *Istiophorus albicans* (SAI), *Sphyrna lewini* (SLE), *Carcharhinidae* (FCA), and *Sphyrnidae* (FSP)

| | | *EM-based Estimates* | | | | | | | | *Observer Estimates* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *Set* | *BUM* | *CFA* | *FCA* | *FSP* | *MRA* | *REX* | *SAI* | *WHM* | *BUM* | *CFA* | *FCA* | *SAI* | *SLE* | *CLO* | *IOX* |
| 1 | 1 | 1 | | | | | | | | 2 | | | | | | |
| 1 | 2 | 2 | | | | | | | | 2 | 2 | | | | | |
| 1 | 3 | | | | | | | | | | | | | | | |
| 1 | 4 | | | | | | | | | | 2 | | | | | |
| 1 | 5 | 1 | | | | | | | | 1 | | | | | | |
| 1 | 6 | | | | | | | | | | | | | | | |
| 1 | 7 | 1 | | | | | | | | 1 | | | | | | |
| 1 | 8 | | | | | | | | | | 2 | | | | | |
| 1 | 9 | | | | | | | | | | | | | | | |
| 1 | 10 | | 1 | | | | | | | | 1 | | | | | |
| 1 | 11 | | 1 | | | | | | | | 4 | | | | | |
| 1 | 12 | | | | | | | | | | | | | | | |

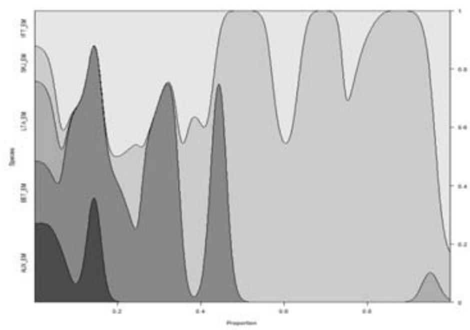
| | | EM-based Estimates | | | | | | | | Observer Estimates | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *Set* | *BUM* | *CFA* | *FCA* | *FSP* | *MRA* | *REX* | *SAI* | *WHM* | *BUM* | *CFA* | *FCA* | *SAI* | *SLE* | *CLO* | *IOX* |
| 1 | 13 | | | | | | | | | | | | | | | |
| 1 | 14 | | 2 | | | | | | | | 5 | | | | | |
| 1 | 15 | 2 | | | | | | | | 1 | | | | | 1 | |
| 1 | 16 | | | | | | | | | 1 | 6 | | | | | |
| 1 | 17 | 1 | 1 | | | | | | | 0 | 1 | | | | | 1 |
| 1 | 18 | | | | | | | | | | 1 | | | | | |
| 1 | 19 | | | | | | | | | | 1 | | | | | |
| 1 | 20 | | | | | | | | | | 9 | | 1 | | | |
| 1 | 21 | | | | | | | | | | | | | | | |
| 1 | 22 | | | | | | | | | | | | | | | |
| 1 | 23 | | | | | | | | | | | | | | | |
| 1 | 24 | | | | | | | | | | | | | | | |
| 1 | 25 | 1 | | | | | | | | 1 | | | | | | |
| 1 | 26 | | | | | | | | | | | | | | | |
| **1** | **Total** | **9** | **5** | **0** | **0** | **0** | **0** | **0** | **0** | **9** | **34** | **0** | **1** | **0** | **1** | **1** |
| 2 | 1 | | | | | | | | | | | | | | | |
| 2 | 2 | | | | | | | | | | | | | | | |
| 2 | 3 | | | | | | | | | | | | | | | |
| 2 | 4 | | | | | | | | | | | | | | | |
| 2 | 5 | | | | | | | | | | | | | | | |
| 2 | 6 | | | | | | | | | | | | | | | |
| 2 | 7 | | | | | | | | | | | | | | | |
| 2 | 8 | | | | | | | | | | | | | | | |
| 2 | 9 | | | | | | | | | | | | | | | |
| 2 | 10 | 1 | | | | | | | | 1 | | | | | | |
| 2 | 11 | | | | | | | | | | | | | | | |
| 2 | 12 | | | 1 | | | | | | | | | | | | |
| 2 | 13 | | | | | | | | | | | | | | | |
| **2** | **Total** | **1** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** |
| 3 | 1 | 1 | | | | | | | | 1 | | | | | | |
| 3 | 2 | 1 | 1 | | | | | | | 1 | 1 | | | | | |
| 3 | 3 | | | | | | | | | | | | | | | |
| 3 | 4 | 1 | | | | | | | 1 | 1 | | | 1 | | | |
| 3 | 5 | | | | | | | | | | | | | | | |
| 3 | 6 | | | | | | | 1 | | | | | 3 | | | |
| 3 | 7 | | | | | | | | | | | | | | | |
| 3 | 8 | | | | | | | | | | | | | | | |
| 3 | 9 | | | | | | | | | | | | | | | |
| 3 | 10 | | | | | | | | 1 | | | | 1 | | | |
| 3 | 11 | | | | | | | | | | | | | | | |
| 3 | 12 | | | | | 1 | | | | | | | | | | |

| | | *EM-based Estimates* | | | | | | | | *Observer Estimates* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Trip* | *Set* | *BUM* | *CFA* | *FCA* | *FSP* | *MRA* | *REX* | *SAI* | *WHM* | *BUM* | *CFA* | *FCA* | *SAI* | *SLE* | *CLO* | *IOX* |
| 3 | 13 | | | 1 | | | | | | | 1 | | | | | |
| 3 | 14 | 2 | | | | | | | | 2 | 1 | | | | | |
| 3 | 15 | | 23 | 1 | 7 | | | | | | 22 | | | 13 | | |
| 3 | 16 | | 1 | | | | 1 | 2 | | | 3 | | 7 | | | |
| 3 | 17 | | 3 | 8 | | | | | | | 24 | 1 | | | | |
| 3 | 18 | | 5 | | | | | | | | 5 | | | | | |
| 3 | 19 | | | | | | | | | | | | | | | |
| 3 | 20 | | | | | | | | | | | | | | | |
| 3 | 21 | | | | | | | | | | 4 | | | | | |
| 3 | 22 | | | | | | | | | | | | | | | |
| **3** | **Total** | **5** | **33** | **10** | **7** | **1** | **1** | **3** | **2** | **5** | **61** | **1** | **12** | **13** | **0** | **0** |

a)



b)



**Annex 1-Figure 1.** Density plots of the estimated proportions of weight captured of each species from video monitoring (a) and observers (b).