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Comparing and contrasting EM derived purse seine fishery data with human observer, onboard sampling and other data sources in support of Project 60

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Comparing and contrasting EM derived purse seine fishery data with human observer, onboard sampling and other data sources in support of Project 60

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Abstract

The use of electronic monitoring systems (EMS) is a rapidly expanding area of fisheries monitoring and compliance with the potential to gather unbiased catch and effort data along with information verifying non-target catch, discards and operational characteristics of fisheries. Longline fisheries are well suited to monitoring by EMS where each fishing event can be referenced to a sequentially set hook that is landed and processed in the same general area of the vessel. Monitoring of purse seine effort is more complex due to the larger size of vessels requiring several camera locations and angles to effectively monitor fishing operations and vessel activity. For the same reasons, monitoring the many aspects of a purse seine trip can be difficult to capture by a single human observer and incorporating EMS may significantly improve the overall monitoring coverage. However, before EM data can be considered for incorporation into existing data streams, the quality of EM derived data must be cross checked and verified to assure accurate and comparable information is supplied for science and management purposes. To explore the potential applications of EM onboard a purse seiner, an eight-camera video EMS was installed on a U.S. flagged tuna purse seine vessel conducting a standard commercial fishing trip in the Western Central Pacific Ocean (WCPO). Simultaneous independent data collection was gathered via multiple sources including: 1) by a certified Regional Observer Program (ROP) human observer (HO), 2) by two onboard fisheries biologists/samplers, 3) using the self-reported vessel logsheet data, and 4) utilizing port sampling and cannery unloading weights. Data examined included verification of school and set type, well loading destination and tonnage estimates, set and trip level catch estimates, species composition, length frequency data for the principal tuna species and observations of bycatch handling and disposition/fate.

Preliminary results highlight the information benefits that observers gain by being on the vessel and able to obtain information from many data sources, such as in the determination of set size and species composition. Conversely, EM video footage with precise time and position stamps bring recorded 24/7 has certain advantages over human interpretation. However, the EM analysts converting the video footage to actionable data would benefit from having more frequent and varied pre-trip length calibrations and greater familiarity of WCPO bycatch species. Findings from this study support previous investigations that EMS monitoring of purse seine effort should not be regarded as a replacement of human observers, but as a complimentary tool that can enhance HO programs potentially replacing repetitive tasks, allowing observers to concentrate on other priority duties. HO and EMS should be regarded as complimentary to each other, where their combined monitoring effort produces higher quality fishery data and monitoring information.

Executive summary

A collaborative research project between The Nature Conservancy's – Indo Pacific Tuna Program (TNC), The Tri Marine Group and the Oceanic Fisheries Programme of The Pacific Community was established to examine the application of electronic monitoring (EM) to assist data collection on tuna purse seine vessels. The study was designed in support of WCPFC *Project 60: Improving purse seine species composition*. An eight-camera Satlink Seatube EM system was installed on a 1930 GRT Tri Marine purse seine vessel to monitor catch, effort, well loading and FAD related activity. Video footage interpretation of catch events, fishing effort and vessel activity was conducted by Satlink's data processing affiliate company, Digital Observer Systems (DOS). EM derived data was compared to data recorded by two TNC biologist/samplers (TNC), a WCPFC Regional Observer Program (ROP) human observer (HO), vessel reported data (logsheet), port sampling data and cannery unloading weights for a commercial fishing trip conducted in Oct/Nov 2018 in the WCPFC convention area. A total of 37 sets were made in 38 days at sea for a total catch of approximately 1300 mt (cannery offloading data) of skipjack, yellowfin and bigeye tuna combined.

Slight differences were noted in the designation of set and school type by data source in part due to the WCPFC definition of FAD set and distance between the set and nearest floating object (FAD). Set size estimates (mt) for all onboard data sources (HO, TNC, logsheet) were similar and close to the cannery offloading weights that should be considered as most accurate. EM derived estimates were significantly lower as they could not benefit from the many information sources available onboard during the school assessment and catch loading process.

The onboard biologists collected spill type length frequency sampling from approximately 200 samples per set which were compared to HO grab sampling that achieved approximately 20 samples/set and 85 samples/set from EM analysis. This sampling was used to generate trip level species composition estimates. EM data predicted a significantly higher proportion of yellowfin in the catch composition than other sampling methods, resulting from a higher proportion of yellowfin that were identified in the video review. These results carried into predictions of higher numbers and average size of yellowfin from interpretation of the EM data. Cannery offloading data confirmed yellowfin per cent composition in the catch was close to those predicted by human observer and onboard sampling. However, species composition estimates for skipjack were similar for the three sampling methods which was confirmed by cannery data. Overall, the observer bycatch record was the most detailed in number of species recorded, including species of special concern (silky and oceanic white tip shark). All data sources accurately recorded the destination of well loading.

Mixed results from the trip suggest that human observers, EM and port sampling all have a role in monitoring purse seine vessel activity and can mesh cooperatively to achieve high quality data and monitoring standards. Onboard human observation will remain important/essential when documenting and interpreting many at-sea activities, e.g. pre-dawn set related activity, FAD actions (which can be complex), discarding activity, bycatch handling and determining bycatch condition and fate on release. However, EM integrated with 24/7 time and GPS location stamped images has great benefit for providing fine-scale data for monitoring and compliance and operates at times when the observer is otherwise occupied with other tasks at various sites onboard the

vessel or taking necessary rest periods. Set type verification, estimates of catch by set, and species composition are some of the areas where observers and EM can work collaboratively to arrive at a more accurate result.

Direct verification of fork length measurements from video images and additional testing for accuracy of species identification is required to further validate EM as a standalone tool in this regard. How fish are selected for identification on the video screen also needs to be investigated to determine how selection bias may impact species composition estimates. Finally, ways to scale up the use of EM across different purse seine vessel types and operations needs to be developed considering the differences in vessel size, well loading procedures and magnitude/frequency of at-sea sorting and discard levels across the fishery. Future work will examine the utility of an "above brail" EM camera angle to obtain length frequency and species composition data.

1. Introduction

The collection of fishery data from tuna purse seine fisheries takes many forms depending on the region and Regional fishery management organization (RFMO) and may include human observers, transshipment monitoring, logbook, port sampling and cannery offloading data. Comprehensive port sampling can enumerate trip level landings but will not capture many aspects of set-level fishery data, such as capture school type, at-sea sorting, transshipment activity, target catch discards and bycatch handling and release procedures. Electronic monitoring (EM) and electronic monitoring systems (EMS) are a potential way to enhance fishery monitoring, either through standalone programs or using EM to enhance existing human observer programs. EM is well suited to monitoring longline fisheries where fishing operations occur in very discrete locations on relatively small vessels and each catch event is hauled through the same door and processed in the same location, thus limiting the number of video cameras. The monitoring of industrial tuna purse seiners is more complex with diverse motivations for camera coverage on larger vessels. Preliminary trials to date demonstrate that EM holds promise to become a useful monitoring tool of purse seine catch and effort. However, the quality of EM derived data must first be cross checked and verified to assure comparable information is supplied to the WCPFC for management purposes.

2. Project Description

2.1. Project structure

This project represents a collaborative effort between The Nature Conservancy's Indo Pacific Tuna Program (TNC) and The Tri Marine Group[1], a vertically integrated seafood harvesting and processing firm that concentrates on tropical tuna fisheries. TNC's Indo Pacific Tuna Program is a non-profit NGO focusing on conservation and sustainability initiatives in the Pacific and Indian Oceans. The Program works collaboratively with industry and other partners to promote sustainable tuna fisheries, reduce bycatch and improve socio-economic returns for island communities. The Oceanic Fisheries Programme of The Pacific Community provided scientific support and linkage to the WCPFC as the designated science provider for the Commission.

[1] http://www.trimarinegroup.com/

To field the project, vendors with expertise in the EM field were solicited. Satlink[2], a Spanish-based firm specializing in satellite telecommunications was selected due to their experience with EM of tuna fisheries, purse seine-specific experience, integrated customer service/field support and mature back-end video review software/analytical support. Satlink operates in collaboration with an affiliated company, Digital Observer Services[3] that specializes in the interpretation and analysis of the video images

2.2. Regional integration and collaboration

The project worked in collaboration with other regional and industry groups to address the objectives of the study, including the WCPFC Regional Observer Programme (ROP), Pacific Islands Forum Fisheries Agency (FFA), the NOAA Fisheries Field Office in Pago Pago and the Starkist Samoa tuna processing facility in American Samoa.

The study worked with the Commission's scientific service provider in support of WCPFC *Project 60: Improving purse seine species composition* (Peatman et al. 2018). The overall objective of Project 60 is:

> *... to improve the collection and representative nature of species composition data for tuna caught by purse-seine fisheries in the WCPO in order to improve the stock assessments of these key target species.*

2.3. Project concept

Video cameras are well suited to the monitoring of some, but not all industrial fisheries. Tuna longline operations are well adapted for electronic monitoring (EM) using fixed video cameras where the baiting, setting and hauling operations taking place in relatively discrete locations on small and medium-sized vessels. Every hook and all catch is hauled through the same door one at a time and processed in the same areas of the vessel. The catch of tuna longline vessels is of low species diversity and usually of mature size aiding the visual identification of catch and bycatch. In fact, EM can be the only way to obtain set level information from smaller vessels that do not have space for an onboard human observer (HO). The testing and application of EM on WCPFC longline fleets is well underway and developing rapidly in the region.

In contrast, using EM to monitor tuna purse seine activity is more difficult due to the larger size of the vessels, the complex operational characteristics of the fishing operation and diverse motivations for monitoring. Vessel owners want cameras to monitor crew safety, cover liability issues, document school set type for Marine Stewardship Council (MSC) requirements and to verify compliance with management measures. Scientists and science providers to the Commission are interested in the potential for EM to provide accurate and unbiased data on school set association, bycatch and protected species handling and release, discards of target and non-target catch and other data useful for stock assessment and management advice. In particular, higher numbers of length frequency and species composition samples are sought at the set and trip level.

[2] https://satlink.es/en/tracking-monitoring/satlink-seatube/
[3] http://digitalobserver.org/en/

Currently, the onboard ROP observer is tasked with taking a random grab sample of five tuna (skipjack, yellowfin or bigeye) from every brailer load as it is hoisted from the net but before it is emptied into the loading hatch that connects to the brine wells for storage. Sampling takes place on the working deck to allow the observer to keep track of other issues such as bycatch handling and release and to facilitate brail counting. Each brailer, depending on vessel size and preference may contain from approximately two to eight mt of catch with sets ranging up to 250+ mt per set. Typical examples: 35 mt/9 brails = 3.9 mt/brail; 120 mt/24 brails = 5 mt/brail.

2.4. **Project justification**

It has become increasing difficult for onboard observers to achieve their 5 fish per brail grab sample protocol due to the increased speed of brailing and decreased use of sorting hoppers by WCPO purse seiners that were commonly used in the past to sort brailer contents for bycatch and undersize tuna (**Figure 1**).

Figure 1. Brailing catch into a sorting hopper prior to release to the wet deck and storage wells.

The use of sorting hoppers is now uncommon in the WCPO fishery with brailer loads typically being released directly to the well deck conveyor or loading chutes (Murua pers. comm.). Sea surface temperatures are often 29° C or higher and can cause spoilage or elevated histamine levels if the fish are held too long in the sack, prompting fishermen to expedite the brailing process. Obtaining a grab sample or removing bycatch requires the crane operator to deposit the brailer on the deck, lower the brail so that the observer can reach over to get his sample and then move the brailer to the loading hatch (**Figure 2**). Given the speed of brailing operations, there are times when no grab sampling is possible or only a portion of the five-fish sample is obtained.

Figure 2. Observer obtaining a 5-fish grab sample from the brail..

Trips with paired spill sampling, carefully enumerated port sampling, or cannery unloading data have indicated a bias in the 5-fish sampling protocol with an under-representation of smaller fish and over-representation of larger individuals (Peatman, et al. 2017a; 2017b). A correction factor can be applied to grab sampling data to provide unbiased results if aggregated over many trips at sufficient areal resolution, such as in the reporting of annual fleet-level catches. However, the variance becomes unacceptably high when considering catch estimates at the set or trip level (Hampton and Williams 2015). Vessel-level catch estimates may be important for research, such as when examining the influence of gear and operational characteristics on catch or for management purposes (e.g. FAD or species-specific management measures).

Given logistical complexities, ongoing paired spill/grab sampling is unlikely to be supported in the long-term and spill sampling is not practical on many vessels due to limited space and other factors. Low sample sizes from grab sampling also impact accurate species composition estimates, particularly for low abundance but management sensitive species such as bigeye tuna. Options for reducing sample bias and obtaining higher resolution data from the purse seine sector have been proposed, including the use of detailed unloading data available at selected ports (e.g. for MSC compliance), modifications to onboard sampling protocols and the application of EM technology (Smith and Peatman 2016).

2.5. Objectives

The focus of this study is to examine the use of video EM data to improve the proportion of purse seine catch sampled at sea, currently only ~0.04% (Hampton and Williams, 2015). A higher sampling rate would improve the accuracy of species-specific length frequency and species composition estimates at the set level. However, the accuracy of these data and ability of EM to fulfil other functions must be verified. The fundamental objective of the study is to compare length frequency and species composition data determined by analysis of EM video images to other data sources, including those obtained by onboard sampling.

The project concept was for TNC scientist/samplers to physically sub-sample catch from the loading conveyor on the wet deck with subsequent comparative analysis of the corresponding EM video footage by trained EM analysts from Digital Observer Services.

Analysis of EM video data was compared to information recorded by the:

- TNC scientific samplers
- WCPFC ROP observer
- Vessel logsheet data
- NOAA port sampling
- Cannery unloading tallies

Information and data examined included:

- Verification of Set type
- Well loading destination
- Set and trip level catch estimates by species (mt)
- Species Composition estimates
- Length Frequency data
- Observations of bycatch encountered, with condition, fate, release and discard information

3. Materials and Methods

3.1. Vessel

Tri Marine and TNC agreed to utilize the *Cape Elizabeth III* (CE3) for the purposes of the study. This is one of the larger purse seine vessels in the Tri Marine fleet at 1930 GRT and 68.8 meters with a rated catch capacity of 1261 mt. The basic specifications of the CE3 are provided in Appendix I. The vessel was well suited for the project with a wide and open well deck and a split conveyor system for catch loading that was necessary for obtaining spill samples for comparison to other sampling protocols and the EM video analysis. Catch loads to one of twenty brine wells for storage. The forward two wells (designated 0C and 1C) are single wells that stretch from port to starboard. The remaining are paired wells from 2 Port and 2 Starboard running aft to 10P and 10S (**Figure 3**). Wells are loaded one brailer at a time entering the well deck through a central hatch located between the #10 wells and carried forward on the conveyor belt system. However, wells 9 and 10 are loaded directly by attaching purpose built metal chutes.

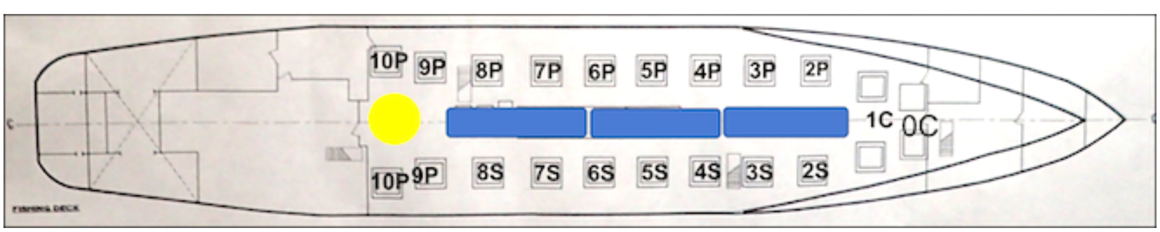

Figure 3. Cape Elizabeth III fish storage well plan and conveyor system.

3.2. EM video camera and data storage system

An 8-camera High Definition (1280 x 720 @ 24FPS) Satlink Seatube EM system was installed for the study with five cameras located above on the working deck and three mounted mid-line directly above the wet deck fish loading conveyor belt system. Video data from all 8 cameras is recorded continuously 24/7 and stored on removable hard drives on the bridge. The five above deck cameras were mounted in the following areas to monitor the activities noted in **Table 1**. Cameras 4 and 5 provide wide angle views of the port and starboard side for complete visual coverage of activities surrounding the vessel.

Table 1. Above deck EM video camera locations

Camera # and type	Mounted Position	Primary responsibility
1 – 110°	Helicopter deck facing forward	FAD retrieval, inspection, deployment, discards
2 – 110°	Port hydraulic console	Fishing start, Fishing end, Gear set and retrieve, catch brailing, FAD deployment, bycatch handling and release, set and school type
3 – 110°	Starboard speedboat deck	Bycatch handling, release, condition, discards, FAD checking, grab sampling
4 - 360° wide view	Port side mast	Wide angle view of port side, school and set type, FAD checking, transshipment, other vessels
5 - 360° wide view	Starboard side mast	Wide angle view of starboard side, FAD checking, transshipment, other vessels

The remaining three cameras were mounted on the well deck above the fish loading conveyor with the following characteristics and monitoring tasks (**Table 2**).

Table 2. Well deck EM video camera locations

Camera # and type	Mounted Position	Primary responsibility
6 – 110°	At well #7 facing aft	Document species composition, LF measurements and loading of wells 7, 8, 9 and 10
7 – 110°	At well #7 facing forward	Document species composition, LF measurements and loading of wells 7, 6, 5 and 4
8 – 110°	Between well #4 and #5 facing forward	Document species composition, LF measurements and loading of wells 4, 3, 2, 1 and Zero

Figure 4 indicates the camera mounting positions above deck while **Figure 5** depicts the video camera positions and field of view of the three cameras mounted on the well deck above the loading conveyor. **Figure 6** shows the actual camera views and viewing angles for the eight-camera EM system. Four views were available at a time on a computer monitor mounted on the bridge chartroom.

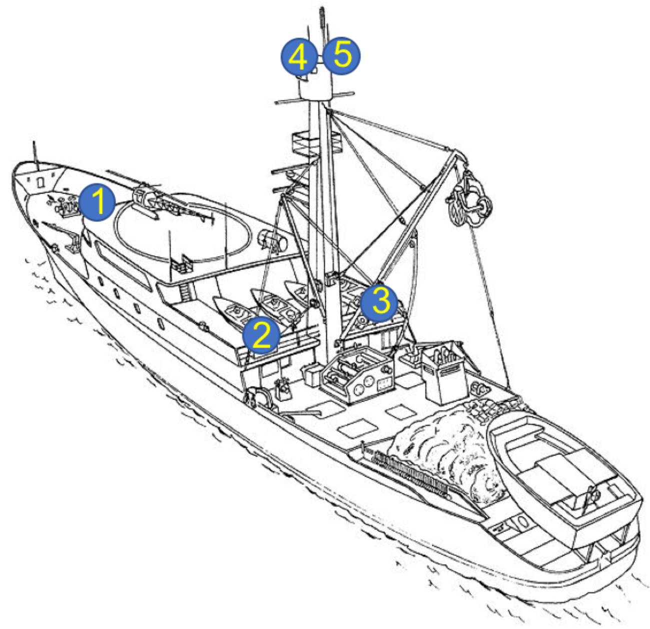

Figure 4. EM camera locations on upper deck and mast for cameras 1 – 5.

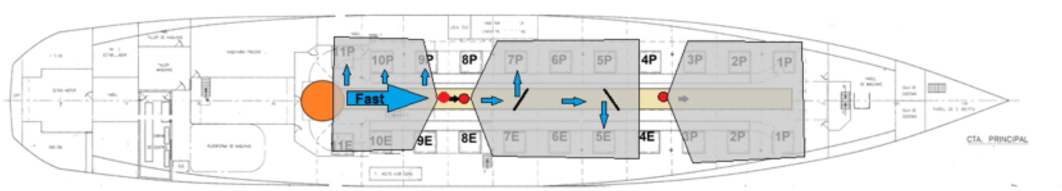

Figure 5. EM camera locations and coverage for well deck cameras 6, 7 and 8.

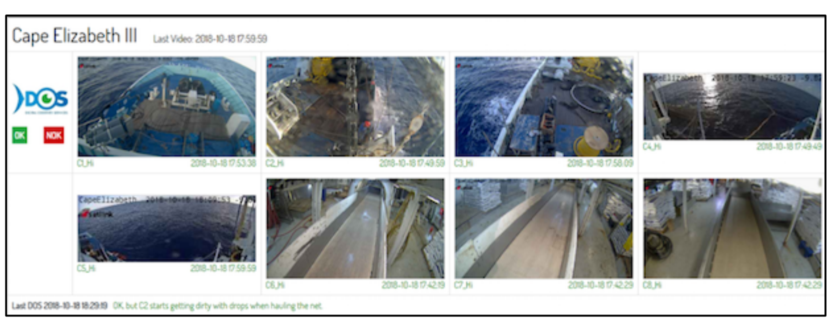

Figure 6. EM video camera views of the 8-camera system.

3.3. Sampling procedures and data sources

3.3.1. TNC spill sampling

Purpose built aluminum sampling bins (2) were fabricated for the study trip to serve as sampling bins with form and dimensions as described in **Appendix II**. The bins had an approximate volume of 0.73 m^3 and were designed to hold about 200 to 250 tuna for sampling. The bin size was a compromise between what could practically be moved and placed on either side of the loading conveyor and still accept an adequate sample size. Bins were placed on heavy wooden boards raising them 10 cm above the wet deck to relieve back strain with the total height scaled to the height of the conveyor unloading doors. One bin was placed on either side of the conveyor and each was fitted with three measuring boards firmly affixed to the sides and back with each board clearly marked in whole cm (**Figure 7**).

Figure 7. Spill sample bin with measuring boards in place adjacent to the conveyor belt spill door.

Fish from the brailer are transported by the conveyor from stern to bow with the vessel loaded bow to stern. Sample bins were positioned next to the loading door located just aft of the well slated to receive catch for a particular set. When a sample was to be taken, the loading door could be opened to allow fish to flow by gravity to fill the bin after which the door was closed. The split conveyor system could be momentarily stopped or reversed if necessary to allow the bins to be filled efficiently (**Figure 8**). The sampling system essentially replicated spill sample protocols except for the sampling interval which was modified to sample as many brails as possible during a set.

Figure 8. Taking a spill sample from the conveyor belt.

Both TNC samplers have long experience in commercial tuna fisheries and are considered expert in the identification of tropical tunas at all sizes. Samplers worked either together or singly on separate bins and then singly after set #15 when one TNC sampler transferred to another vessel at sea to return to American Samoa to attend other projects. All species ID and length frequency data collected was considered of comparable quality and was combined for all analyses.

Samplers identified and measured the caudal fork length of all tuna to the nearest whole cm (rounding down), replacing them to the conveyor until the bin was empty. Another sample was then taken. When all samples were completed another spill sample was taken from a subsequent brailer. The corresponding brail number, species and fork length was recorded on digital voice recorders and later transcribed to data sheets, entered into a spreadsheet and backed up daily.

3.3.2. ROP Observer

The study did not request a specific or highly experienced observer be assigned to the study cruise, wanting instead to compare observer data with a random participant from the ROP observer pool. However, a cross endorsed observer was requested in the event the vessel operated in both WCPFC and IATTC convention areas. This may have selected for an observer with a higher level of experience. The ROP observer on the trip was a veteran observer who had also made the two prior trips on the same vessel, and was familiar with the vessel and crew. ROP observers are trained to complete a suite of general vessel and purse seine specific forms that document vessel characteristics, crew details, daily activities, set details, length frequency measurements, well loading and transfer and details of all FADs set upon or encountered. He performed his normal duties throughout the trip as for any other trip.

Grab sampling is conducted during each successful set with observers tasked with randomly selecting five tuna per brail with each fish measured to the next lowest cm using a calibrated caliper. If a sample is missed they are instructed to take an extra fish from the next brail. If brailing is too fast, they are advised to take less than 5 tuna per brail but try to take a consistent number of tuna throughout the brailing process. Attempting to obtain a random sample is stressed. Instructions state that tuna should not be selected because they are easier to handle or of a species or size that has not yet been sampled.

Identification and measurement of non-target catch is recorded as time permits. Fork length measurements are taken for all finfish and sharks. Billfish are measured from lower jaw tip to caudal fork. If sampling problems occur, a notation is required in the comments field.

3.3.3. EM Video analysis

The Satlink SeaTube Electronic Monitoring system was used to record HD quality video from the 8-camera system with all data stored onboard the vessel on removable, encrypted hard drives. Each still image from video is permanently watermarked with the vessel name, date (GMT), timestamp accurate to 0.01 seconds and a GPS position to the nearest 0.00001° of latitude or longitude.

The video images were reviewed and analyzed by Satlink's partner company Digital Observer Services (DOS) that produced an overall trip report, set resume, and detailed data files on set details, brail details, bycatch, FAD sightings, discards, tuna identification, and tuna measurements. The following set specific information was identified.

- Start fishing + Gear Set. Set begins at skiff release
- Purse rings up finish pursing. Gear retrieval
- FAD description (if visible)
- Set type
- Net sacking time
- Brail observations
- Brail total
- End fishing. Skiff brought on board.

Detailed information on FAD related activity (FAD setting, retrieving, change buoy, checking, etc.) was monitored and recorded to an events log. Total catch estimation by set was made with information on the number of brails, estimated brail capacities and well capacity.

Regarding the identification, counting, measuring and species composition estimates, the digital reviewer first determines the sampling grid/area of the conveyor belt to work in for each of the three cameras mounted above the conveyor belt. The selected area depends on the camera angle and available lighting with this camera-specific sampling/counting area being maintained for the entire trip review (**Figure 9**). Sampling is conducted on the same brails that were spill sampled by TNC. Unique screenshots are taken of the grid area where as many species are identified as possible. The DOS reviewer places a colored dot on each fish within the grid corresponding to skipjack (blue), yellowfin (green), bigeye (red) or yellow (not identifiable) (**Figure 10**).

Figure 9. Sampling grid for camera #5 for species ID.

Figure 10. EM Species identification and marking of sampled catch.

Fork length measurements were made using the DOS digital measuring tool that allows a video analyst to place a line from tip of upper snout to the caudal fork which automatically records a length in cm to 0.01 cm. Measurements were taken when fish were on a single layer on the conveyor (**Figure 11**)., or when fish were being spilled into the sample bin creating a momentary single layer effect (**Figure 12**). Only fish with a clearly visible snout and caudal fin were measured.

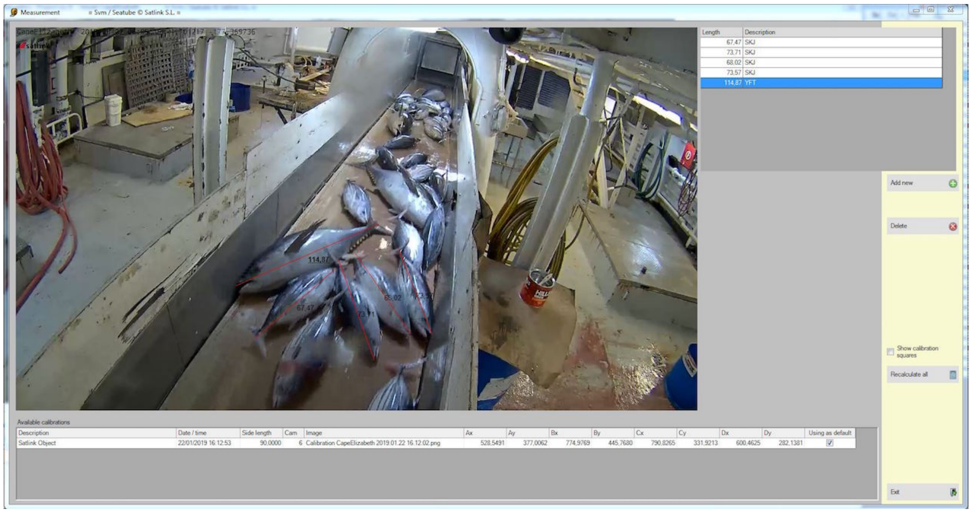

Figure 11. Digital measuring of samples on the conveyor belt.

Figure 12. Digital measuring of tuna as they are entering the spill sample bin.

Bycatch can appear throughout the net hauling and catch loading process. The portside wide-angle camera (#4) is used to identify individual catch and bycatch that are entangled and meshed in the net as it is being hauled. Cameras #2 and #3 are used to identify and monitor bycatch released from the net and brails and to monitor tuna discards. The well deck cameras (#6, #7, #8) are useful to identify and enumerate bycatch removed from the conveyor belt.

3.3.4. Vessel logsheet data

All commercial fishing vessels operating in the WCPFC Convention area are required to submit set level catch and effort data to the Commission. The main data form of interest to the study is the South Pacific Regional Purse-Seine Logsheet where information is recorded on the main activity conducted (fishing set, FAD check, etc.), date, location, catch, well loading and bycatch information. Normally, the licensed master of the vessel completes logsheet data. Retained catch in mt/species and discards of tuna (mt) and bycatch species (number of pieces) is noted for every set and was compared to other data sources.

3.3.5. Port sampling

NOAA Fisheries operates a field station in Pago Pago, American Samoa that administers observer programs and catch monitoring of vessels unloading in Pago Pago Harbor, primarily at the Starkist Samoa seafood processing facility. A team of port samplers monitor purse seine unloadings following a sampling protocol that targets length frequency measurements from the tropical tuna species based on completing a spatio-temporal grid across the extent of the fishery (Coan and Yamasaki 1990).

Data collected by this protocol cannot be compared to other data sources in this study as sampling may not be random, i.e. some selection of a specific species may be targeted to achieve a specified sample size. However, NOAA personnel were able to conduct, upon request from TNC a limited amount of random sampling of tuna as it was being unloaded in Pago Pago to address the objectives of the study. In order to examine set specific data, only wells that were filled entirely by a single set were targeted for random sampling in this manner.

3.3.6. Cannery unloading data

All retained catch was delivered to the Starkist Samoa Co. cannery in Pago Pago. Wells are unloaded by hand and sorted to general species and commercial size categories and stored in lots, later to be sorted more carefully by size and species or species groups. Eventually, the frozen product is divided into lots of skipjack (sized at <3, 3-4, 4-7.5 and >7.5 lbs) or bigeye or yellowfin (sized at <3, 3-4, 4-7.5, 7.5-20 and 20+ lbs). Size discrimination for skipjack and yellowfin is considered good but bigeye of <20 lbs may be mixed with other species.

3.4. Set size, species composition and length frequency protocols

3.4.1 TNC Sampling – Spill sample estimates

Set size and species composition estimates were made as follows:

- Total set size (mt) was estimated visually and in relation to well filling volumes noted against rated fish well volumes provided by the Chief Engineer.
- Fish were identified and measured to fork length during well deck spill sampling.
- Fork lengths were converted to weights in kgs using WCPO length/weight factors
- Weights were summed by brail and species.
- A total set weight was calculated.
- Total species weights were divided by the total set weight to produce a percentage ratio by species.
- This percentage was applied to the estimate of total tons for the set to produce an estimate of weight of each species in the set.
    - Note, this procedure produces set level estimates of species composition by weight.

- Sets filling wells #9 and #10 could not be spill sampled due to the speed of brailing as catch flows directly from the unloading hatch to the wells. In these cases, visual estimates of species composition were applied.

Spill samples were used to generate brail, set and trip level length frequencies by:

- Brail-specific spill samples were used to calculate (brail-specific) proportions (by number) by species and length.
- Brail-specific proportions by species and length were then raised to estimated numbers caught by species and length, using the brail-specific average weight of sampled fish and observer's estimated total catch for the set to estimate the total number of individuals caught.
- The brail-specific numbers caught by species and length were converted to set-level numbers caught (by species and length) by taking the average (mean) estimated number across the sampled brails.
- The set-level estimated numbers caught by species and length were then raised to the trip level by summing across sets. Unassociated sets with no spill samples were assumed to have the same length frequency as the overall estimated length frequency for sampled unassociated sets. The same for associated sets.

3.4.2 ROP Observer Grab Sampling

Observers calculate total set size (mt) based on an estimated total full brail capacity which for this trip was 8.0 mt. Each brail load is estimated as to fullness by eights and summed to arrive at the total number of full (presumed 8 mt) brails that were required to load the set onto the boat. This figure represents the total weight of everything removed from the net. An estimate of bycatch in this total is then subtracted to arrive at an estimate of total mt of target tuna landed for the set.

Purse seine observers in the WCPO used to apply a similar methodology as the TNC samplers used on this trip to calculate and apply species composition percentages derived from their grab samples. This protocol was found deficient as the low sample numbers often missed sampling low abundance species completely, namely bigeye tuna. This protocol has been changed to have observers make visual estimates of skipjack, yellowfin and bigeye composition based on what they see and estimate during the net hauling, sacking and brailing stages. This estimate is then applied to the estimate of total catch for the set to obtain the set level estimate of species composition

Grab samples were measured on the working deck using a measuring tape or calibrated measuring calipers.

Grab samples were converted to set and trip level length frequencies using the following methodology:

- Set-level proportions by species and length class were calculated directly from the grab samples (by combining samples from all brails).

- The proportions were corrected for 'grab sample bias' using the estimated grab sample bias presented to SC14 (Peatman et al. 2018) to correct for the finding that grab samples over-estimate proportions of large fish, and under-estimate proportions of small fish.
- Set-level proportions were then raised to numbers caught by estimating the total number of fish caught. This was done using the same approach as the spill samples – estimating total number caught using the average weight of grab sampled fish and the total estimated catch for the set and applying this to the proportions by species and length.
- Set-level proportions by species and length were then raised to trip level using the same approach as for spill samples.

3.4.3 EM Video Analysis

Total catch estimates (mt) from video analysis were made in a similar way to the observer estimates. Each brail was estimated visually as to fullness based on an assumption that a full brail contained 8 mt. Brail fractions were summed to whole brails and multiplied by 8 to obtain a set level estimate.

Estimates of the proportion (mt) per species from the total was made using the per cent abundance from visual counting and conversion of length data to weights.

The EM fork length measurements recorded by the DOS data reviewer with the SeaTube software were converted to set and trip level length frequency data using the approach outlined for observer grab samples but with no correction for grab sample bias.

3.4.4 Logsheet data

The vessel master provides logsheet data of set level estimates of retained catch (skipjack, yellowfin, bigeye, other species by weight) and discards (tuna species by weight, other species by number and weight) to the Commission. There is no standardized way in which these estimates are made across fleets or fisheries. Estimates of total catch (mt/set) utilize many years of experience that may include visual estimates of the school before and during setting, use of marine electronics (depth sounder and sonar), behavior of tuna in the net, number of corks taken on the brailing boom when sacking up the catch, amount of sacking net in the water when brailing starts, number of brails taken, well filling rates and other factors.

Species composition and bycatch (retained and discarded) estimates are made visually but may be guided by other observations. For example, bigeye tuna have a large, well developed swim bladder that provides a strong and characteristic return on depth sounder and sonar equipment. The swim bladder can also inflate and float individuals to the surface inside the net, alerting the crew that there may be more bigeye than usual in the set. Observations of bycatch discards may include those that are observed to be meshed in the net during net retrieval, are sorted out of the brailer or are culled from the loading conveyor on the well deck. Visual estimates of brail contents and catch loading occur from the upper hydraulic console which is about 10-12 m away from the brailing and fish loading operations making detailed observations and discrimination of small bigeye and yellowfin difficult.

3.4.5. Port sampling

The NOAA port sampling of purse seine unloading in Pago Pago does not conduct trip level sampling of catch and does not make any set, trip or well level estimates of catch. Catch sampling is conducted to record catches in established time and area grids by set type (associated and unassociated). The normal protocol targets wells that were filled by a single set, so are representative of set level data and wells that were filled by multiple sets of the same set type made in the same time/area strata. However, the sampling protocol may not be random in order to obtain length frequency numbers from less common species, i.e. bigeye tuna. NOAA staff were able to accommodate the study by targeting some single set wells and selecting fish at random for length frequency measurements. Species composition ratios can be taken directly from these raw data, noting that not all fish from that set will be represented.

3.4.6 Cannery data

Cannery data was provided to the study indicating catch by species and unloading lot number and including “scrap” which is presumed to be tuna that has been damaged during storage or unloading or is otherwise unfit for processing.

3.4.7. Numbers of fish caught

Calculations were made to convert the number of fish sampled (by Spill, Grab and EM sampling) to the estimated numbers of fish caught by the following methodology:

- Use the samples to calculate the proportion of fish in each (1cm) length bin for each species;
- Use the average weight of the samples and the total weight of the set to estimate the total number of fish caught;
- Apply the proportions (by species and length) to the estimated total number of fish to estimate # caught by species and length bin;
- The weight of each sampled fish is itself estimated using WPO length-weight parameters.

4. Results
4.1. Trip overview

The research trip was conducted on the tuna purse seine vessel *Cape Elizabeth III* from 16 October – 22 November 2018 for a total of 38 sea days, fishing in the EEZs of Tokelau and the Cook Islands (**Figure 13**). The trip was made outside the WCPFC FAD Closure period so both FAD associated and free schools were targeted. The trip originated from Pago Pago, American Samoa and returned to the same port to unload catch at the Starkist Samoa facility in Pago Pago Harbor. Thirty-seven sets were made of which six were considered null sets with zero catch recorded by all data sources. Thirty-one successful sets filled the twenty brine wells to capacity. Two TNC samplers boarded the vessel at the start of the trip with one disembarking to another vessel on 1 November.

Fishing effort, especially successful effort was mainly on free drifting FADs but the associated tuna schools were not closely aggregated to FADs observed during the trip. In some areas, schools of skipjack were observed actively feeding on the pelagic anchovy (*Encrasicholina punctifer*), at times in close proximity to FADs. In general, tuna biomass was strongly dominated by skipjack in free and FAD associated aggregations with a very low abundance of juvenile yellowfin and bigeye tuna noted on FADs.

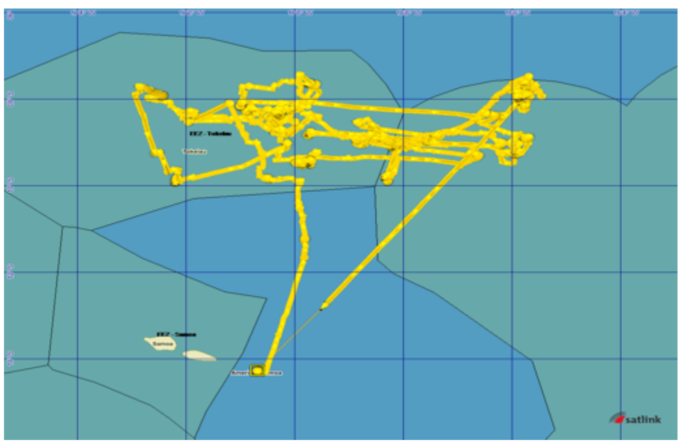

Figure 13. Cruise track of the Cape Elizabeth III from Pago Pago, American Samoa, operating in Tokelau and Cook Islands EEZs.

4.2. Determination of set type

All sampling sources recorded a total of 37 sets to complete the trip. The TNC samplers and onboard observer recorded a total of 28 FAD and 9 free school sets totaling 37 sets made during the trip. The vessel logsheet entries agreed with these determinations except for set #8 which the vessel recorded as a free school (**Table 3**).

On this set #8, a breezer of skipjack came up near the FAD at dawn but then moved away. The vessel set on the school about 300 meters away from the FAD and excluded the FAD and towboat from the set but succeeded in capturing about 145 mt of skipjack of uniform size. The school was "acting" like a free school but was clearly within one mile of a FAD so technically was a FAD associated school.

Table 3. Set type declarations, FAD or unassociated (free school) sets.

	School Association			
Set #	**TNC**	**Observer**	**Vessel**	**EM**
1	FAD	FAD	FAD	FAD
2	UNASS	UNASS	UNASS	UNASS
3	FAD	FAD	FAD	FAD
4	FAD	FAD	FAD	FAD
5	FAD	FAD	FAD	FAD
6	FAD	FAD	FAD	FAD
7	FAD	FAD	FAD	FAD
8	FAD	FAD	~~UNASS~~ FAD	FAD
9	UNASS	UNASS	UNASS	FAD ?
10	FAD	FAD	FAD	FAD
11	UNASS	UNASS	UNASS	~~FAD~~ UNASS
12	UNASS	UNASS	UNASS	UNASS
13	UNASS	UNASS	UNASS	UNASS
14	UNASS	UNASS	UNASS	UNASS
15	UNASS	UNASS	UNASS	UNASS
16	FAD	FAD	FAD	FAD
17	FAD	FAD	FAD	FAD
18	FAD	FAD	FAD	FAD
19	FAD	FAD	FAD	FAD
20	FAD	FAD	FAD	FAD
21	FAD	FAD	FAD	FAD
22	FAD	FAD	FAD	FAD
23	FAD	FAD	FAD	FAD
24	FAD	FAD	FAD	FAD
25	FAD	FAD	FAD	FAD
26	FAD	FAD	FAD	FAD
27	UNASS	UNASS	UNASS	UNASS
28	FAD	FAD	FAD	FAD
29	FAD	FAD	FAD	FAD
30	FAD	FAD	FAD	FAD
31	FAD	FAD	FAD	FAD
32	FAD	FAD	FAD	FAD
33	FAD	FAD	FAD	FAD
34	UNASS	UNASS	UNASS	UNASS
35	FAD	FAD	FAD	FAD
36	FAD	FAD	FAD	FAD
37	FAD	FAD	FAD	FAD
	28 FAD 9 UN	**28 FAD 9 UN**	**27 FAD 10 UN**	**30 FAD 7 UN**

The EM analysis differed from the TNC + Observer assessments on set #9 and #11, which were both recorded as FAD associated sets. When consulted, DOS analysts re-examined the respective video footage and found that their FAD set determination for set #11 was in error and was subsequently changed to an unassociated set in agreement with the TNC and Observer recordings.

The EM analysis indicated that set #9 was FAD associated while the other three sources had classified it as an unassociated set. The observer data indicated that a piece of plywood was checked at 1740 hours (local time) and a free school set #9 occurred at 1804. Distance and time between those positions calculates to 24 minutes and 2.01 nautical miles supporting the designation as an unassociated school. However, fine-scale frame by frame analysis of the time stamped video feed indicates an 11:43 minute delay between placing a radio buoy on the piece of plywood and when the skiff was dropped to begin the set at 1804 with a separation of less than one nautical mile.

4.3. Estimation of total catch per set and trip

Estimates of retained tuna catch by Set and Number of Brails for the TNC samplers, Observer, Vessel logsheet and EM data sources are provided in **Appendix III**.

The TNC samplers spent the entire brail loading period on the wet deck where the brailing activity and pace can only be recognized by the flow of fish onto the conveyor. Some differences in estimates with the observer occurred with the observer brail count observations assumed to be correct due to his direct observation of brailing on the working deck. Slight differences between brail counts were also noted between the EM analysis and the observer. These differences were likely due to what each data source considered to be a “brail” load. For example, as the net is retrieved, meshed fish may be removed and thrown into the empty brailer on deck. This initial quantity falls onto the conveyor when the brailer is readied for use. These fish may or may not be counted as a brailer for counting purposes. The vessel brail winch operator may have kept track of brails informally but if so, this data was not recorded or preserved for analysis.

Estimates of catch by species (target tuna) at the set level by the TNC samplers, Observer, Vessel and EM are also provided in **Appendix III**. A subset of these data are summarized in **Table 4** listing total catch by set. Set level data is not available for port sampling or cannery offloading data.

Table 4. Total set level catch estimates made by TNC samplers, ROP Observer, Vessel and EM review.

	TNC	Observer	Vessel	EM	Cannery
Set #	Catch estimates (mt)				
1	13	13	15	19	-
2	2	2	0	1	-
3	30	25	30	17	-
4	120	120	122	103	-
5	16	16	15	11	-
6	55	48	45	32	-
7	70	68	65	53	-
8	145	140	150	81	-
9	0	0	0	0	-
10	3	3	5	2	-
11	2	3	0	0	-
12	30	30	35	18	-
13	0	0	0	0	-
14	0	0	0	0	-
15	0	0	0	0	-
16	55	54	55	36	-
17	8	9	5	3	-
18	66	65	65	39	-
19	30	29	30	20	-
20	50	48	50	34	-
21	40	42	40	30	-
22	40	39	40	27	-
23	0	0	0	0	-
24	97	93	102	67	-
25	100	99	100	68	-
26	81	72	75	47	-
27	12	12	5	5	-
28	6	4	5	2	-
29	15	17	15	7	-
30	25	30	25	15	-
31	0	1	0	0	-
32	45	47	50	29	-
33	60	60	60	38	-
34	30	27	25	20	-
35	12	9	10	4	-
36	2	1	0	0	-
37	32	29	34	26	-
Sub totals	1292	1255	1273	855	1319

The TNC sampling and Observer estimates are similar though derived by different protocols. The Vessel (logsheet) data is similar in total catch by set but systematically underestimates yellowfin catch and lists zero bigeye tuna for the entire trip. Yellowfin and bigeye were present during the trip in FAD associated sets but were unusually low in relative abundance on this trip that was heavily dominated by skipjack schools on FADs and free schools.

The EM video analysis consistently underestimated skipjack tonnage resulting in significantly lower estimates of total catch at the Set and Trip Level compared to other data sources. Yellowfin estimates were comparable to TNC and Observer estimates but lower for bigeye.

A summary of this data (**Appendix III**) aggregated at the trip level is given in **Table 5**. Note the average rated capacity of the vessel is 1261 mt when full. However, the amount of tuna that can be stored in each well will vary depending on the size and species of catch and how densely the engineers choose to pack the wells. In general, small and medium-sized skipjack will pack closer and return higher total well weights than large yellowfin.

Table 5. Trip level catch estimates by species (mt) with calculated species composition from different data sources.

Source	SKJ	YFT	BET	SK %	YF %	BE %	Total
TNC	1165	85	42	90.2	6.6	3.2	**1292**
Observer	1171	53	28	93.3	4.2	2.2	**1255**
Vessel	1238	35	0	97.3	2.7	0.0	**1273**
EM	778	65	13	90.9	7.5	1.5	**855**
Cannery	1245	64	9	94.4	4.8	0.7	**1319**

The total trip level estimates made by TNC, the Observer and Vessel were close to each other, ranging from 1255 to 1292 mt despite different estimation methods being used. TNC and Vessel estimates were made with a combination of visual and other information sources. The observer used an independent method of brail counting and estimation of brail fullness to arrive at a similar total weight estimate. However, the vessel under-estimated yellowfin compared to other methods and did not record any bigeye catch as noted previously.

The standard to which Trip Level catch estimates should be held is the total weight figure of 1319 mt resulting the sum of cannery bin weights taken during unloading. However, the species breakdowns from cannery data should not be taken as precise due to the mixing and blending of juvenile bigeye with skipjack and yellowfin.

4.4. Species composition estimates for Grab, Spill, Vessel, EM and Cannery sources

Raw estimates of Trip Level catch by species (mt) by the different data sources is also provided in **Table 5** (from Appendix III). These figures provide an initial comparison between data sources and tuna species reporting levels. Skipjack clearly dominated the catch composition for all estimates at some level above 90%. Total catch for the three onboard estimates are similar but differ in per cent species composition. The trip was characterized by a high proportion of skipjack with generally low proportions of yellowfin and bigeye on FAD sets making estimates and comparisons difficult for these two species. The vessel did not report any bigeye catch at all while the EM and Cannery declarations were the lowest of the remaining data sources.

TNC spill sampling, observer grab sampling and EM video analysis estimates were used to generate trip level length frequencies and species compositions as described in Section 3.4, based on sample sizes of 8402 (TNC spill), 760 (Observer grab) and 3143 (EM Video). **Table 6** provides a summary of results indicating the sample sizes and estimates of species composition.

Table 6. Sampling based Trip level species composition estimates from spill, grab and reviewer interpretation of video sampling.

source	TNC Spill				Observer Grab				EM Video			
Species	n samples	lower 95% CI	MEAN	upper 95% CI	n samples	lower 95% CI	MEAN	upper 95% CI	n samples	lower 95% CI	MEAN	upper 95% CI
SKJ	**7749**	88%	**91%**	95%	**704**	90%	**94%**	97%	**2613**	73%	**81%**	87%
YFT	336	3%	**5%**	8%	18	0%	**2%**	4%	423	11%	**17%**	24%
BET	317	2%	**3%**	5%	38	2%	**4%**	7%	107	1%	**2%**	3%
	8402				760				3143			

TNC spill and Observer grab sampling species compositions were similar. Results from the EM analysis indicated a significantly higher mean ratio of yellowfin in the catch (17%) with a linked drop in the skipjack abundance estimate. This results from a relatively high proportion of yellowfin in the EM identified sampling. Ideally, the direct comparison of the same fish identified and measured individually during spill sampling and EM review could be used to directly evaluate EM accuracy. Unfortunately, deep layering of fish on the conveyor and rapid well loading prevented direct comparisons to be made.

4.5. Length Frequency

4.5.1. Set level

Length frequency plots were generated at the set level for all samples taken and an estimate of numbers of fish taken. As an example, **Figure 14** shows the length frequency of samples taken from **Set # 17** from TNC Spill (a), Observer Grab (b) and EM Video fork length estimates (c). Set 17 was a FAD associated set that was loaded with four brails. Total catch estimates ranged from 2.8 – 9 mt. Spill sampling indicated that skipjack (red), yellowfin (green) and bigeye (blue) were present in the set. Horizontal axis are identical for all plots. Vertical axis vary between data sources a, b, c but are consistent within each data source. Spill sampling achieved the highest sampling levels that produce length frequency plots that are roughly mirrored by a lower level of EM sampling. Grab sample length frequency plots by species do not represent the set accurately due to low sample sizes that did not encounter any yellowfin and only one bigeye for the set.

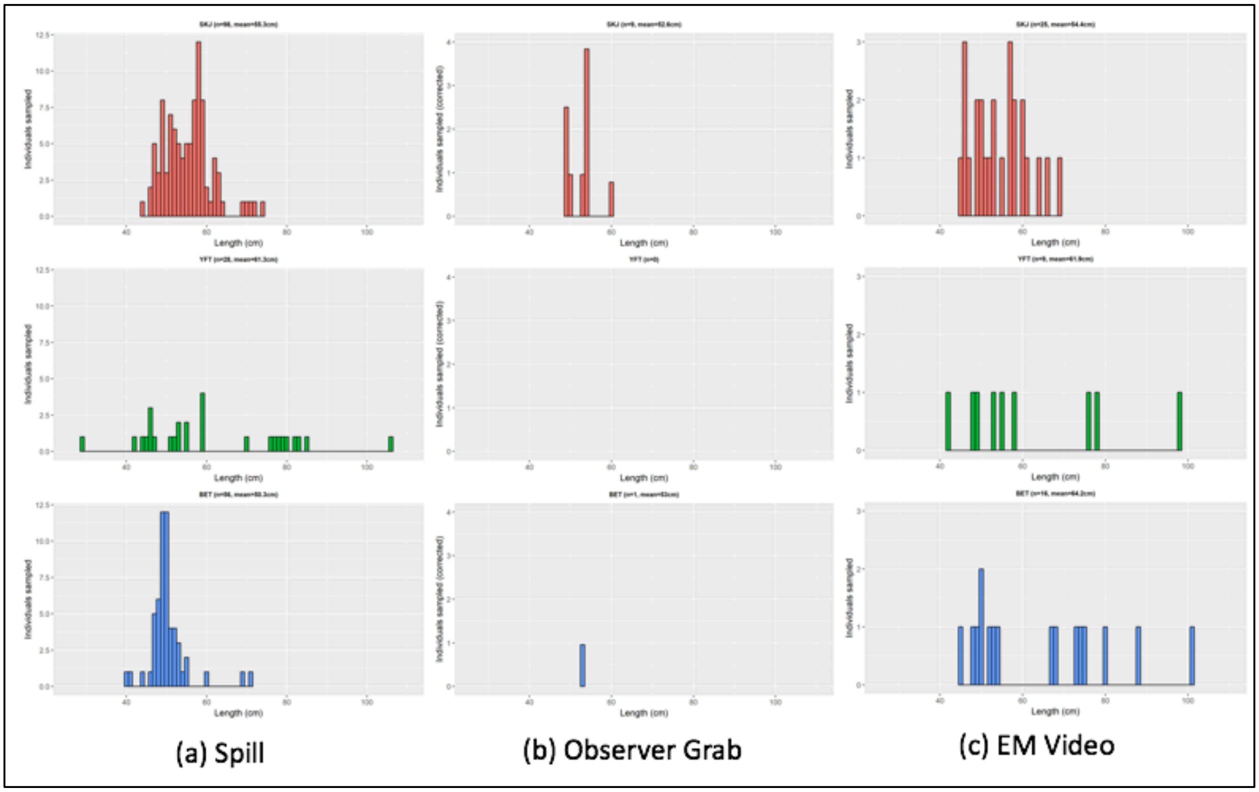

Figure 14. Length frequency of samples taken or estimated (from EM) from Set # 17. Skipjack (top, red); Yellowfin (middle, green); Bigeye (bottom, blue)

Figure 15 expands the total samples taken by data source applied to the total estimated catch to estimate total numbers of fish harvested for the set by species. Sample numbers clearly have a significant impact on the shape and distribution of the resulting data and length frequency plot. Limited grab sample numbers also resulted in no yellowfin being sampled resulting in an estimate that no yellowfin were present in the set. Expansion of spill and EM data to estimate total numbers of fish produce comparable results but are not consistent with expanded grab sample data (**Table 7**).

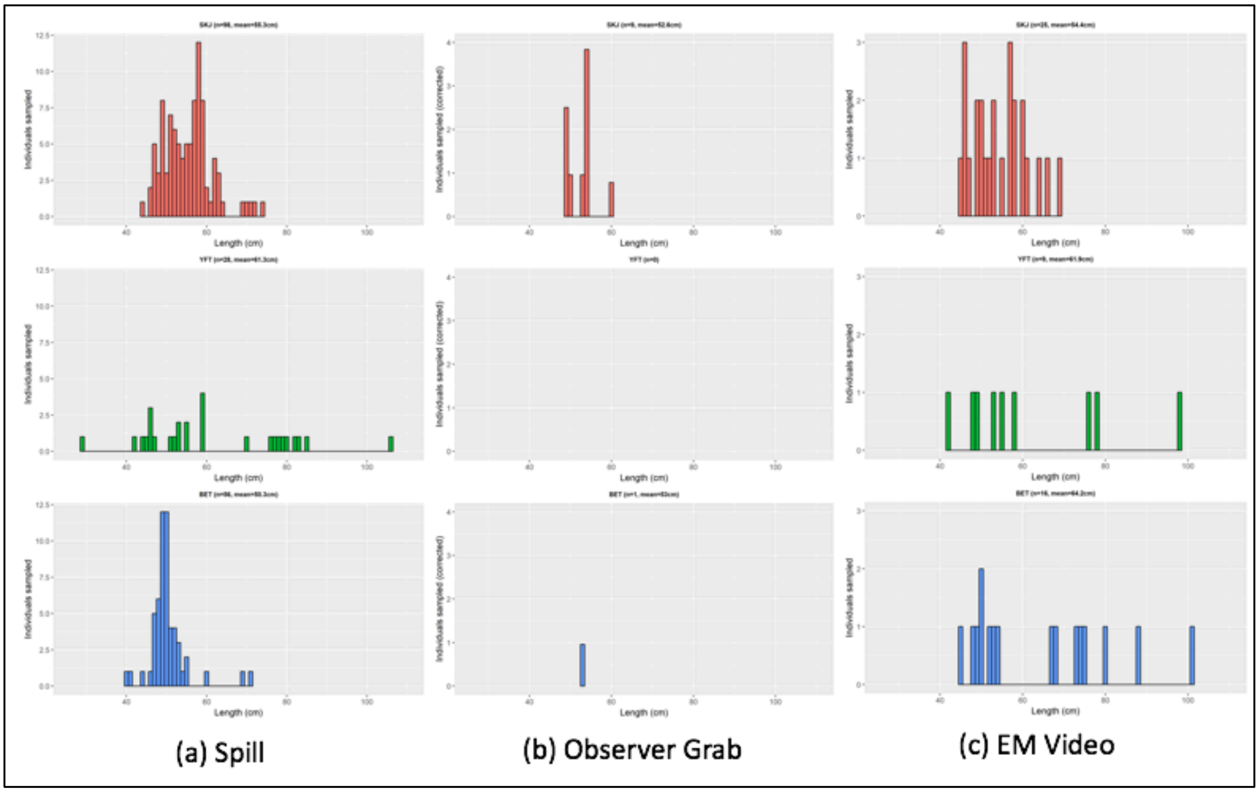

Figure 15. Estimates of numbers of fish caught based on sampling levels for Set #17. Skipjack (top, red); Yellowfin (middle, green); Bigeye (bottom, blue)

Table 7. Number of fish estimated from sampling of set # 17.

	Spill		Grab		EM	
	# Fish	Mean (cm)	# Fish	Mean (cm)	# Fish	Mean (cm)
Skipjack	1211	55.3	2477	52.6	832	54.4
Yellowfin	346	61.3	0	NA	299	61.9
Bigeye	692	50.3	262	53.0	533	64.2

4.5.2. Trip level Length Frequency

The length frequency of all samples taken during the trip from TNC Spill (a), Observer Grab (b) and EM Video fork length estimates (c) are shown in **Figure 16**. Horizontal axis are the same for all plots but vary between data sources. The spill and grab samples indicate a trimodal distribution of skipjack sizes while the EM interpretation only shows the lower two length modes. The EM review also shows a much higher sampling rate for two modal classes of yellowfin tuna that do not appear in the spill or grab samples. The EM dataset show some unrealistically large skipjack tuna that were video sampled.

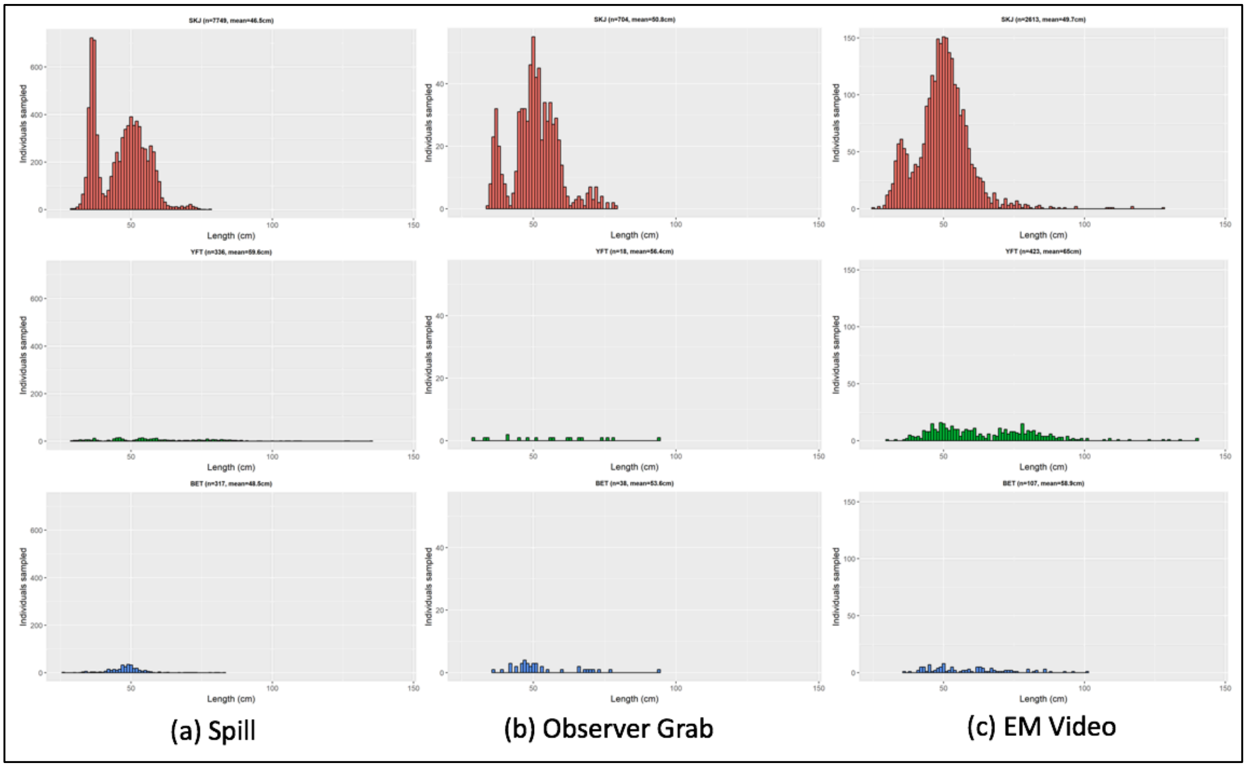

Figure 16. Length frequency measurements of samples taken or estimated (from EM) from the entire trip. Skipjack (top, red); Yellowfin (middle, green); Bigeye (bottom, blue)

These estimates were raised to provide estimates of the numbers of fish caught by species (**Figure 17**). Set level estimates of numbers of fish caught are shown in **Table 8**.

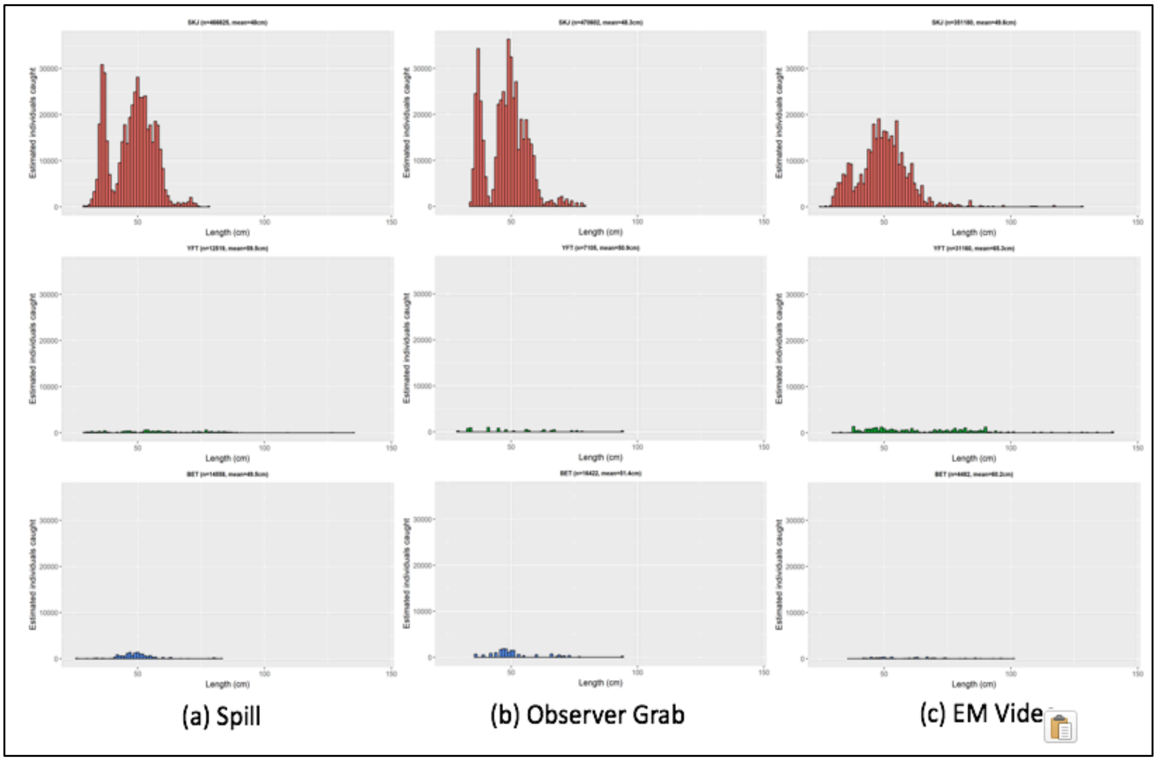

Figure 17. Estimates of numbers of fish caught based on sampling levels for the trip. Skipjack (top, red); Yellowfin (middle, green); Bigeye (bottom, blue)

Table 8. Number of fish estimated from the trip.

	Spill		Grab		EM	
	# Fish	Mean (cm)	# Fish	Mean (cm)	# Fish	Mean (cm)
Skipjack	466625	48.0	470602	48.3	351180	49.6
Yellowfin	12519	59.5	7105	50.9	31160	65.3
Bigeye	14558	49.5	16422	51.4	4482	60.2

4.6. Port sampling

Port sampling of purse seine unloadings by NOAA personnel in Pago Pago does not independently produce trip level estimates of catch by species, so no trip level comparisons of catch, species composition or length frequency were made. However, well #1C was filled entirely with skipjack from Set #8. The set total tonnage was estimated at 145 mt (TNC sampler estimate) of which 106 mt was loaded to well #1C with the remainder sent to well 5P. The onboard observer and vessel master estimated total catch at 140 and 150 mt of skipjack respectively (**Appendix III**).

Fish from this well was therefore considered to be 100% from set #8 and was randomly sampled for length frequency by NOAA dock sampling personnel. A close look at onboard sampling data from Set #8 and port sampling from well #1C is provided here.

Table 9 provides basic statistics of length frequency data taken by observer grab sampling and TNC spill sampling (onboard), port sampling (at time of unloading) and EM video measurements taken post-trip using the DOS measurement software.

Table 9. Summary statistucs of length frequency sampling of skipjack taken in set #8.

	Grab	Port sampling	EM Video	Spill
Mean	56.8	56.4	55.1	56.9
Standard Error of mean	0.6	0.6	0.4	0.2
Median	56.0	57.0	55.1	57.0
Mode	57.0	58.0	48.5	58.0
Standard Deviation	4.4	4.0	5.3	3.9
Count	47.0	47.0	211.0	274.0
Minimum	50.0	47.0	41.7	46.0
Maximum	70.0	70.0	72.4	73.0
Range	20.0	23.0	30.7	27.0
Sample Variance	19.6	16.1	28.3	15.3
Kurtosis	2.0	1.9	0.3	2.8
Skewness	1.1	0.4	0.3	0.8

The mean and associated statistics of the port sampled fish mirror statistics from other data sources. The port sampling conducted on unloading essentially repeated onboard grab sampling and coincidentally took the same number of samples, n-47. The similarity between these data sets is illustrated by length frequency plots in **Figure 18** (grab sample length frequency sampling from set #8) and **Figure 19** (port sampling of skipjack length frequency being unloaded from well # 1C. The same data is plotted on vertical axis of 8 and 50 for each sample source.

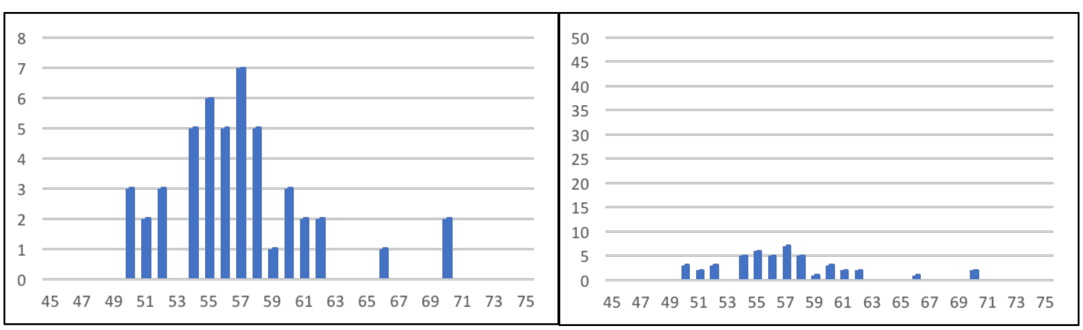

Figure 18. Grab sample length frequency measurements (cm) of skipjack from set #8.

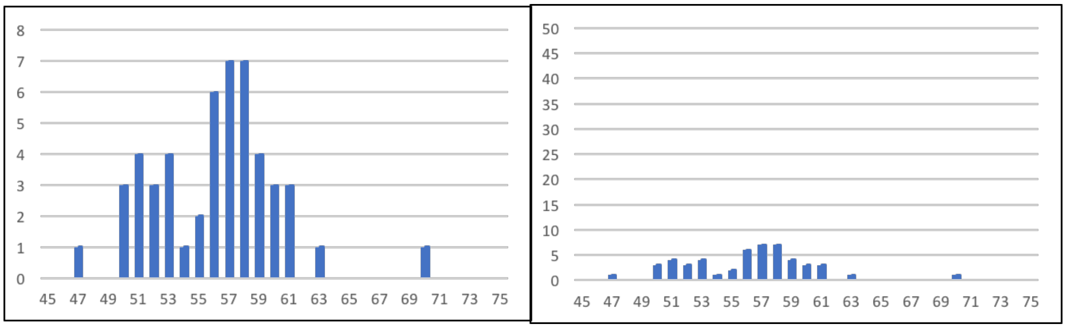

Figure 19. Port sampling length frequency measurements (cm) of skipjack from well #1C (set #8).

Figure 20 plots length frequency data from EM derived length frequency measurements with a sample size of 211 skipjack. The range of data remains the same with additional data filling out the shape of the data. TNC spill sampled length frequency measurements are plotted in **Figure 21.**

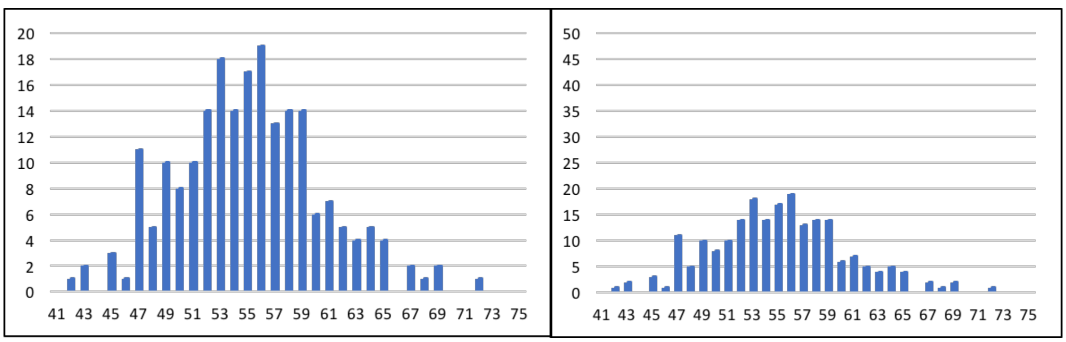

Figure 20. EM measured length frequencies (cm) of skipjack from set #8.

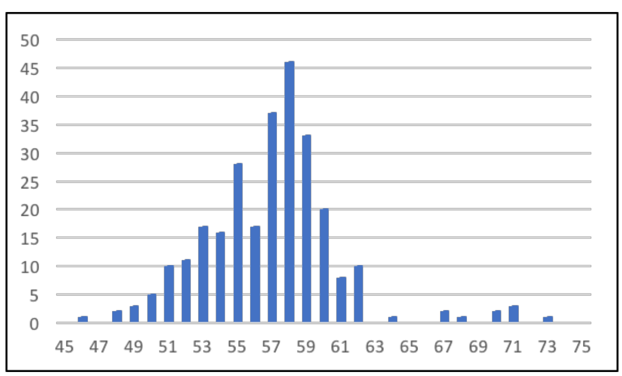

Figure 21. Spill sampled length frequency measurements (cm) of skipjack from set #8.

4.7. Bycatch

Non-target purse seine catch was observed and recorded by the onboard observer, the vessel master (logsheet recorded) and also noted by the EM video reviewer. Detailed fate codes were used to describe the handling, condition and release of bycatch by the observer and EM analysis. **Table 10** summarizes fifteen bycatch categories (specific and generic) that were recorded by all data sources combined.

Table 10. Bycatch encountered during the trip and recorded by the observer, vessel (logsheet data) and observed by EM review. Numbers in brackets (x) indicate quantity of protected species released alive.

FAO Code	Common name	Observer	EM	Vessel log	Comment
OCS	Oceanic Whitetip	2 (2)	1	2	WCPFC non-retention, 2 discarded alive
FAL	Silky Shark	50 (35)	0	44	WCPFC non-retention, 35 discarded alive, 15 discarded dead
RSK	Requium shark	0	38	0	likely all silky sharks
BUM	Blue marlin	7	3	5	often retained for consumption
MLS	Striped marlin	0	1	0	`
SFA	Sailfish	1	3	0	
SSP	Shortbill spearfish	1	0	0	
WAH	Wahoo	79	30	19	often retained whole for consumption
RRU	Rainbow runner	51	22	20	discarded
CNT	Ocean Triggerfish	4	10	0	discarded
CXS	Bigeye Jack	10	0	0	discarded
MSD	Mackerel scad	18	0	0	discarded
RUB	Blue runner	0	86	0	not found in Pacific Ocean
DOX	dolphinfish nei	0	1	0	
CFW	Pompano dolphinfish	69	0	0	often retained whole for consumption
BAF	Flat needlefish	3	1	0	retained for consumption

Oceanic whitetip and silky sharks are both currently managed by the WCPFC under a non-retention policy (CMM 2011-04, 2013-08). The measures require the release of these species as soon as possible in a non-injurious manner and to record the status on release (dead or alive) and report this information to the WCPFC annually. Two oceanic white tip sharks were observed by the observer and recorded by the vessel and the observer reported both as being released alive. EM analysis recorded only one oceanic whitetip (released alive). A review of EM footage of the set in which the second whitetip shark was recorded did not reveal another confirmed whitetip shark though a possible elasmobranch was noted on the well deck. It is possible that the second whitetip was missed due to the malfunction of camera #4 that has a wide-angle view of the net as it is being retrieved, but this cannot be verified.

The observer recorded 50 interactions with silky shark of which 35 were recorded as released alive while the vessel recorded 44 silky shark interactions. EM review did not record any silky shark bycatch but did report 38 requiem sharks that were most likely to be silky shark. No interactions with other ETP species were noted by any data collection system.

Overall, the observer record was the most detailed in number of species and number of interactions recorded. An informal review during the cruise indicated the observer had a detailed and accurate knowledge of WCPO purse seine bycatch species. The only questionable bycatch species entry was for blue runner (*Caranx crysos*) that was identified by EM review. This is a small species of jack only found in the Atlantic and Mediterranean seas that is a large component of finfish bycatch in the Atlantic Ocean tropical tuna purse seine fishery. These observations were more likely of mackerel scad (*Decapterus* spp.) or juvenile bigeye jack (*Caranx sexfasciatus*) that were not reported by EM.

4.8. Well filling

The TNC observers, Observer, Vessel Master and EM reviewer kept detailed records on the well destination of catch. Comparison of EM analyzed video data to other data sources indicated that the three EM cameras positioned on the well deck were able to accurately determine the well being loaded and when loading shifted to another well.

5. Discussion

5.1. Determination of set type

Levels of juvenile tuna and bycatch are much higher on FAD or floating objects sets when compared to free schools that tend to contain mature tuna of a more uniform size and far fewer non-target species. Correct classification of purse seine effort as to association type is a fundamental requirement for fishery data collection. Accurate and verifiable determination of school type is a critical issue in the WCPO due to FAD-based effort controls that have been adopted by the Parties to the Nauru Agreement (PNA) and WCPFC. FAD closure periods in combination with the current definition of a FAD set[4] being within one nautical mile of any FAD and a broad definition of a FAD[5] make observer declarations critical to monitoring and compliance of these measures.

This has also become important for many fleets that are accredited to supply specialty markets for free school (FAD free) tuna. Under these conditions, tuna caught on FADs or free schools must be

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[4] *A set on a FAD is a set with a purse seine net made by a fishing vessel that is a distance of one nautical mile or less from a FAD at the moment in which the skiff is released into the water for the purposes of that set.*

[5] *.. any object or group of objects, of any size, that has or has not been deployed that is living or non-living, including but not limited to buoys, floats, netting, webbing, plastics, bamboo, logs and whale sharks floating on or near the surface of the water that fish may associate with.*

physically separated into different storage wells on the vessel and maintain a rigid chain of custody clearly separating and demarcating free school fish all the way to the end buyer.

The multiple data sources compared in this study agreed on the designation of set school type in all but three instances. A 100% skipjack school (set #8) found breezing and "acting" like a free school was listed as unassociated despite the FAD being nearby and clearly within one mile. Both the observer and EM correctly noted the situation and designated set #8 as a FAD associated school.

Set #11 was incorrectly classified as FAD associated by initial EM analysis but was reversed after a quick review of the video image of the set. Set #9 is more complex with the TNC samplers, observer and vessel declarations independently classifying the set as an unassociated set on a 100% skipjack school that was found actively feeding (detected visually on the surface, aka "boiling" on baitfish) typical of unassociated schools seen during the trip. Positions of relevant HO logged events indicated a distance between checking FAD and Set Start of greater than 2 nm supporting a designation as a free school. However, close examination of the timestamped GPS positions for when a FAD was checked and the start of set (net skiff released) indicated that these events were logged within one nautical mile of each other. This appears to be a situation where human observation and EM technology can work together to supply information useful for compliance verification.

It is difficult at sea to judge whether a floating object is within or beyond one mile. It can also be difficult for an EM reviewer to judge what is or is not a FAD given the resolution and camera angle. The strength of the EM system is that it logs a precise time and position continuously on all captured images that can be used to verify exact position in relation to previously logged events.

Both the observer and EM review were able to determine set type with a high degree of accuracy during the trip. EM analysis uses visual imagery to judge school type, such as set time, speedboat and skiff activity, FAD removal from net, towboat activity and other visual cues. All of these are available to the observer in addition to many more available onboard the vessel. Observer monitoring and judgement in combination with precise position stamped video documentation should contribute to highly accurate set type determinations.

In combination with set type determination, the well destination needs to be determined, both to verify separation of FAD and free school fish and to track catch on vessels that sort catch at sea. The EM camera setup on the well deck was able to determine well filling destination that was in agreement with other data sources.

5.2. Estimates of total catch per set and trip

All onboard data sources arrived at set level total catch estimates that were similar in scope, ranging from 1255 – 1292 mt for total catch. The TNC sampling and vessel estimates were based on similar methods (visual and well filling rates) as well as many additional information sources leading up to the brailing process. It is noteworthy that the TNC samplers and the vessel Master (who makes the set level catch estimates entered on the logsheet) all spent the entire fish loading period on the well deck where well filling rates can be closely monitored. These estimates are refined and adjusted throughout the fish loading process and every crewman has his own estimate that he is willing to share. The observer developed his catch by set estimate on the upper working deck using a calculation based on summing the number of brails against estimated brail fullness. Due to communications onboard and interest in the level of catch, it is no surprising that catch estimates were limited to a similar range of values.

The estimate of set and trip level catch by weight made by the EM analysis was significantly lower than all other data sources at 855 mt for the trip. These estimates used the same system of brail numbers and estimating brail fullness against a maximum brail capacity of 8 mt. EM should be able to count the number of brails precisely and without error, suggesting there was a systematic underestimate of brail fullness or weight for conversion to individual brail weights. A closer comparison of well filling rates to known rated well volumes may have improved overall estimates. Theoretically, EM should be able to obtain highly accurate catch volume data but familiarization and calibration with vessel-specific information is required. The EM estimates made by reviewing video images in isolation from onboard information greatly reduced accuracy.

In the end, all total catch estimates made on the vessel and by video review of EM footage were lower than the total cannery weights taken at unloading which are assumed to be the closest to reality (1319 mt). As noted earlier, the species and size of catch can weigh out differently due to the fact that skipjack pack tightly while larger yellowfin develop spaces between fish due to their large second dorsal, anal and caudal fins. However, the total amount (by weight) of tuna that are in a brine well depends on how tightly the fish are loaded in the well which is difficult to judge visually until the unloading process begins.

All onboard data sources made estimates that were close to each other using different methods, and were close to the visual estimate made by the vessel master. EM review significantly under estimated the total catch which resulted from a sum of underestimates of each set. EM has great potential for accurate catch estimates but apparently needed real time calibration and closer adjustment to known well volumes. In the end, the cannery weights were higher than all other estimates, highlighting the importance of species composition and fish size to final well volume and weight. This information requires experience to judge visually but could be obtained from EM if accurate size and species data were obtained. A new approach for estimating catch volume from EM data may need to be tested and developed.

5.3. Species composition estimates

TNC spill sampling collected and used data from the largest sample size examined and developed a species composition estimate based on these data which was used to generate total set level catch estimates. Considering the relatively high sample sizes, these estimates are considered to have high confidence levels. Observer visual estimates of species composition were very similar in set and trip level species composition (**Tables 4, 5**), despite being developed in a different manner.

Not surprising, the observer's corrected (from spill sampling) grab samples arrived at species composition estimates similar to those from TNC spill sampling (**Table 6**). The most anomalous and contradictory data point for species composition is the EM derived estimate that yellowfin made up 17% (mean) of the trip level catch compared to 5% for TNC spill sampling and 2% for the observer grab sample based estimate. Cannery unloading data lists 4.8% yellowfin by weight, very close to the estimate from TNC spill sample data.

The main driver for the high yellowfin proportion in the EM based estimates is the high proportion of yellowfin sampled by EM, with yellowfin accounting for 13% of samples in EM data compared to 4% from the TNC spill sampling. Sampled yellowfin were also larger on average than sampled skipjack and bigeye, further increasing the estimated catch proportion (by weight) of yellowfin.

The reason for the high sampling rate of yellowfin by EM is difficult to determine without knowing exactly how the EM reviewer selected fish for sampling. Misidentification of bigeye as yellowfin seems unlikely as a contributor to the high yellowfin count with the proportion of bigeye samples in the EM data low and reasonably consistent with spill sampling. Misidentification of skipjack as yellowfin seems highly unlikely due to morphological and marking differences. There is a range of factors that may contribute to selection bias from conveyor belt footage that need to be compared and examined. The large volumes of catch that are loaded with each set, deep layering of fish on the conveyor, possible between-brail species composition differences and potential for different sizes of fish to have different exposure to the cameras remain as challenges to EM data collection.

5.4. Fork length measurements

Cameras 6, 7 and 8 mounted above the fish loading conveyor on the well deck were calibrated to measure fish only when they were presented in a single layer on the conveyor belt or when a single layer of fish was being spilled into one of the sample bins. Layering of fish thins out over the length of the conveyor when filling the forward wells but remains several layers deep when filling the stern wells. EM review should be designed to adapt in a more dynamic way to accommodate measuring fish from different heights during the loading process.

Some unrealistically large skipjack measurements appear in the EM data review record (**Figure 16C**). The raw numbers are low but are expanded at the trip level for estimated numbers of fish caught (**Figure 17C**). Plausible size ranges by species could be input to the measuring system to alert data reviewers to check outliers during data entry.

5.5. Bycatch estimation

In general, the observer recorded the most detailed bycatch data in terms of the total number of species identified, information on fate and release condition and apparent accuracy with identification to the species level. The vessel logsheet declarations faithfully recorded interactions with sharks and blue marlin at a comparable rate as the observer but under reported wahoo and rainbow runner and did not report any dolphinfish or small finfish species.

The EM review had some issues with bycatch ID, possibly related to unfamiliarity with some WCPO bycatch species while listing another species only encountered in the Atlantic fishery where their office is based. These issues highlight the importance of training EM analysts in the identification of bycatch species relevant to the area examined and also the need for species-specific identification of all ETP species likely to be encountered.

The strength of having EM available is the documentation of interactions, handling practices, condition and release of bycatch and ETP species. In this way, observer and EM monitoring can be seen as complimentary tools for the collection of bycatch data.

6. Recommendations and summary statements

The large size and well loading system onboard the Cape Elizabeth III was ideally suited for the sampling and verification work conducted by TNC personnel. The split, reversible conveyor loading system allowed fast and efficient spill sampling of catch on the well deck without disturbing the brailing process or influencing in any way the observer grab sample protocol. Future work of this nature would benefit by using a similarly equipped vessel.

Results and observations made during the cruise highlight the relative strengths and weaknesses of EM and human observers in collecting different data elements. It is clear that the 5-fish per brail grab sample is not large enough to characterize species composition and size characteristics of catch on the set and trip level, and the five-fish sample is often not achieved due to the high speed of brailing. Developing ways for EM to increase sample sizes and obtain unbiased species composition estimates are needed.

One of the great strengths and value of onboard EM is the ability to view trip level data to document, cross check and verify events of interest captured by the camera array that is available for repeated playback and analysis by multiple observers, debriefers, and subject matter experts. The value is maximized when each image is permanently watermarked with a fine scale GPS location and timestamp as was the case with the Satlink system used for the study.

Currently, the data reviewer keeps a long list of event declarations listing events such as: FAD checked, radio buoy changed, investigate school, encounter vessel, etc. These events are timestamped but the individual camera viewed is not listed. A subsequent review of that event would require searching all eight cameras to verify and check the log entry.

In order to make best use of EM data and systems, the following recommendations are noted:

- Carefully review camera angles and magnification to avoid blind spots and to assure events of interest are at sufficient resolution, such as bycatch handling and release, discards, FAD related activities;
- Make notation linked to trip data when a camera goes offline or is not recording (date/time range);
- Institute rigid lens cleaning schedule with crew;
- During video review, specify the number of the camera viewed when an EM declaration is made.

The use of EM to monitor purse seine catch, effort and 24/7 vessel activity is clearly in early stages with a great deal of work needed to improve data interpretation and quality. These areas of testing, improvement and recommendations are suggested:

- Measuring of layered catch on the conveyor is an issue. Mark inside of conveyor or loading chute sides at different heights with marks or painted lines of known length to provide in situ calibration marks;
- The actual fork length and species ID obtained from EM is still in question. Conduct size and species identification tests of EM review against fish of known size and species;
- Some unusually large skipjack appear in the EM reviewed fork length raw data. Plausible size ranges could be put in the measuring system to alert reviewers to double check outliers during data review.
- EM data from this trip sampled a high proportion of yellowfin compared to other data sources, inflating estimates of yellowfin composition in the catch. Investigate potential causes of bias in sampling protocols;
- Bycatch species identifications could be improved. Train EM reviewers in the species diversity, dominant species, species of special concern and identification criteria for the region in which the data was collected;
- Limited grab sample length frequency sampling at the set level can produce a biased picture of school characteristics. Identify and develop ways for EM to increase the sample size of length frequency sampling;
- Relatively few purse seiners are equipped with a conveyor belt loading system adapted to video monitoring. Investigate approaches for EM systems to be scaled up a larger portion of the fishery.
- EM data review can be tedious, time consuming and has a cost, both financial and manpower related. Efforts to develop artificial intelligence/machine learning methods to speed video review and automate tasks will be a key driver to making EM more cost effective and less onerous for EM analysists to review.
- Given the significant underestimation of total catch by EM, the current "brail fullness" method to generate set-level catch estimates need to be improved or a new method developed.

In summary, human observers, port samplers and EM all have a role in monitoring purse seine vessel activity and can be meshed cooperatively to achieve high data quality standards. Onboard human observation will remain important/essential when documenting and interpreting many onboard activities, e.g. pre-dawn set related activity, FAD actions (which can be complex), sorting and discard activity, bycatch handling and determining bycatch condition and fate on release.

Enumeration of catch by port sampling is routinely used to characterize purse seine catch in the eastern Atlantic Ocean and EPO fisheries managed by the Inter American Tropical Tuna Commission (IATTC). The WCPFC monitors catch at sea due in part to the fact that many fleets in the WCPO re-sort catch into size and species-specific lots and cull bycatch and discards while at sea thus mixing all set level catch and effort data. However, not all fleets operate in this manner. For example, the US flag vessels operating from Pago Pago, American Samoa load catch to one well where it remains sealed until unloading in Pago Pago. Port sampling could be used to provide accurate trip, and in some cases, set level information. However, onboard human and/or EM efforts remain necessary to document bycatch handling and at-sea discards.

A primary benefit of EM is the 24/7 time/GPS stamped images that provide fine-scale data for monitoring and compliance and operate at times when the observer is otherwise occupied or is occupied with necessary rest periods. Set type verification, estimates of catch by set, and species composition are areas where observers and EM can work collaboratively to arrive at a more accurate result.

During a fishing operation, current protocols have the observer stationed on the starboard side of the working deck during the entire brailing process where he/she takes and measures grab samples and monitors bycatch. This is the kind of repetitive work at a fixed location that EM is best suited to conduct. Ideally, EM could be applied to brail counting, assessment of brail fullness, species identifications and increasing the number of catch measurements. This would free the observer to move around the vessel during the brailing stage to conduct other duties and improve coverage of bycatch handling, enumeration, condition assessment and release.

Results from the cruise indicate that improvements in estimates of catch weight from brails is needed to achieve required levels of accuracy. Species composition estimates from EM were also contrary to other data sources suggesting that the manner in which EM samples are taken from the conveyor needs to be examined closely. One aspect of purse seine monitoring is that the level of sampling currently achievable from grab sampling is not high enough to address trip or set level data needs. Such estimates may be important both for research (e.g. understanding the effect of operational factors such as FAD design on species composition) and management purposes (e.g. if there were measures related to vessel-specific bigeye or yellowfin catches). For these reasons, it would be desirable to increase the sampling rate from the levels currently possible using grab sampling to reduce the variance on species composition estimates. EM holds promise as a platform to increase sampling levels and contribute to observer data collection efforts.

The vessel used in this study was large and equipped with a conveyor belt fish loading system making it well suited for EM on the well deck. However, the stern wells are filled directly from the loading hatch. Loading of these wells takes place so rapidly that EM imaging to obtain species and size frequency measurements are not practical. Capturing this data on the work deck before catch is released to the well deck is a possibility that will be discussed in the next section. However, additional work to validate the accuracy of EM reviewed species identification and size data will be still be needed.

Findings from this study support previous investigations that EMS monitoring of purse seine effort is not regarded as a replacement of human observers, but as a complimentary tool that can enhance HO programs or in in the future may replace specific observer tasks allowing observers to concentrate on other duties (Ruiz et al. 2017; Briand et al. 2018). Finding ways to reduce the time and costs linked to EM data review, such as the incorporation of artificial intelligence and machine learning will be essential to the improvement and adoption of EM technology. HO and EMS should be regarded as complimentary to each other, where combined monitoring impact produces high quality fishery data and monitoring information. However, further verification and calibration work is needed before EM data can enter existing data systems. Finding the balance when applying HO and EM elements to take advantage of the benefits of each will be the goal.

7. Next Steps

Currently, the observer must request the winch operator to lower the full brailer on deck and lower it to allow him to take a random grab sample. This protocol was more efficient when vessels sorted catch in loading hoppers, but these have largely been eliminated in favor of depositing brail loads directly into the loading hatch. Fishermen are reluctant to slow the process due to the warm surface waters that can cause spoilage and histamine loads if brailing takes too long.

A sampling system that would increase the number of samples per brail without slowing the loading process is required. Results and observations from the Cape Elizabeth trials suggest that a different camera angle looking down on the open brail could be used to visually "sample" each brail for species composition and size frequency at a higher rate and free the observer for more detailed observations of non-target catch and other duties. Every purse seine vessel brails catch in this manner so the concept is scalable to the entire fishery. (See **Figure 22**)

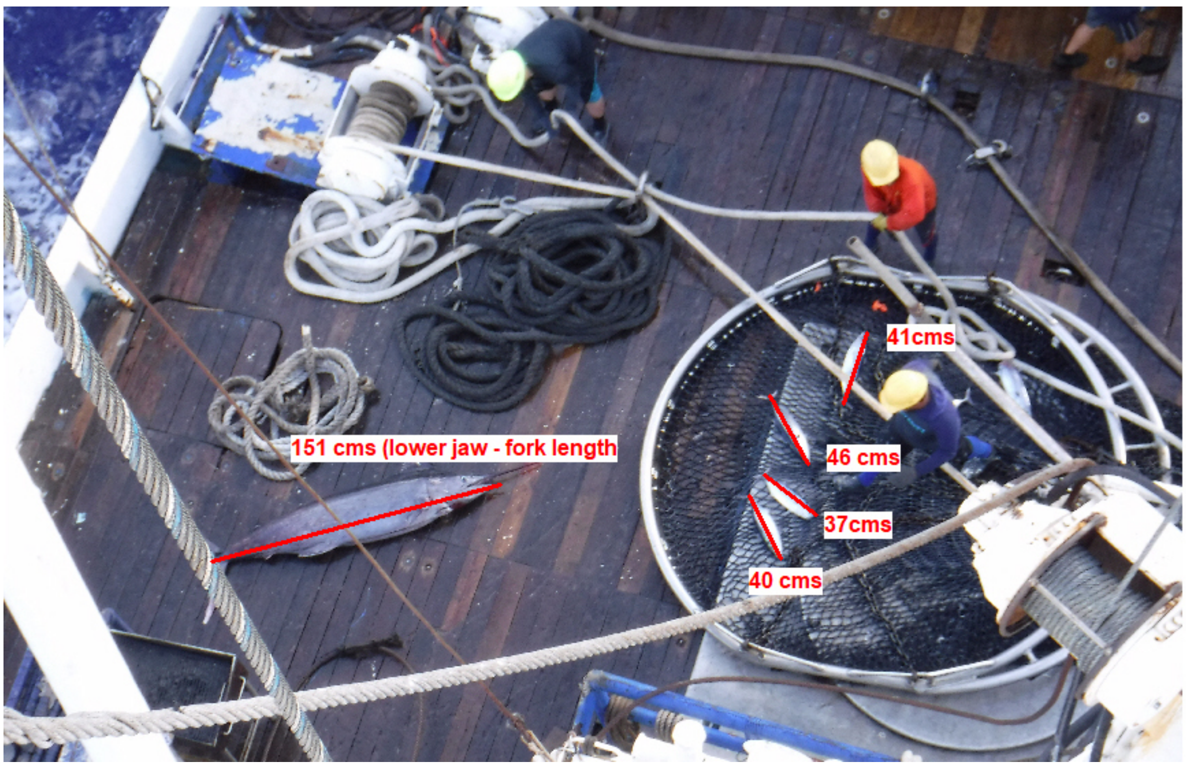

Figure 22. EM above brail view.

The Commission science provider continues to engage in Project 60 activities and has expressed interest in this "above brail" sampling concept and also verifying EM data at selected ports where the size and species of target and non-target catch is carefully enumerated as a requirement for MSC certification. In taking this work forward, the following activities are proposed:

- Continued liaison, scientific support and potential funding from SPC through Project 60 support;
- Testing length frequency and species composition accuracy of the "above brail" camera concept through paired spill and grab sampling comparisons;
- Comparisons of EM (including above brail camera) and HO data, logbook and cannery records with detailed port sampling/unloading data*.

*There are unloading ports in the WCPO where purse seine catch is identified to species and size category at a high resolution to comply with MSC requirements or for other purposes. This opens the possibility of making direct comparisons between onboard EM, HO and other data sources to accurate port sampling/cannery data at the well and set (if well filled by one set) level.

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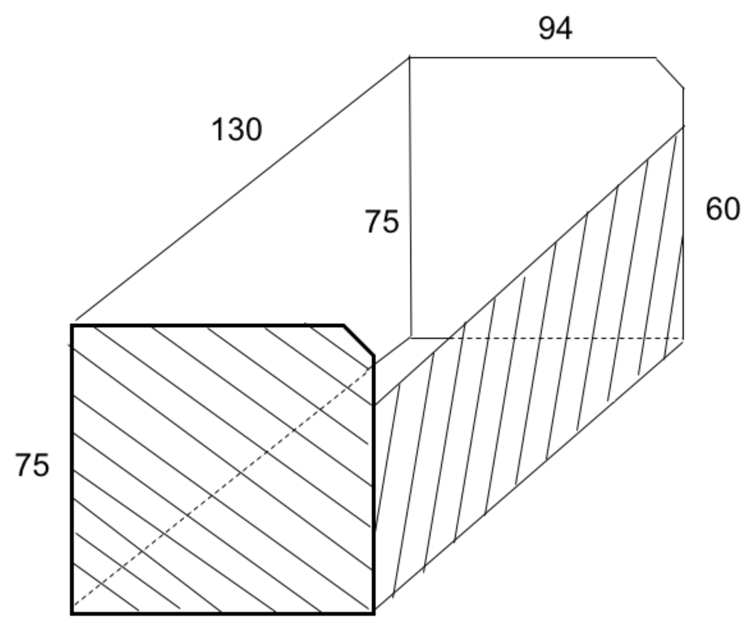
Appendix I. Cape Elizabeth III description

Flag	United States of America
Built in Country	United States of America
Built in Year	1990
Length	68.8 m
Tonnage	1930 GRT
Number of fish wells	20
Rated Freezing Capacity	1261
Home Port	Pago Pago, American Samoa

Appendix II. Aluminum spill sample bin constructed for the cruise (measurements in cm)



Appendix III. Estimations of tuna catch by set

	TNC					Observer					Vessel					EM				
Set #	SKJ	YFT	BET	Total mt	# Brails	SKJ	YFT	BET	Total mt	# Brails	SKJ	YFT	BET	Total mt	# Brails	SKJ	YFT	BET	Total mt	# Brails
1	6.0	3.0	4.0	**13**	NA	6.0	2.5	4.0	**13**	7	10.0	5.0	0.0	**15**	NA	6.5	5.0	7.5	**19**	7
2	2.0	0.0	0.0	**2**	NA	2.0	0.0	0.0	**2**	1	0.0	0.0	0.0	**0**	NA	0.8	0.0	0.0	**1**	1
3	20.4	9.5	0.1	**30**	11	20.0	4.0	1.0	**25**	11	25.0	5.0	0.0	**30**	NA	13.5	2.5	1.0	**17**	11
4	112.2	2.7	5.1	**120**	24	118.0	1.0	1.0	**120**	24	122.0	0.0	0.0	**122**	NA	99.7	2.8	0.6	**103**	27
5	13.0	1.6	1.4	**16**	7	14.0	1.0	1.0	**16**	7	15.0	0.0	0.0	**15**	NA	9.1	1.1	0.4	**11**	8
6	52.4	0.7	1.9	**55**	14	47.0	0.5	0.5	**48**	14	45.0	0.0	0.0	**45**	NA	30.4	1.4	0.3	**32**	14
7	59.6	6.0	4.5	**70**	16	65.0	1.5	1.5	**68**	16	65.0	0.0	0.0	**65**	NA	45.9	6.6	0.6	**53**	15
8	145.0	0.0	0.0	**145**	24	140.0	0.0	0.0	**140**	24	150.0	0.0	0.0	**150**	NA	81.4	0.0	0.0	**81**	30
9	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
10	2.5	0.4	0.0	**3**	3	1.5	1.0	0.5	**3**	3	5.0	0.0	0.0	**5**	NA	1.6	0.4	0.0	**2**	4
11	2.0	0.0	0.0	**2**	1	3.0	0.0	0.0	**3**	1	0.0	0.0	0.0	**0**	NA	0.2	0.0	0.0	**0**	1
12	30.0	0.0	0.0	**30**	8	30.0	0.0	0.0	**30**	8	35.0	0.0	0.0	**35**	NA	18.3	0.0	0.0	**18**	9
13	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
14	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
15	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
16	49.7	0.9	4.4	**55**	14	52.0	1.0	1.0	**54**	14	55.0	0.0	0.0	**55**	NA	34.9	1.2	0.3	**36**	16
17	4.2	1.9	1.9	**8**	4	7.0	1.5	0.5	**9**	4	5.0	0.0	0.0	**5**	NA	1.4	0.8	0.6	**3**	4
18	59.0	4.9	2.1	**66**	16	63.0	1.0	0.5	**65**	16	65.0	0.0	0.0	**65**	NA	34.9	3.8	0.5	**39**	17
19	19.1	9.4	1.5	**30**	11	25.0	3.0	1.0	**29**	11	25.0	5.0	0.0	**30**	NA	13.7	5.9	0.0	**20**	11
20	46.1	3.1	0.8	**50**	10	44.0	2.5	1.5	**48**	10	50.0	0.0	0.0	**50**	NA	30.1	3.8	0.0	**34**	11
21	29.8	7.2	3.0	**40**	11	35.5	4.0	2.0	**42**	11	35.0	5.0	0.0	**40**	NA	24.9	4.8	0.1	**30**	11
22	32.1	2.0	5.9	**40**	11	32.5	4.0	2.0	**39**	11	40.0	0.0	0.0	**40**	NA	23.0	4.1	0.0	**27**	12
23	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	0	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
24	95.2	1.2	0.6	**97**	20	91.5	0.5	1.0	**93**	24	102.0	0.0	0.0	**102**	NA	60.5	6.7	0.0	**67**	23
25	99.4	0.4	0.2	**100**	23	95.5	2.0	1.0	**99**	23	100.0	0.0	0.0	**100**	NA	64.4	2.7	0.7	**68**	23
26	79.0	1.5	0.5	**81**	18	70.5	1.0	0.5	**72**	16	75.0	0.0	0.0	**75**	NA	46.7	0.0	0.0	**47**	16
27	12.0	0.0	0.0	**12**	6	12.0	0.0	0.0	**12**	6	0.0	5.0	0.0	**5**	NA	5.1	0.0	0.0	**5**	6
28	5.0	1.0	0.0	**6**	2	1.0	2.0	1.0	**4**	4	5.0	0.0	0.0	**5**	NA	0.6	1.5	0.0	**2**	4
29	13.8	0.9	0.2	**15**	6	14.5	1.5	1.0	**17**	7	10.0	5.0	0.0	**15**	NA	6.3	1.1	0.0	**7**	8
30	9.8	14.2	1.0	**25**	11	25.5	3.0	1.5	**30**	11	25.0	0.0	0.0	**25**	NA	14.6	0.6	0.2	**15**	9
31	0.1	0.1	0.0	**0**	0	0.5	0.5	0.0	**1**	1	0.0	0.0	0.0	**0**	NA	0.1	0.1	0.0	**0**	1
32	38.9	5.3	0.9	**45**	14	43.0	3.0	1.0	**47**	14	45.0	5.0	0.0	**50**	NA	24.8	4.4	0.0	**29**	14
33	59.2	0.5	0.3	**60**	14	55.0	3.5	1.0	**60**	14	60.0	0.0	0.0	**60**	NA	37.3	0.8	0.0	**38**	13
34	30.0	0.0	0.0	**30**	NA	27.0	0.0	0.0	**27**	9	25.0	0.0	0.0	**25**	NA	20.1	0.0	0.0	**20**	9
35	9.0	2.0	1.0	**12**	NA	8.0	0.5	0.5	**9**	5	10.0	0.0	0.0	**10**	NA	3.5	0.0	0.0	**4**	6
36	1.5	0.0	0.0	**2**	NA	1.0	0.0	0.0	**1**	1	0.0	0.0	0.0	**0**	NA	0.0	0.0	0.0	**0**	0
37	27.0	4.5	0.5	**32**	NA	20.0	7.0	1.5	**29**	8	34.0	0.0	0.0	**34**	NA	23.2	2.4	0.0	**26**	8
Sub totals	1164.9	84.9	41.9	**1292**	-	1170.5	53.0	28.0	**1255**	**336**	1238.0	35.0	0.0	**1273**	**NA**	777.5	64.5	12.8	**855**	**349**
%	**90.2**	**6.6**	**3.2**			**93.3**	**4.2**	**2.2**			**97.3**	**2.7**	**0.0**			**91.0**	**7.5**	**1.5**		