UNIVERSITY OF TROMSØ UIT

NORWEGIAN COLLEGE OF FISHERIES SCIENCE

Pilot study of an electronic monitoring system on a tropical tuna purse seine vessel in the Atlantic Ocean

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By

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SUMMARY

One challenge of the implementation of observer programs is the difficulty of ensuring an adequate statistical coverage of whole fleets, and this may hamper the usefulness of the data for management purposes. These constraints make it necessary to find alternative cost-effective methods. 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 and reliability of EM on a tropical tuna purse seiner in the Atlantic Ocean. To achieve this objective 61 free and FAD sets of a tuna purse seiner were closely monitored to compare information provided by EM and onboard observers to determine if EM can reliably document fishing effort, set-type, tuna catch, and bycatch. Set-type was correctly identified using EM for 60 of the 61 sets. Total tuna catch per set was not significantly different between EM and observer data sets; however, species composition did not match for all the species between EM and observers. Overall, bycatch species were underestimated by EM, but large bodied species such as billfishes were well documented. 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. Operational aspects that need to be improved for an EM program to be implemented include standardising installation and onboard catch handling methodology, as well as improvements in video technology deployment.

KEYWORDS: Electronic Monitoring System, data collection, observers, purse seining, catch composition, by catch, Atlantic Ocean, tropical tuna

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1. Introduction

Fisheries managers need to understand the dynamics of the fish stocks, fishery operations, infrastructure, communities and individuals involved in the fisheries sector in order to set policy and manage fisheries. Fisheries data collection and analysis, is one of the first steps during this process. The collection of data is not an end in itself, but is essential for informed decision-making (FAO, 1999).

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. Thus, autonomous observer programs are one of the key components of effective fisheries management, due to their importance during the scientific data collection, but also due to their actions related to monitoring, control and surveillance (MCS). Indeed, research has shown that the presence of observers on board commercial fishing vessels can improve the boat's compliance with regulations, and that if violations do occur they are more likely to be recorded on a vessel with an observer on board (ISSF, 2012)

Observer programs are becoming an increasingly important tool to monitor tropical tuna fisheries. Under the IATTC (Inter American Tropical Tuna Commission) and WCPFC (Western and Central Pacific Fisheries Commission) regulations, there is a requirement for 100% observer coverage of large-scale purse seiners. Under the ICCAT (International Commission for the Conservation of the Atlantic Tunas) and IOTC (Indian Ocean Tuna Commission) 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.

A remarkable range of technologies is now being applied to monitor and collect fishery data. They include for instance; VMSs (Vessel Monitoring System) that record fishing activities in time and space with real time transmission, electronic logbooks that store traditional catch and effort information, or electronic monitoring (EM) techniques that involve video surveillance of the fishing deck. These technologies provide traditional and new information at fine spatial scales and near real time availability, supporting multiple objectives, from scientific research to compliance monitoring.

Electronic monitoring (EM) systems are being used in some fisheries as an alternative and/or a complement to human observers onboard. This technology is quickly gaining popularity with management agencies do to ease of use and financial considerations. However, as EM become more widespread, problems and limitations inherent to its use become more apparent. Different strengths and weaknesses arise depending on the study cases (Blass, 2013), but one of the most discussed shortcomings of EM is the lack of sampling capability.

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. 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, catch, fishing methods and protected species interactions. (McElderry, 2008)

Over the past decade, pilot studies have been carried out in more than 25 fisheries to test the efficacy of this technology, being involved different countries, gears and target species. In some places EM systems have been fully integrated as a fishery monitoring tool, this is the case on the West Coast of Canada and the USA, where there is a significant level of EM acceptance by fishers and fishing management agencies. Mc Elderry et al (2008) provide a list of pilot studies conducted between 2002 and 2008, and concluded that the efficacy of EM for monitoring issues varies according to fishing methods and other factors. But, in general, , EM has a number of advantages over traditional observer programs, including suitability across a broad range of vessels, creation of a permanent data record, lower cost, and the ability to engage industry in self-reporting processes. Observer programs are more suited as a tool for industry outreach, complex catch sampling operations, and collection of biological samples.

The utility of EM systems to monitor catch is dependent upon the fishing method, working very well with fishing methods such as gillnet and longline gear where catch is retrieved serially. EM is not well suited for catch monitoring in high volume fishing gears such as trawl and seine. EM is also not well suited for complex activities such as the collection of biological samples (Mc Elderry, 2008).

In Europe it was not until 2008 when first EM pilot studies were conducted in Denmark, Sweden and Scotland. (Dalskov, 2009; Dalsko 2010). Reliability and functionality of the EM systems as a tool monitor discarding in different fisheries and gears was evaluated during these studies. Results showed that EM can collect accurate discard data.

Several studies over a number of Australian and New Zealand fisheries (Mc Elderry el al, 2011, McElderry et al. 2005a, McElderry et al. 2005b), including the Antarctic longline, Southern Shark gillnet, mid-water trawl, Northern Prawn Fishery and New Zealand inshore trawl fishery, identified that electronic monitoring technology addresses many of fisheries monitoring needs. More recent studies (Piasente et al, 2012), evaluated the efficacy of EM for fishery monitoring issues in the Australian East Tuna and Billfish longline fishery. EM provided in this case as accurate data on effort and retained catch as observers; there were, however, significant differences between the data sources when released catch was compared, as EM failed to capture some of the discards.

Despite past efforts EM technology has never been tested in the tropical tuna purse seine fishery. These happen to be some of most important fisheries in the world in terms of value. The present work is a first attempt to document the feasibility of monitoring the catch operation of tropical tuna seiners in the high-seas by means of electronic systems.

2. Objectives

The purpose of this study was to test the use of an EM system on a tropical tuna purse seine vessel in the Atlantic Ocean, with a view to examining the possibility of effectively implementing EM in tropical tuna purse seine fisheries.

The main objective of this study is to:

- 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-type.
    - **b.** Evaluate the reliability and functionality of EM to estimate tuna catches (total catch and 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.

3. Tropical tuna purse seine fishery

Tuna and tuna-like species are important socio-economic resources as well as a significant source of protein for the society. Among the most commercially important tuna species are found 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.

For management purposes, 12 stocks of tropical tuna species are considered worlwide. For both bigeye and yellowfin tunas, two stocks are considered in the Pacific Ocean (the eastern and western stocks, respectively), while a single stock is considered in the Atlantic and Indian Oceans. Regarding skipjack tuna, two stocks are considered in both the Pacific and Atlantic oceans (the eastern and western stocks, respectively), while a single stock is considered in the Indian Ocean. These stocks are managed by the respective tuna Regional Fishery Management Organizations (RFMO) in each Ocean: 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 commissions face similar situations and problems, as for example in relation to data collection and observer programs, and they have recently started to cooperate through information sharing and common discussion (see Kobe I and Kobe II reports at www.tuna-org.org). Among other things, they have discussed on the necessity of having standardized and common data collection and observer programs as well as to increase the observer coverage in order to better monitor the catches and discards of many 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, their catch was around four million tonnes, which represents around 60 % of the total catch of all tuna and tuna-like species. The individual contribution to total catch of principal commercial tuna species in 2010 was around 60 % for SKJ, around 31 % for YFT, and 9 % for BET.

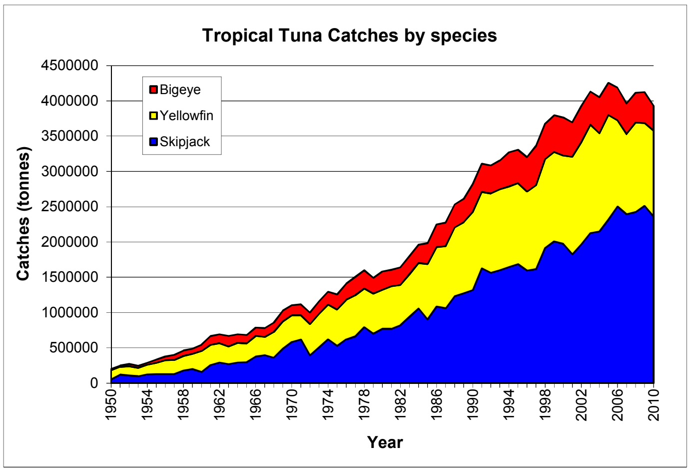

Figure1. Global tropical tuna catch by species for skipjack, yellowfin and bigeye tunas from 1950 to 2011. (Source: AZTI-Tecnalia)

The same increasing trend can be observed in each of the tropical tuna species: for example, BET reached the highest records of about 0.56 million tonnes in 1997, maintaining at 0.5 million tonnes level up to 2005 and decreasing to levels around 0.4 million tonnes in 2009; YFT catch was highest, around 1.5 million tonnes in 2003, decreasing afterwards to 1 million in 2007 and increasing again to 1.2 in 2010, whereas SKJ catch was highest in 2009 with a total catch of about 2.5 million tonnes, similar to the 2006 level (figure 2).

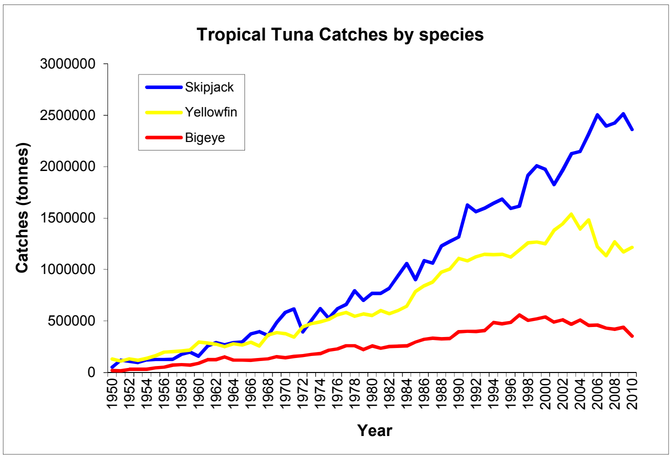

Figure2. **Tropical tuna catch by species for skipjack, yellowfin and bigeye tunas from 1950 to 2011. (Source: AZTI-Tecnalia)**

With regard to the Atlantic Ocean, the relative contribution of the Atlantic to the total catches of tropical tuna is currently around 9 % whereas this contribution was around 20 % up to the mid-1980s but this contribution decreased since then (figure 3).

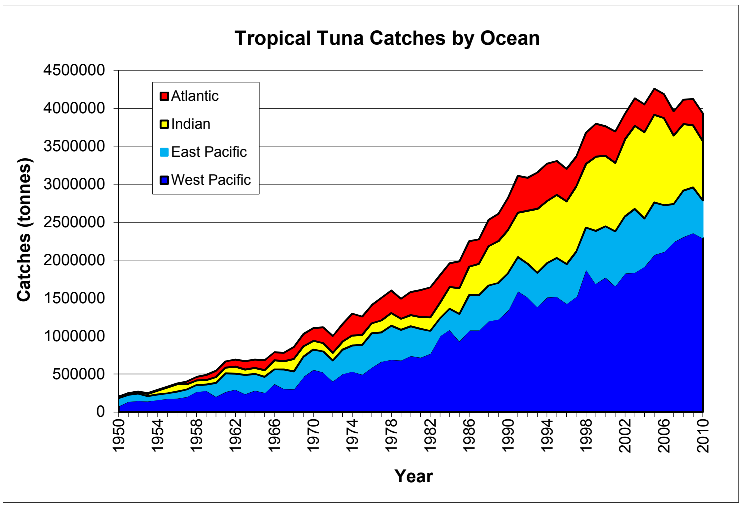

Figure3. **Global tropical tuna catch by ocean from 1950 to 2011. (Source: AZTI-Tecnalia)**

The contribution of each species within the Atlantic Oceans is shown in the figure 4. In the Atlantic, most of the catches consisted mainly of yellowfin followed by skipjack and bigeye up to 1976; since then the majority of catches were comprised by yellowfin and skipjack at similar level (40 % each) followed by bigeye (20 %); however, since 2003 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.

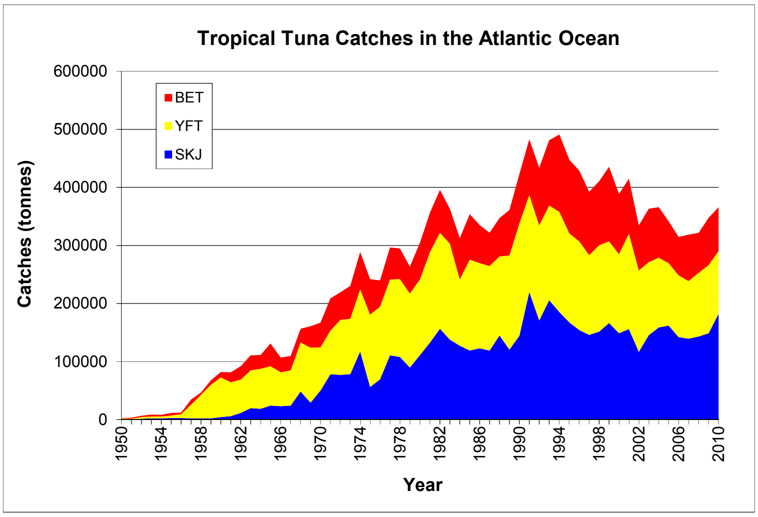

Figure 4. Tropical tuna catch in the Atlantic Ocean, by species for skipjack, yellowfin and bigeye tunas from 1950 to 2011. (Source: AZTI-Tecnalia)

Skipjack are caught almost exclusively by surface gears throughout the Atlantic, although some minor catches are made by longline as by-catch. The catches of SKJ in the eastern Atlantic increased steadily from the late 1960s, reaching around 115000 tonnes in 1974. After that the catches fluctuated without a clear trend at the level of around 100000 tonnes, until 1991 when the maximum catch of 186000 tonnes was taken with the introduction of FADs (Fishing Aggregating Devices) in the fishery (figure 5). Since then, a general declining trend was observed, the catch level remaining relatively stable during the last 11 years at around 120000 tonnes, although it is notably lower than that of 1991 and 1993. The catch increased to 165000 tonnes in 2010.

In the Western Atlantic, the most important fisheries are the Brazilian and Venezuelan bait-boat fisheries. Catches increased in the late 1970s, reaching the historical maximum of 40000 tonnes in 1985. Since then, a decline was observed, the catch remaining relatively stable between 25000 and 30000 tonnes from the mid-1980s. The catch in 2010 decreased to 18000 tonnes.

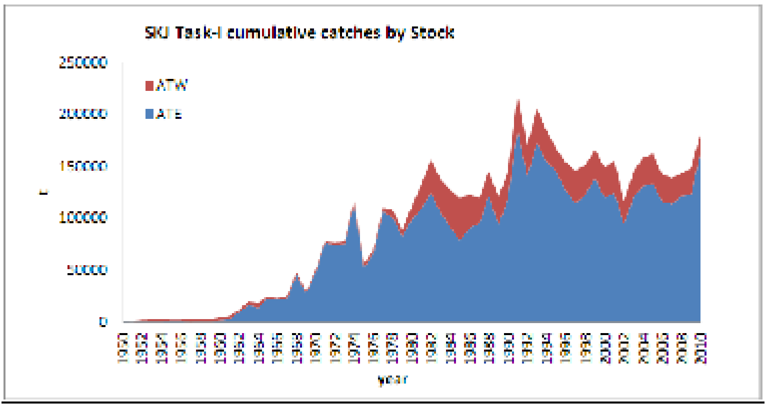

Figure 5. SKJ catches by stock in the Atlantic Ocean from 1950 to 2010. ATW: West Atlantic stock,ATE: East Atlantic stock (Source: AZTI-Tecnalia)

The catches of YFT in the Atlantic Ocean (figure 6) have increased steadily since the start of the fishery in the late 1950s, reaching the 100000 tonnes levels in 1974, the 150000 tonnes level in 1981 and fluctuating around 160000 till 1989. In 1990, the maximum catch of 193000 tonnes was reached and, since then, a general decline was observed, being the catches around 100000 tonnes since 2005 (at the same level as in 1974). This overall decline of 45 % since 1990 contrasts with the increasing catches of yellowfin tuna in other oceans. These variations in global catches correspond, mostly, to variations in the purse-seine catch, which is the major component of the total catch.

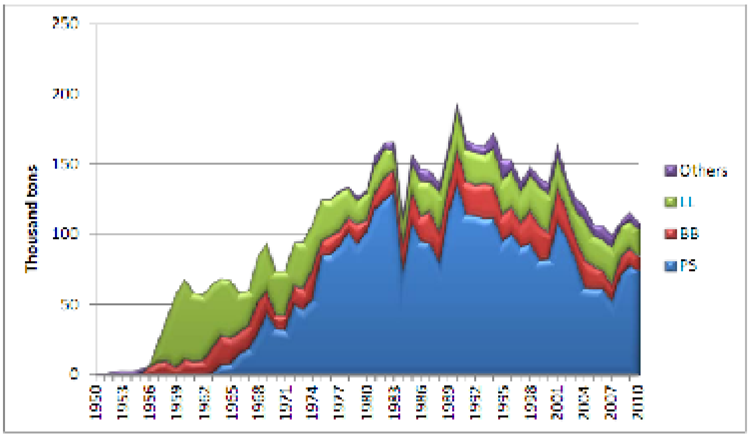

Figure 6. YFT catches by gear in the Atlantic Ocean from 1950 to 2010. (Source: AZTI-Tecnalia)

In the Atlantic, bigeye has been exploited by three major gears (longline, baitboat and purse-seine fisheries) and by many countries throughout its range of distribution (figure 7). The total annual catch increased up to the mid-1970s reaching 60000 tonnes and fluctuated over the next 15 years. In 1991, catch surpassed 95000 tonnes and continued to increase, reaching a historic high of about 133000 tonnes in 1994. Reported and estimated catch has been declining since then and fell below 100000 tonnes in 2001, and reached 65800 tonnes in 2006, which is the lowest recorded level since 1988. The total catch increased the following years reaching around 75000 tonnes in 2010.

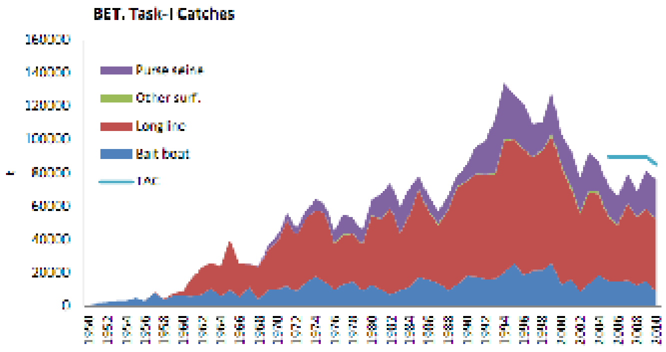

Figure 7. BET catches by gear in the Atlantic Ocean from 1950 to 2010. (Source: AZTI-Tecnalia)

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 regulated by ICCAT rules that dictate mandatory discarding (ICCAT Rec. 11-08 & 10-08).

4. Material and methods

4.1. DATA COLLECTION

4.1.1. Survey Plan

The installation of the electronic equipment onboard a commercial vessel took place in Abidjan, Ivory Coast, during three days, between 26th and 28th November, 2011. EM equipment was installed by technical staff from both Archipelago and Azti-Tecnalia. The vessel set off on November 28th , and during the next three trips data were collected simultaneously by EM and the observer onboard. The initial plan was to sample the two initial fishing trips only, but the duration of the second trip was too short and a third trip was sampled instead (**¡Error! La autoreferencia al marcador no es válida.** 1).

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

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.

4.1.2. Vessel Details

A vessel owned by Pesquería Vasco Montañesa, S.A. (PEVASA), the *Playa de Bakio* (Figure) 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).

Figure 8. F/V *Playa de Bakio*.

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

4.1.3. 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). 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.

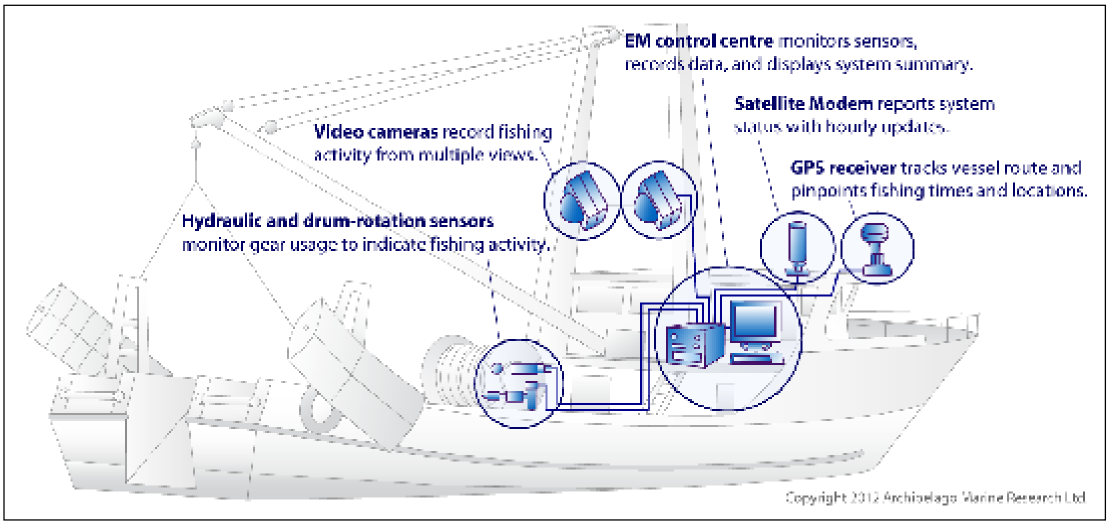

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Figure 9. Schematic of a standard EM system.

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 technician spoke with officers, crew and the observer to gather information and design the most effective EM system installation. The 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 (figure 11).

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

- Four cameras (Figure):
    - 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):
    - 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.

Figure 10. Original camera views from the above-deck and below-deck EM system cameras as installed in November, 2012.

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.

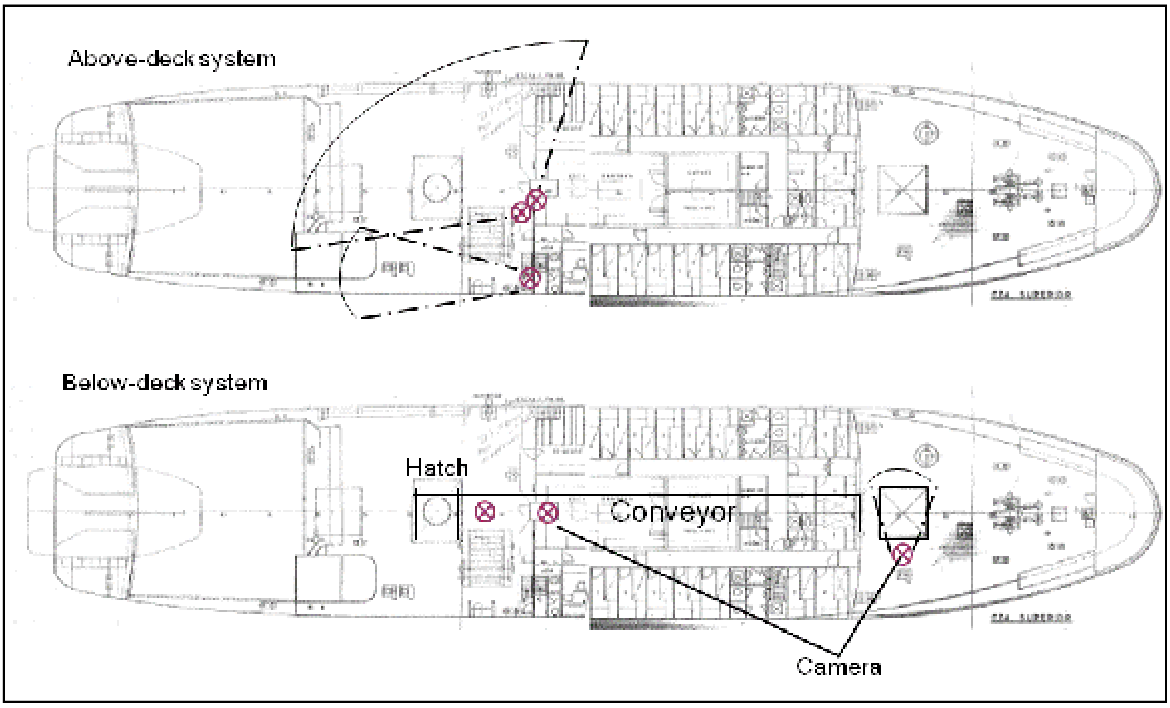


Figure 11. Final location and field of view for each of the cameras installed as part of the EM systems.

The data collected using the EM systems were reviewed in the lab using the Archipelago EM Interpret^{TM} software. EM Interpret is a software package that integrates and displays EM sensor and imagery data for review.

4.1.4. 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 was not included in the logbook, but was identified by the observer, the total was estimated and recorded by the observer.

4.2. OBSERVER AND EMS DATA COMPARISON

4.2.1. Classification of Set-types

Differences in set-type classification made by the observer and by the EMs were analyzed first. This is a crucial element of the tropical tuna purse seine fishery monitoring program, and helps to define the fishing effort of the fleet. The set classification made by the observer (free school set or FAD set) was considered as the correct one, and the degree of sets correctly classified during the EM data review process was calculated. Exact binomial test (Concover, 1971) was used to calculate the probability of success during the set classification. EMs classification was based on imagery review, but 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.

4.2.2. Catch comparison

Secondly, three main categories of data collected by both observers, and EM were compared: 1) tuna catch, 2) bycatch of large- sized species, and 3) bycatch of other bony fish. In the case of tunas, discarded and retained fractions of catch were analysed separately. Contrastingly, for the bycatch the retained and discarded fractions were combined and analyzed jointly. Statistical analyses were conducted in a similar fashion for the three categories of data.

4.2.3. Tuna catch comparison

Analysis of tuna catch

First, total retained tuna catch per set was compared between EM and observer records using in a GLM (Generalized Linear Model) regression model. Skunk (failed) sets were omitted and only sets with more than 0.1 metric tons of catch were included in the analysis. In this case, we had a continuous variable with positive values, biomass. A GLM with gamma error distribution and link =identity was used. The gamma error distribution, which is appropriate for continuous variables, was selected because the variance of the observations tended to increase with the mean. It provided thereby a more symmetric distribution of residuals than normal error.

The following model structure was used:

$$Y = a + bx$$

Where, Y= *Total tuna estimate made by EM* and X= *Total tuna estimate made by observer.*

Although for estimation and fishery control purposes it is the “true” catch, as far as it would be measured by observers, that should be predicted by EM, the equation is here reversed for testing purposes: it is the catch registered by the observers, assumedly measured without error, that is the independent variable. Common regression type I requires that the x variable be experimentally controlled, i.e. measured with little error.

Then, the null and alternative hypotheses were stated as:

H_0: There is not linear relation between EM and observer total tuna catch estimates (b=0)
H_1: There is linear relation between EM and observer total tuna catch estimates ($b \neq 0$)

Further, if the 95% confidence intervals of the estimated intercept encompass 0 and the confidence intervals of the estimated slope embrace 1, the hypothesis that EM catch estimates are as reliable as observer estimates cannot be rejected.

The same approach was used in a second step to compare the tuna catch data, discriminated by species, registered by EM and observers

Analysis of discarded tuna

For discarded tuna, no analyses were performed due to the limited data availability. A comparative summary, of the discards recorded by EM and the observer is, however, presented.

4.2.4. Comparison of bycatch estimates

In the case of bycatch, a GLM with the same model structure and procedures as in 4.4.3 was also used to compare the total number of captured individuals estimated by both monitoring methods. The difference in the two cases consisted of the error structure of the model. In the case of bycatch the measured variable consisted of counts, as both observer and EM reviewer estimated the number of sharks and billfishes caught instead of their biomass. Sets where bycatch was detected by neither sampling methods were omitted from the regression analysis because they were considered to be structural (0,0) zeros. A GLM with Poisson error distribution and *link =identity* was used. Using the *link= identity,* we compared bias from the 1:1 relationship, this is, if there are significant differences from slope =1. Poisson error distribution takes into account that the variable is a count and that the variance increases proportionally to the mean. This procedure was made possible owing to recent advances made by Marschner (2011).

The same analytical approach was used for both large size bycatch species (sharks and billfishes) and small size bycatch species. In first place, indiscriminate groups of species (total sharks, total billfishes and total small bony fishes) were analysed. In a second step more detail was introduced by analysing individual species or families.

Model fits were performed using the statistical software R (http://www.r-project.org/), including the packages stats and glm2 (Marschner, 2011)

4.3. 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 (cameras 1 & 3 on the above deck EMs, figure 10), the imagery was classified as high quality when the reviewer was able to clearly see the brailer, and brailer fullness. Imagery was classified as low quality imagery if the reviewer had a poor view of the brailer, and had difficulty assessing the brailer fullness. For cameras placed on the conveyor belt (below deck MEs cameras 1 & 4, figure 10), which were used for species identification, imagery was classified as low quality imagery if the reviewer had difficulty identifying different species within a set. This difficulty was that felt by the reviewer at the moment of reviewing, and should not be confused with the species recording bias between EM and observers, something that could only be assessed *a posteriori*. This means, that images from sets with less number of species and larger individuals (free school sets) had more probabilities to be classified as high quality. Other external 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.

4.4. 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 as it is one of the key points with respect to the total cost of the EM, and is presented in the results.

5. Results

5.1. DETERMINING SET-TYPE USING EM

Both EM and observer records allowed identification of set-type for all fishing events; 60 of the 61 monitored sets were correctly identified using EM (Annex, Table 1). Exact binomial test shows a probability of success of 98.36 % (*p-value* < 2.2e-16) and 95 % confidence interval between 91.2% and 99.9% of success. 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 12), 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.

Figure 12. Example of a FAD visible within camera view during a set.

The EM sensor data were not used as the main method of determining set-type, and only video data were used for this purpose. However, a coarse qualitative assessment suggested that sensor data are good indicators 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 13). 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). Similar to FAD sets, during free-school sets, the vessel speed dropped to nearly 0 knots for pursing, sacking, and brailing activities.

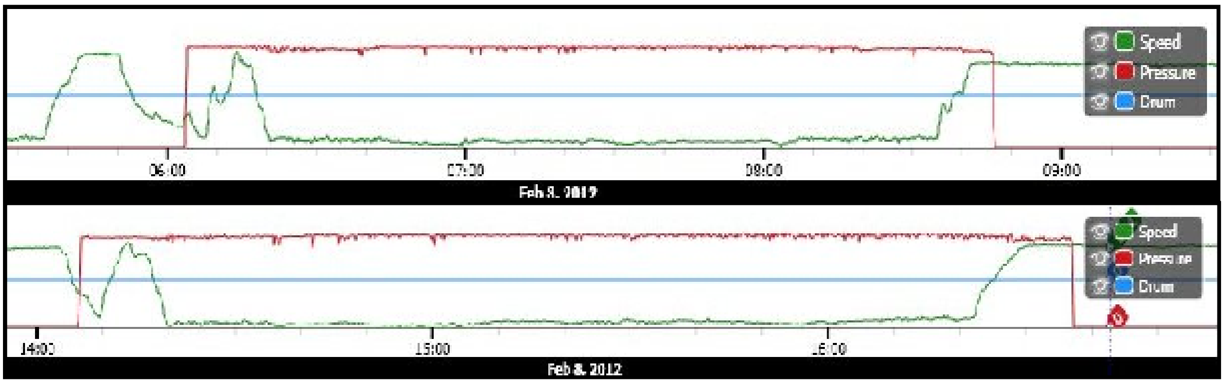


Figure 13. Examples of two typical sensor data sets for FAD fishing on the *Playa de Bakio*, February 8, 2012.

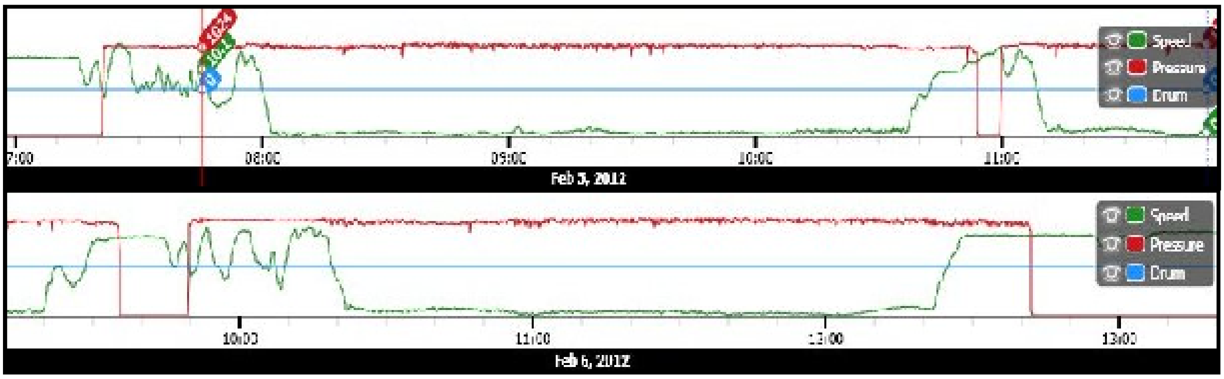


Figure 14. Example of two typical sensor data sets for free-school fishing on the *Playa de Bakio*, February 5 and 6, 2012.

5.2. TUNA CATCH ESTIMATION

5.2.1. Retained Tuna

There were good indications that EM and observer data were equally reliable methods for estimating total catch per set (Figure 15) and this was corroborated by the GLM (table 3). The solid line in the figure shows the fitted linear regression (slope = 1.089± 0.049), and the dashed line indicates the expected 1:1 relationship. The 95% confidence intervals for the intercept encompass 0, and 1 is enclosed by the 95% confidence intervals for the slope.

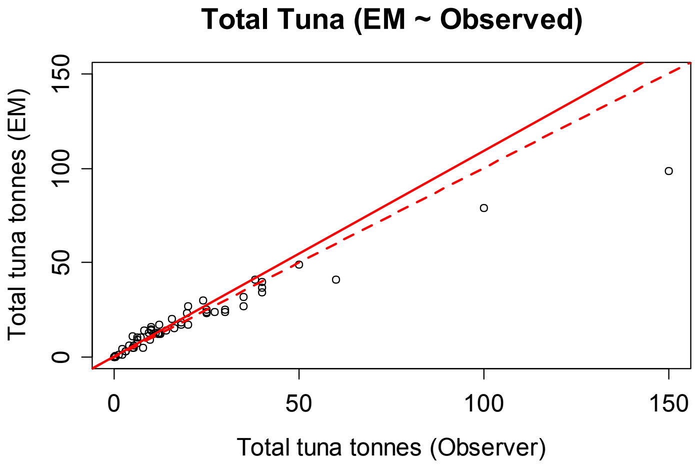


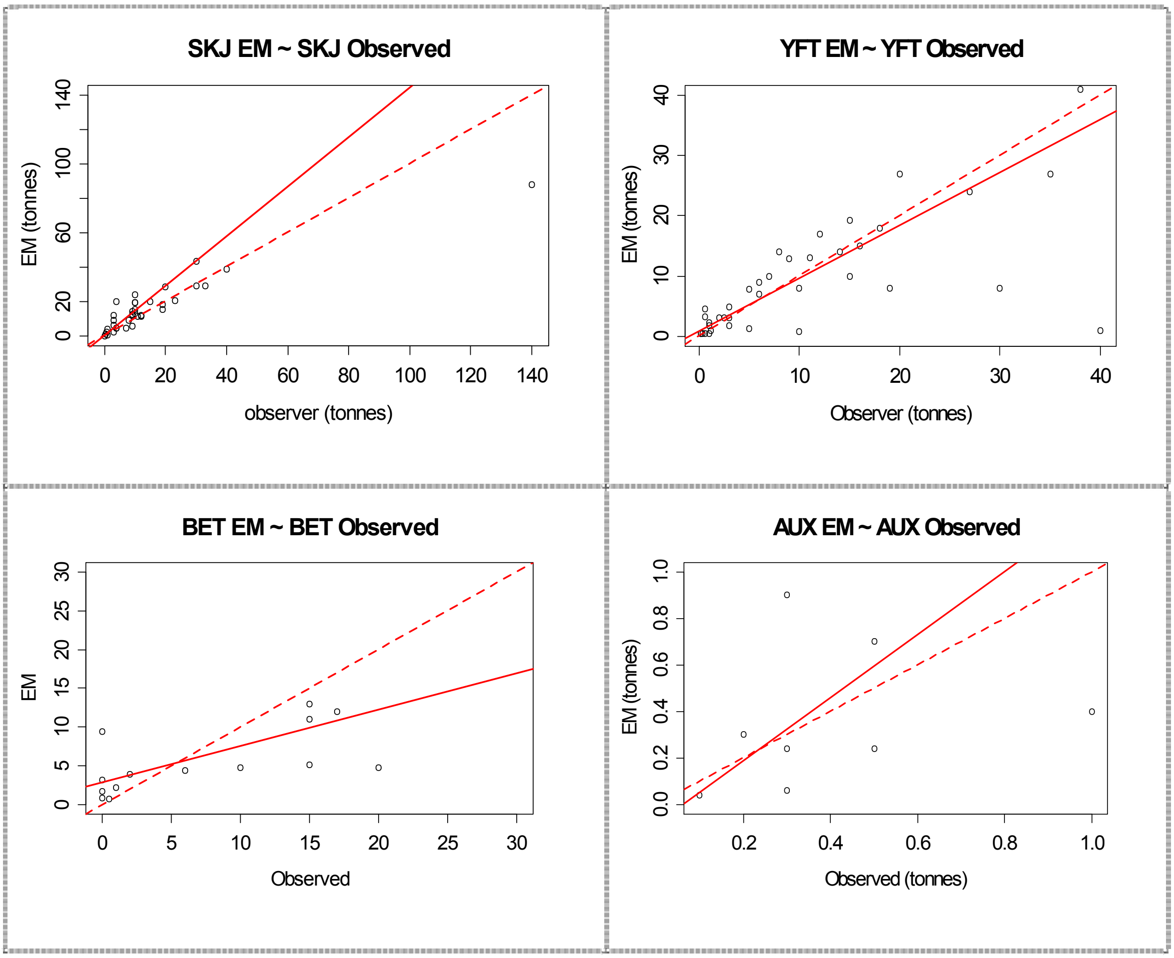
Figure 15. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of total tuna catch in all valid fishing sets. The GLM estimates are given in Table 5.

Table 3. Summary output of the GLM of the relationship between EM estimates and observer records in the determination of the total tuna catch. The GLM model assumed an identity link and gamma error.

	Coefficient estimate	**Confidence intervals**		**p-value**
		2.5%	**97.5%**	
Intercept	0.119	-0.083	0.543	0.355
Observer tuna catch	1.089	0.993	1.193	<2e-16***

The EM allowed also a successful identification of the main tuna species in the catch. Five tuna species were identified using observer and EM methods: *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, but EM failed to record that species. Table 2 in Annex shows the tuna catch estimates made by the observers and EM.

The EM and observer data were not equally reliable methods for estimating tuna catches discriminated by species, at least for some of the species. Figure 16 shows the comparison of the estimated weight of retained tuna per set from EM and observer, by species, and table 4 shows the result of the GLM for the different species. The solid lines in the figure shows fitted linear regressions and the dash line indicates the 1:1 relationships. In general, the EM tended to slightly overestimate the catch of the different species. The exception was BET that was clearly underestimated by nearly half when catch volumes were high (about 10-15 tons). For the main species in volume, YFT and SKJ (with maximum set catches of about 40 and 140 tons), however, the EM estimates were reasonably close to the observed catch. Their estimated slope coefficients had narrow limits and encompassed or were close to the expected value of 1.0. Less important species like LTA and AUX failed to provide strong regressions, because either the number of observations was too low or the EM estimates too variable. Although their regression coefficients were close to the expected 1:1 relationship their variance was too high.



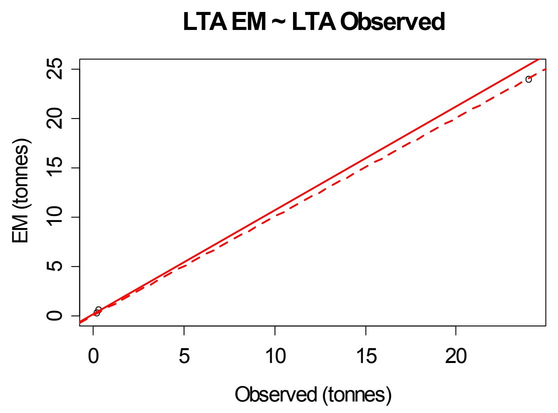


Figure 16. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of tuna catch by species in all valid fishing sets. Katsuwonus pelamis (SKJ), Thunnus albacares (YFT), Auxis spp. (AUX), Thunus obesus (BET) and Euthynus alleteratus (LTA). The GLM estimates are given in Table 6

Table 4. Summary statistics of the slopes of the GLM applied to EM and observer data of the different tuna species.

		Confidence intervals		
	Coefficient estimate	**2.5%**	**97.5%**	**p-value**
SJK	1.44	1.061	1.823	**2.15e-10****
BET	0.468	0.18	1.004	**0.03841***
LTA	1.053	-3.308	5.414	0.201
YFT	0.8762	0.639	1.192	**6.87 e-8****
AUX	1.36	-0.0656	2.786	0.0583

5.2.2. 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). The discarded capture was detected by both methods in this set, but it was underestimated by EM (0.5 Ton) in relation to the observer estimate (2.5 Ton).

Table 5. 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

5.2.3. Bycatch estimation

Bycatch of large size species

While the observer registered 109 sharks and 29 billfishes in the bycatch, the EM data only contained records of 58 sharks and 20 billfishes (Annex 1, Table 3). The most frequent species of sharks and billfishes were observed by both monitoring methods at least in some sets. The main species identified by both methods were: *Makaira nigricans* (BUM), *Carcharhinus falciformis* (CFA) and *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 by one of the methods. One *Isurus oxyrinchus* (IOX) and one *Carcharhinus longimanus* (CLO) were 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 were identified using EM only, but crosschecking with observer data indicated that they were

Istiophorus albicans (SAI) individuals (Annex, Table 3). They were, therefore, likely misidentified by EM.

EM and observer methods were not equally reliable for estimating bycatch of most large size species. For most species the EM estimates were significantly lower than the observer estimates. Figure 17 shows the comparison of the estimated numbers of the bycatch estimates per set from EM and observer for the main shark and billfish species; by total shark and total billfish first, and by species later. The solid line in the figure shows fitted linear regression and the dashed line indicates the expected 1:1 relationship. The summary of the statistical GLM fits for the different species is shown in Table 6. In general, the EM tended to underestimate consistently the catch of the different species. In the case of sharks, total sharks and *Carcharinidae* family sharks, the estimated slope coefficients had narrow limits, but they were clearly below the expected value of 1.0. Billfishes provided a weaker regression because of the low number of observations. Furthermore, the estimated slope coefficients were also clearly below the expected value of 1.0. The exception was blue marlin for which the estimated slope coefficients encompassed 1 and estimated intercept embraced 0 (intercept= 0.555 ± 1.02). However as for the rest of the billfishes, the variance was too high, and the power of the regression was thereby low. In the particular case of blue marlin this lack of power can be nearly totally attributed to the low number of positive observations (sets) rather than observation errors: in 12 out of 14 sets the number of specimens detected by EM was totally consistent with the onboard observations, and in two cases the disagreements amounted to one fish only. Thus, the divergence in estimates for this species is not unequivocal.

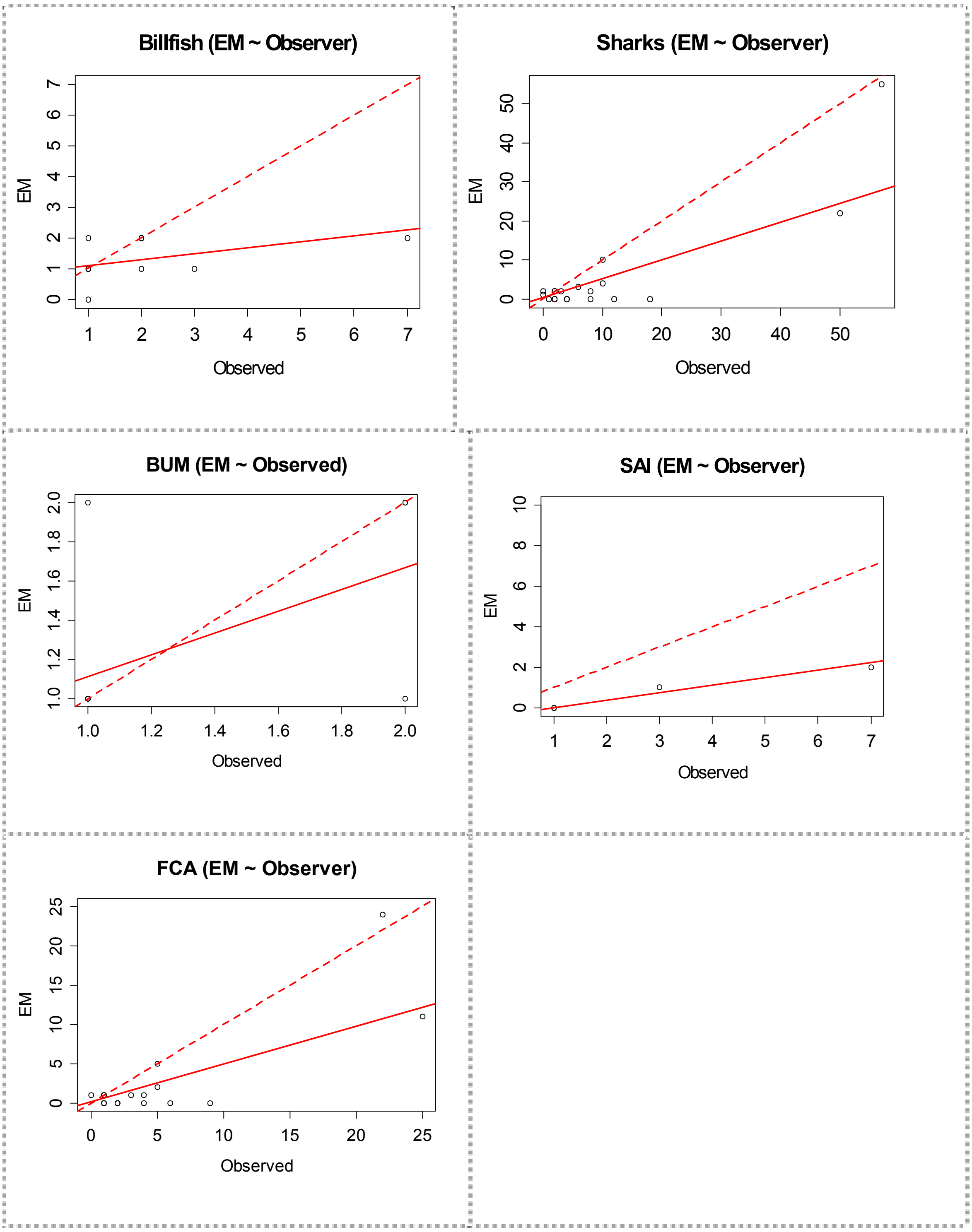


Figure 17. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of bycatch of the large size species: Total billfish (a), total sharks (b), *Istiophorus albicans* (SAI) (c), *Makaira nigricans* (BUM) (d) and *Carcharhinidae* (FCA) (e).

Table 6. Summary statistics of the slopes of the GLM relationship between EM and observer data of the different large size bycatch species.

	Estimate	**Confidence intervals 2.5%**	**Confidence intervals 97.5%**	**p-value**
Total Shark	0.482	0.389	0.501	**<2e-16*****
Total billfish	0.195	-0.116	0.823	0.409
BUM	0.555	-0.836	2.559	0.486
FCA	0.479	0.301	0.656	**1.52e-8****
SAI	0.375	-0.049	0.799	0.833

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, it was however, impossible to identify them to species level in both cases.

Bycatch of small size Species (other bony fishes)

Although rare bony fish species were never detected or identified using EM, the most common species in these trips were observed by both methods. The 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).

Overall EM underestimated the total bycatch of small fish species. In total, the observer estimated the capture of 15,007 small bony fish during the three trips. Contrastingly only 3,801 (25.3%) individuals were estimated using EM.

The difference in the estimated numbers in the bycatch from EM and observer data for the main small bycatch species is illustrated in figure 18; total small bony fishes in a first place and by species later. The summary of the GLM model fit for the different species is given in Table 7. These findings suggest that EM and observer data were not equally reliable methods for counting the bycatch of small size species.

The estimated slope coefficients were clearly below the expected value of 1.0 for all the species. This suggests that EM consistently underestimated bycatch estimates for all the small size species.

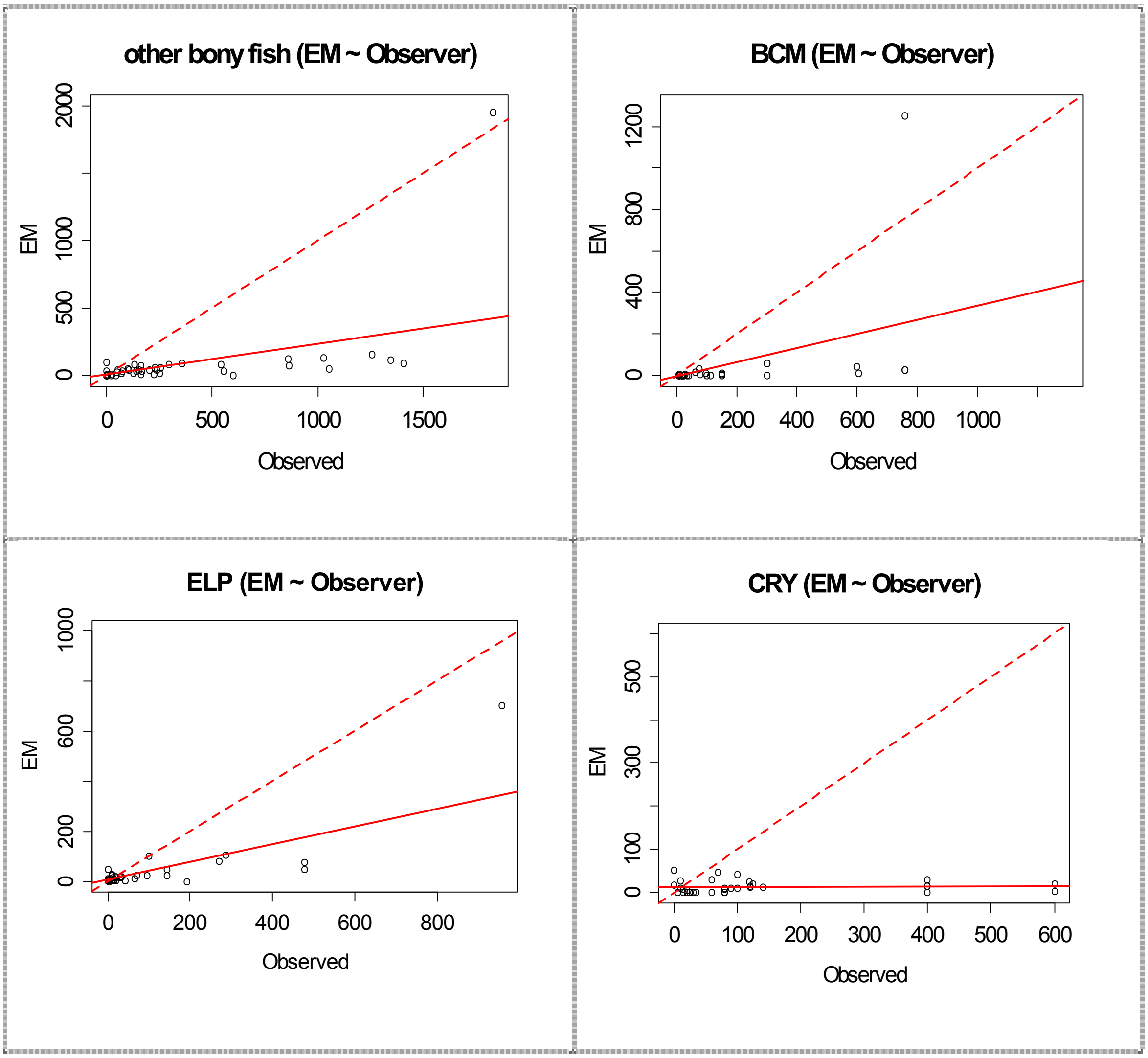


Figure 18. Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of bycatch of the small size species:: Total small bony fish (a), *Canthidermis maculatus* (BCM) (b), *Elegatis bipinnulata* (ELP) (c), *Caranx crysos* (CRY) (d) *Coryphaena hippurus* (COH) (e) and *Acanthocybium solandri* (WAH) (f).

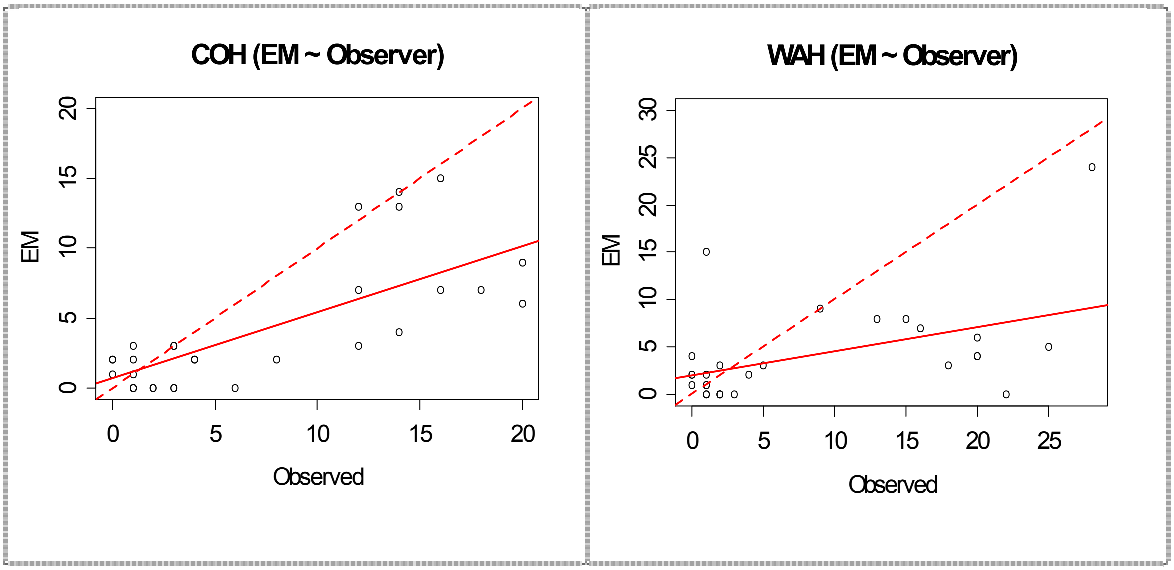


Figure 18 (cont.). Estimated regression (solid line) and expected 1:1 relationship (dashed line) between observer and EM records of bycatch of the small size species:: Total small bony fish (a), *Canthidermis maculatus* (BCM) (b), *Elegatis bipinnulata* (ELP) (c), *Caranx crysos* (CRY) (d) *Coryphaena hippurus* (COH) (e) and *Acanthocybium solandri* (WAH) (f).

Table 7. Summary statistics of the slopes of the GLM applied to EM and observer data of the different small size bycatch species.

	Estimate	Confidence intervals		p-value
		2.5%	97.5%	
Total small bony fishes	0.226	0.212	0.234	**<2e-16*****
ELP	0.351	0.330	0.372	**<2e-16*****
CRY	0.005	-0.002	0.013	0.181
BCM	0.334	0.323	0.355	**<2e-16*****
COH	0.473	0.368	0.586	**2.92e-15****
WAH	0.259	0.170	0.356	**9.18-e8****

5.3. 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 8). 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 the first trip.

Table 8. 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

5.4. 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 9); for each FAD set the EM reviewer spent an average of 68.13 minutes (most sets lasted around three hours in real time). In FAD sets the catch composition is more mixed with regard to sizes and species, and there was higher abundance of small bycatch than in free school sets. Contrastingly, free school sets are predominantly mono-specific, with large tunas and few small bycatch species. This simplified the review process and decreased 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.

Table 9. 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**

6. Discussion:

6.1. SET TYPE CLASSIFICATION

Species composition and mean individual length are very different between free school and FAD sets (see for example: Amandé et al. 2008; Amandé et al. 2010). This information is used for stratification in most computation on tropical tuna purse seine fishery statistics. It is therefore very important to be able to discriminate between the two types of sets. The approach used in this research to identify set types from imagery and sensor data signatures appears to be effective for the fishing techniques of the *Playa de Bakio*, and was able to correctly identify 60 of the 61 sets. Contrastingly, preliminary results in similar studies carried out recently in the French tropical purse seine fleet operating in the Indian Ocean (Chavance, Institut de Recherche pour le Développement IRD, pers. com. 2013) failed to achieve such high performance with reference to the set type classification. This suggests that the usefulness of the EM methodology is limited to vessels with similar fishing behaviour (may include the entire Spanish fleet). Future research should focus on the validation and development of the EM method for identification of set-type without previous disclosure of the observer and fishing logbooks.

While this study used imagery to determine set-type, the exclusive use of EM sensor data is a very promising method as well. The differences in how vessels approach and initiate the fishing operation on either FAD or free-school seem to be unequivocal and consistent in the EM sensor data. 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 they were consistent with sensor data collected for free-school sets (Figure). Thus, the set could have been identified correctly if imagery and sensor data were combined to identify set-type. Future examination of EM data collected onboard other vessels should emphasize the differences in sensor data between FAD and free-school operations.

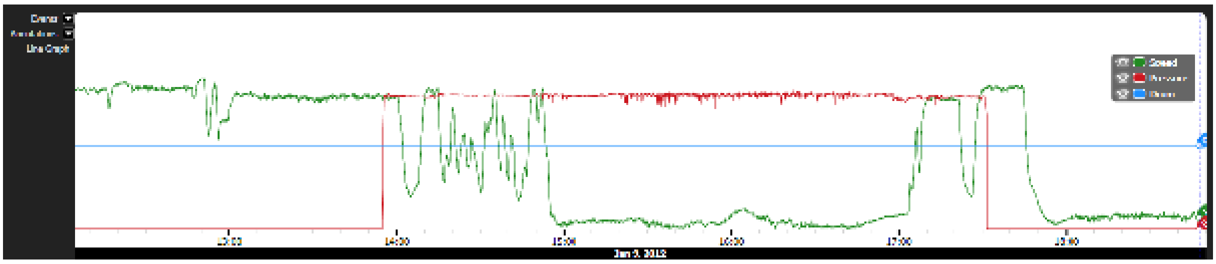


Figure 19. Sensor data for a set on January 9, 2012, which was wrongly identified from the imagery review as a FAD set. Sensor data is consistent with free-school set sensor data (i.e., highly variable speed at the beginning of the set).

6.2. TUNA CATCH ESTIMATION

It is a general requirement that catch be accurately recorded (or recorded to within a determinate percentage of the true value), as measured in the landings. The total catch of tuna in 61 sets performed in the present study could generally be accurately estimated using EM.

Both monitoring methods lead to correct identification of the same tuna species, with the exception of a single set when the EM imagery reviewer failed to detect several albacore recorded by the observer. Although for the most important tuna species, such as the yellowfin tuna, the estimates made by the EM were quite accurate and statistically undistinguishable from the estimates made by observers, this was not the case for all tuna species. Free school sets are normally mono-specific sets dominated by yellowfin tuna, and the identification of the species is quite easy for the imagery reviewer. Contrastingly, FAD sets tend to be dominated by skipjack, and this species seems to be slightly overestimated at the expense of accompanying tuna species. It would seem like the pronounced lines that the skipjack possess on the ventral side make it stand out over the rest of the species. Clearly, mixed sets like FAD sets require extreme attention from experienced EM reviewers.

A major difficulty reported by EM reviewers with regard to identification of species in large mixed sets is the large volume of fish that enter the conveyor belt at once. A large portion of the fish beneath the top layer of the melee becomes out of sight in the EM footage. Given the combination of the camera views (see Figure), and a known brail volume or weight, it is feasible to accurately estimate the total catch using the number of brails and the fullness of each. 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.

These results are consistent with other studies that have been conducted in other fisheries that have to deal with similar problems. Mc Elderry (2008) concluded after several pilot studies that the determination of catch composition using EM is challenging in fishing gears such as seine and trawl, which bring catch aboard *en masse*.

6.3. **BYCATCH ESTIMATION**

The EM technology utilized on the *Playa de Bakio* permitted a reliable identification and quantification of some billfish catches, but underestimated the bycatch for most other species. This is, to a large degree, a result of the methods used to handle catch on the *Playa de Bakio* that allow easy identification of large bycatch, but make it very difficult to track and identify small fish bycatch mixed with the tuna.

Large bycatch species (blue marlin, and some large size sharks and billfish) were well documented by EM, because the catch handling of the fish was easily visible to the reviewer. This type of bycatch is normally sorted from the brailer in the above-deck area because they are too large to go directly through the hatch into 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. In contrast, the EM system allows the simultaneous analysis of the above- and below-deck areas, without the need for crew collaboration. A case in point was the detection of a devil ray by the EM reviewer that was unaccounted for by the onboard observer (trip 3, set nº 12). Overall, the present findings suggest that EM is able to fully document large bycatch species that are handled in the above-deck area, sometimes better that the onboard observer.

Another challenge for the EM technology is the coarser grade of taxonomic identification of the catch. For some purposes, for instance protection of threatened species such as the Scalloped Hammerhead (*Sphyrna lewini*) (IUCN, 2013), precise taxonomic identification is critical. While 23% of the *Charcharinidae* sharks and 100% of the hammerhead sharks (*Sphyrnidae*) were identified to the family level in the EM data, the observer identified each one of them to the species level. Additionally, during this survey, two turtles were caught and released alive. Although all of them were documented by the EM reviewers, it was impossible to determine the species from the imagery. For species with small distinctive identifying characteristics the camera views may not allow clear enough images to discriminate bycatch to species level. Each of these examples highlights the importance of matching the catch handling process flow to the EM installation and monitoring objectives. The taxonomic performance with regard to large bycatch may also be improved with increased imagery resolution and frame rate.

The amount of bony fish and smaller bycatch species captured in the present experiment was generally underestimated by EM, but their presence was well documented. During the catch handling operation these fish pass directly through the hatch in bulk 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 in the EM review process. In most cases bony fishes were retained in the wells together with tunas and they were not sorted by crew. In the case of the small sharks sorting and discarding was done in many different control points. This catch handling method complicates the discrimination of the species bycatch 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, a discard pile was used, and EM based estimates were more accurate than in the other sets. These details highlight the importance of using standardized catching handling methods onboard in conjunction with EM to ensure complete data capture.

Complex catch handling method has been also identified by other authors as one of the main barriers for the identification of catches to species level (Mc Elderry et al., 2008; Pria et al.,2008; Mc Elderry et al. 2011; Dalskov et al., 2009; Piasente et al., 2012). These authors agree that working with the crew to develop and adopt a standardized approach to handling catch would improve the EM system's ability to accurately document events.

The high concentration of bycatch fish being simultaneously processed on the conveyor belt represents the biggest challenge for the use of EM, and is one factor complicating the estimation of bycatch in the area below-deck. Just like the handling of the targeted tuna 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. Given the limited number of cameras on the current EM system and high number of control points, monitoring bycatch with EM will be difficult until either more cameras are installed or fewer control points are used.

6.4. IMAGE QUALITY

The imagery had sufficiently good quality overall, and the bulk of the reviewer assessments were medium or high quality. As mentioned above, the species diversity or the total amount of catch within a set will influence the classification of the images. Thus, images taken during free school sets (low number of species) were more likely to be classified as high-quality. There are, however, several factors (not related directly with the set complexity) 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) reduced the image quality, and in some cases, made 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. Fouling of the lenses, and the required cleaning, are features that have to be taken into consideration in future commercial applications of the EM system in the physical absence of observers or technical staff.

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.

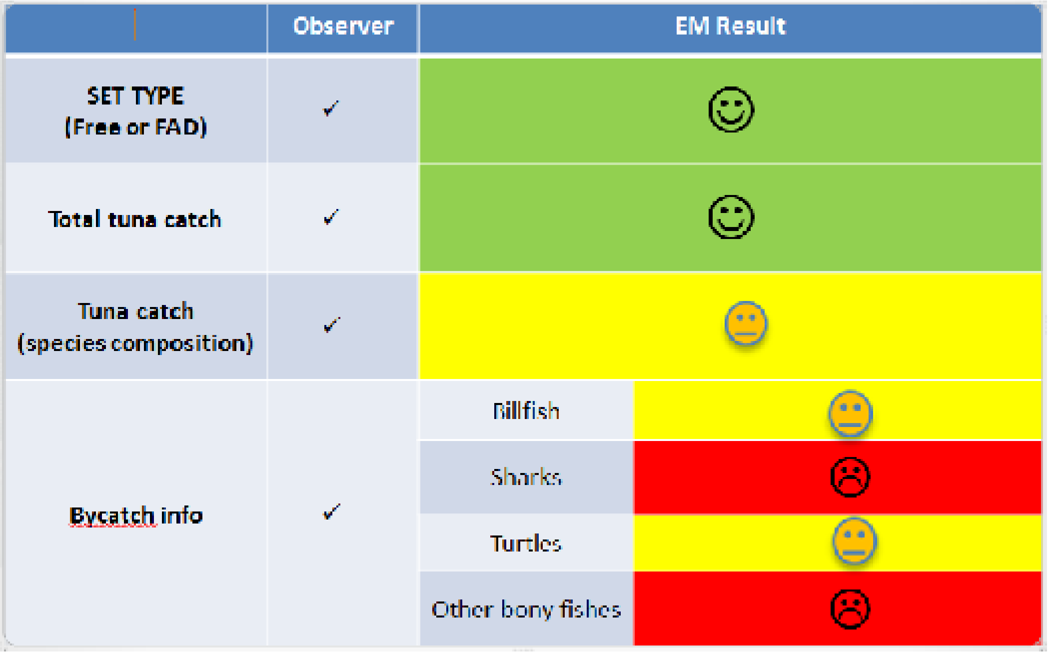
6.5. IMAGERY REVIEW TIME

One of the main aims of EM is the reduction of monitoring cost while still providing 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. This was achieved because much of the imagery contains idle operation time that could be rapidly skimmed through. Relative to the total length of all three trips, 31 hours of review time correspond to a highly efficient method of monitoring a trip. Moreover, when compared to the effort involved in deploying an observer onboard to collect roughly 3 hours of data per set EM may provide a highly cost-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 reviewer, 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 of the sets, suggesting that EM may be an economical monitoring method, provided that high quality data are collected. The short time utilized per set indicates that it can be feasible to even re-visit complex sets by one or several interpreters to improve estimates.

6.6. SUMMARY

Based on this research, EM is a viable tool for monitoring effort, set-type and total tuna catch within the tropical tuna purse seine fishery; however some limitations exist for the estimation of the species composition and for the monitoring of the bycatch. Figure 20 shows the summary of the potential and limitations detected in the present study.



	Observer	EM Result	
SET TYPE (Free or FAD)	✓	🟩 ☺	
Total tuna catch	✓	🟩 ☺	
Tuna catch (species composition)	✓	🟨 😐	
Bycatch info	✓	Billfish	🟨 😐
		Sharks	🟥 ☹
		Turtles	🟨 😐
		Other bony fishes	🟥 ☹

Figure 20. Schematic description of the results obtained aboard the Playa de Bakio. Green shows high agreement between EM and observers estimates, yellow shows moderate agreement, and red shows a low agreement.

The differences observed in this study between the two observation methods are the result of several factors related to the EM observations as well as the EM technology itself. These limitations appear to be similar to those found by other authors regardless of the type of vessel, gear or species, unless in some cases these limitations are more or less determinant (Mc Elderry, 2008; Dalskov, 2010). 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, it is difficult to estimate the absolute bias and precision of the EM technology.

Despite the potential uncertainty of the observer estimates, these provide 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. Similarly, large bycatch species could also be assessed if they were handled on the fishing deck. After the catch was brailed aboard and transferred to the conveyor-belt below deck imagery reviewers could still identify the major species. However, 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 in good vantage points. More cameras than those used in this study would have been an improvement, but the best vantage point for retained catch would be a clear view of the point where fish are transferred from the conveyor to the well itself.

Potentially the most influential factor for the difference between the EM-based and the observer estimates was the highly distributed catch handling on the vessel. Figure provides a schematic view 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, the limited ability to assess catch by EM technology results not just from the technology itself but from the application of the technology.

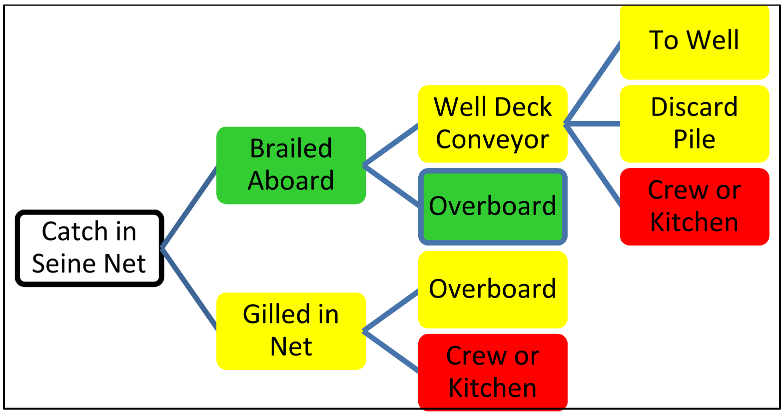


Figure 21. Schematic description of catch handling processes aboard the Playa de Bakio. Green shows catch handling processes that were well covered by EM imagery, yellow shows moderate coverage, and red shows a low ability to monitor.

7. Conclusion and Recommendations

The main objectives of this study was to compare the data collected using EM to the data collected by onboard observers to determine if EM systems can be used in purse seine vessels to collect unbiased data on commercial tropical tuna. A main finding of this study was that EM can be used to determine the fishing effort (number of sets), set-type, and total tuna catch as reliably as observers can. To be fully comparable with observer data the EM system must be improved for accurately estimating the bycatch.

The success of an EM program requires 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 permit the collection of 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. Obviously, this requires a good dialogue so that installation of the system does not hamper the operation of the crew, vessel and gear.

Despite some of the limitations, the EM system, in conjunction with port sampling for proper validation of taxonomic identification and catch volumes, will be valuable to gather catch statistics on target species in situations where these data are non-existing (most vessels and trips) or of poor quality. 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 fisheries control and enforcement reasons or objectives. An example is the ICCAT requirement to increase observer-coverage to 100% for purse seiners during a two-month prohibition on FAD fishing in an area off western Africa (ICCAT Rec. 11-01). Another advantageous utilization would for companies and vessels under “eco label” certification schemes (e.g., Friend of the Sea). These may require very close monitoring, including 100% observer coverage. In this case, EM could become a reliable tool for monitoring operations that the fishing industry would readily adhere to owing to its cost efficiency.

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 alternatives 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. In this study suggestions to improvements in critical control points were made, as well as to required improvements in video technology deployment.

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9. Appendix

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). **(FSC: Free School; FAD: Fishing Aggregating Device)**

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

Table 2. Tuna catch (t) 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. *Thunnus obesus* (BET), *Katsuwonus pelamis* (SKJ), *Thunnus albacares* (YFT), *Auxis spp* (AUX) and *Euthynnus alleteratus* (LTA)

		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**

		EM-based Estimates						**Observer estimates**						
Trip	**SET**	**BET**	**SKJ**	**YFT**	**AUX**	**LTA**	**TOTAL**	**BET**	**SKJ**	**YFT**	**AUX**	**LTA**	**ALB**	**TOTAL**
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**
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

Table 3. 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															
1	13															
1	14		2								5					
1	15	2								1					1	
1	16	1								1	6					
1	17		1								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															

		EM-based Estimates								**Observer Estimates**						
Trip	**Set**	**BUM**	**CFA**	**FCA**	**FSP**	**MRA**	**REX**	**SAI**	**WHM**	**BUM**	**CFA**	**FCA**	**SAI**	**SLE**	**CLO**	**IOX**
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										
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**