Precision of Data from Alternative Fisheries Monitoring Sources Comparison of Fisheries-dependent Data Derived from Electronic Monitoring, Logbook and Port Sampling Programs from P...

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Precision of Data from Alternative Fisheries Monitoring Sources

Comparison of Fisheries-dependent Data Derived from Electronic Monitoring, Logbook and Port Sampling Programs from Pelagic Longline Vessels Fishing in the Palau EEZ

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KEY FINDINGS

- Catch rates from electronic monitoring (EM) data were about an order of magnitude higher than from logbook data. The species richness from logbook data was about half of that from EM data. Logbook data are very likely inaccurate due to substantial underreporting.
- There were no significant differences in catch composition, nominal mean catch rates, and mean discard rates from logbook data with versus without EM systems. The presence of EM appears to not change logbook data recording.
- Port sampling data from trips with EM coverage lacked information on the total retained catch of non-tuna and non-billfish species, while the EM data recorded 22 species other than tunas and billfishes were retained in the three trips. Port sampling data from trips with EM coverage provided information on retained catch rates for only bigeye and yellowfin tunas and billfishes, representing a very small proportion of the number of retained species.
- The mean retained tuna catch rate from EM data was 41% higher than that from port sampling data. Port sampling data indicated that 46 bigeye and 144 yellowfin tunas were retained, while EM data indicated that 45 bigeye, 172 yellowfin and 11 other tuna species were retained. Based on limited available data, port sampling produces imprecise estimates of retained species catch rates relative to estimates from EM coverage.

1. INTRODUCTION

Fishery-dependent data from observer, logbook and port sampling programs enable meeting fundamental monitoring requirements. Data collected from these programs support applications ranging from conducting robust stock assessments to monitoring ecosystem pressure and state indicators to assess the performance of ecosystem-based harvest strategies (e.g., FAO, 2002; Gilman et al., 2017).

Attributes and potential biases of alternative fisheries monitoring methods, including the three that were assessed in the study, are summarized in Appendix 1. Having data collected and reported by independent onboard observers to meet scientific and compliance objectives is understood to produce more accurate and detailed information than would be collected and reported in logbooks by fishers: crew may lack the time and training to conduct prescribed data collection methods, and may have an economic disincentive to record accurate data, e.g., to avoid catch or size limits (FAO, 2002; Walsh et al., 2002). Port sampling programs obtain information on retained catch during unloading in port, but not information on discarded (non-retained live released and dead discarded) catch or on effort within trips.

Electronic monitoring (EM) systems are increasingly used, in many cases to augment conventional coverage by human onboard observers, as well as to provide at-sea coverage where none previously existed. EM systems typically use onboard cameras, global positioning systems, sensors and data loggers to collect a variety of information (Restrepo, 2012). EM systems also include programs for analyzing EM data by an independent authority. EM can complement traditional human onboard observer programs, or in fisheries where vessels are unsuitable (too small, unsafe, remote or unpredictable location for placing and retrieving observers, high incidence of coercion/corruption of human observers) to place a human observer, may offer an alternative method for scientific and/or compliance monitoring. This is because vessel specification requirements for EM systems are much lower than what is needed to deploy a human observer. Several trials of EM systems have occurred in longline tuna fisheries (e.g., McElderry, 2010; AFMA, 2011; Hosken et al., 2014). The eastern Australia longline fishery requires EM systems on 100% of vessels (AFMA, 2012). And numerous non-tuna fisheries have taken up EM systems (e.g., Lowman et al., 2013).

Optimal EM equipment specs, and the way the equipment is installed need to account for vessel-specific fishing operations, and the types of data that are planned to be collected (e.g., Restrepo, 2012). Systems for evaluating EM data likewise must be tailored to fishery-specific monitoring objectives, where, applicable to both electronic and human fisheries observers, fishery-specific objectives of analyses (i.e., required levels of accuracy and precision of catch rate estimates), the frequency of occurrence of catch and bycatch for each species of interest, amount of fishing effort, and distribution of catch and bycatch determine the requisite onboard observer and EM coverage rate (Hall 1999; Gilman et al., 2017).

There is a growing body of literature from studies comparing the quality of data collected by electronic monitoring systems vs. traditional onboard observers on longline and purse seine tuna fisheries, with findings in most cases indicating that EM data have relatively high precision (i.e., are similar to data collected by onboard observers), but with some areas identified where EM systems are in need of improvement, such as detection of some species of non-retained catch (McElderry et al., 2008; McElderry, 2010; AFMA, 2011; Chavence et al., 2013; Hosken et al., 2014; Monteagudo et al., 2015; Briand et al., 2017). There is also evidence from an Australian pelagic longline fishery that EM systems have improved logbook data, where the program conducts random audits of logbook data and fines fishers when misreported logbook data are identified (Larcombe et al., 2016). However, other than the Australia fishery, there is a gap in understanding of how the introduction of EM systems affects logbook data quality in other fisheries, where random audits against EM or human onboard observer program data and a penalty scheme for misreporting do not occur.

Here we analyze EM and logbook data from the Palau locally-based and distant water pelagic longline tuna fisheries to assess whether logbook data from trips with vs. without EM systems are significantly different. We also analyze EM, logbook and port sampling data from Palau longline fisheries in order to: (a) determine whether findings from previous studies documenting substantial differences between logbook and observer data is also apparent in the Palau longline fisheries, and (b) determine whether there are significantly different mean retained catch rates per set between EM and port sampling data from the Palau longline fisheries.

2. QUESTIONS BEING TESTED AND METHODS

2.1. Retained and Discarded Catch Rates from Trips with and without EM Systems from Logbook Data

Hypotheses: Retained and discarded catch rates estimated from logbook data from trips without EM systems onboard are both significantly lower than rates estimated from trips with EM systems onboard. Here discarded catch refers to all non-retained catch, including live released and dead discarded organisms.

Implications and caveats: The presence of EM systems may cause fishers to produce more accurate logbook data. Fishers may underreport both retained and discarded catch when not being monitored for reasons explained in Appendix 1. The study component includes an assessment of target catch; endangered, threatened and protected (ETP, sea turtle, shark, ray, marine mammal, seabird) catch; and incidental market species.

The study enabled only an inference of causation. Even if findings support the hypothesis, the presence/absence of EM may not have been a significant factor, and if this variable were a significant explanatory effect, there are other potentially significant explanatory variables. For example, differences in the temporal and spatial distribution of fishing effort may significantly explain observed differences in catch rate estimates from the logbook data between the sample of trips without vs. trips with EM systems.

We have not included hypotheses or study methods to assess the effect of EM systems on fishing methods (temporal and spatial distribution of effort and amount of effort). This is because we assume that observer effects, such as on the amount of fishing effort, duration of trips, and location of fishing effort, documented to occur when a human observer is randomly assigned to a vessel for a small proportion of trips made by a vessel, will not occur on vessels with EM systems that are installed on vessels for a long time period (e.g., >1 year).

Methods: For trips that have occurred since EM systems were installed, for sets by pelagic longline vessels that occurred in the Palau EEZ, we used logbook data to compare retained and discarded catch rates from trips with vs. without EM systems. Only trips without human observers onboard were included in the study sample in order to avoid introducing a confounding effect of the presence of the human observer on the logbook data. Catch rates were calculated by individual species where possible. Otherwise, for records that were not recorded to the species level, catch rates were lumped by relevant higher taxonomic group (e.g., combined species of marine mammals). We also calculate rates of (i) the number of records of ETP species captures per trip for trips with vs. without EM systems onboard, (ii) the number of records of non-tuna species retained per trip for trips with vs. without EM systems onboard, and (iii) the number of records of discarded animals per trip for trips with vs. without EM systems onboard. Catch rates were reported in units of number of catch per 1,000 hooks.

We determined the magnitude of differences and conducted two-sample t-tests to determine the statistical significance of mean retained and discarded catch rates per set in trips with vs. without EM systems.

2.2. Catch Rates from EM, Logbook and Port Sampling Data from the Same Trips with EM Coverage

Hypothesis: Catch rates estimated from electronic monitoring (EM) data are significantly different from rates estimated from logbook and port sampling data collected from the same trips.

Implications and caveats: If findings support the hypothesis, then this lack of precision in estimates would indicate that one or more of the methods is not accurate (i.e., is not close to a true value). Further investigation would be needed to determine the cause for the discrepancy, though we hypothesize that EM data are more accurate than the other data sources. If there are differences we will examine where they occur (species-specific catch rates, and when and where different species are caught). Further investigation would be required to establish which method is most accurate. For example, mean retained catch rates per set may be more accurate from EM data because, in the Palau locally-based fishery, vessels routinely transship catch between vessels at sea, introducing the potential for errors in assigning catch to the correct vessels, while EM data is not subject to this source of error.

Methods: We calculated catch rates from logbook and EM data, and retained catch rates from port sampling and EM data, for trips with EM coverage, for sets by pelagic longline vessels that occurred in the Palau EEZ. Only trips without human observers onboard were included in the study sample in order to avoid introducing a confounding effect of the presence of the human observer on catch rates from the three different monitoring programs. Catch rates were calculated by individual species where possible, and otherwise where records were not recorded to the species level, were lumped by relevant higher taxonomic group (e.g., combined species of marine mammals). Catch rates and retained catch rates were presented in units of number of catch per number of hooks. We determined the magnitude of differences and conducted two-sample t-tests to determine the statistical significance of differences of: (i) Mean catch rates per set estimated from EM and logbook data; (ii) Mean retained catch rates per set estimated from EM, logbook and port sampling data, and (iii) Mean discarded catch rates per set estimated from EM and logbook data.

For the EM records, we assumed that office observed analyzed each entire fishing operation, this despite the EM observer records having values in fields for the number of baskets (gear between two floats) and hooks observed for each set being not equal to the total number of baskets and hooks deployed per set. In 24 of the 70 records, the value for the number of baskets observed was > the total baskets deployed.

It was not possible in many cases to match records of a unique set between the three databases, thus preventing a direct comparison of catch rates for a unique set by the different monitoring methods.

3. RESULTS AND DISCUSSION

3.1. Catch Rates from Trips with and without EM Systems from Logbook Data

Table 1 summarizes catch rates from logbook data by groupings of tunas, other teleosts and elasmobranchs, by sets with vs. without EM, and also reports the number caught and percent retained by individual species and higher taxonomic group.

Table 1. Catch rates, sample sizes and percent retained for sets with vs. without EM systems, logbook data of locally-based and distant-water pelagic longline vessels making sets in the Palau EEZ, 2016.

	Sets with electronic monitoring				Sets without electronic monitoring			
Common Name	**Mean catch rate (no.*10^{-3} hooks)**	**95% CI**	**% retained**	**N (total caught)**	**Mean catch rate (no.*10^{-3} hooks)**	**95% CI**	**% retained**	**N (total caught)**
Tunas	1.23	0.09	100	127	1.17	0.01	99.8	11,274
Albacore			100	5			100.0	84
Bigeye			100	58			100.0	5,178
Pacific bluefin			na	0			100.0	15
Skipjack			100	4			81.9	127
Yellowfin			100	60			100.0	5,870
Other Teleosts	0.32	0.12	90.9	33	0.38	0.01	98.1	3,638
Barracudas			na	0			100.0	33
Black marlin			100	1			100.0	96
Blue marlin			100	11			100.0	1,207
Indo-Pacific sailfish			100	4			99.3	425
Mahi mahi			100	2			92.1	331
Oilfish			na	0			100.0	96
Opah			100	3			83.9	31
Other not specified			na	0			100.0	24
Pomfrets & ocean breams			0	3			98.1	378
Striped marlin			na	0			100.0	15
Sunfish			100	2			na	0
Swordfish			100	7			99.9	941
Wahoo			na	0			55.7	61
Elasmobranchs	0.07	0.07	0	7	0.11	0.01	1.9	1,157
Blue shark			0	4			2.2	496
Hammerhead shark spp.			na	0			25.0	4
Mackerel sharks, porbeagles not elsewhere included			na	0			50.0	2
Mako shark spp.			na	0			1.3	151
Oceanic whitetip shark			na	0			10.0	10
Silky shark			na	0			1.1	90
Thresher shark spp.			0	3			1.2	404
Total retained	1.52	0.16	100	157	1.51	0.02	100	14,578
Total discarded	0.10	0.10	0	10	0.15	0.01	0	1,591

Logbook Data from Trips with EM Systems: Logbook data were available for 106 sets in 10 trips by vessels with EM systems. Of these, 84 sets were made by 3 locally-based vessels, and 22 sets were by 1 Okinawa-based vessel. Of the 106 set records, we excluded 39 sets from the study sample that lacked values on the number of hooks deployed, precluding the calculation of catch rates. The remaining 67 sets that made up the study sample were all conducted within the Palau EEZ, with 6 sets made by the one Okinawa-based vessel, and 61 sets made by 3 locally-based vessels. The sets were conducted between 10 January and 25 December 2016, based on the logbook data.

In each of the 67 sets, the maximum catch recorded by fishers was 1 individual of a single species. Discarded catch was recorded in only 4 of the 67 sets. All reported caught sharks (blue and thresher spp.), pomfrets and ocean breams were recorded as being discarded in these 4 sets. Based on a previous study using observer program data for the locally-based fleet of Palau (Gilman et al., 2016) and the EM data analyzed in this study (Section 3.2), it is likely that the absence of the capture of any elasmobranch species and the lack of any discarded catch in 63 of the 67 sets of logbook records was due to misreporting. These results suggest that misreporting in logbooks is occurring despite the presence of EM systems.

Logbook Data from Trips without EM Systems: Logbook data were available for 9,197 sets in 904 trips by vessels without EM systems. Of these, 8,490 sets were by 42 locally-based vessels, and 707 sets by 18 Okinawa-based vessels. Of these sets, 2,355 lacked values on the number of hook deployed and were removed from the study sample. An additional 268 sets that were conducted outside of the Palau EEZ (high seas areas abutting the Palau EEZ, N=137; Solomon Islands EEZ, N=91; high seas areas not abutting the Palau EEZ, N=14; Federated States of Micronesia EEZ, N=11; Indonesia EEZ, N=7; Cook Islands EEZ, N=6; and Philippines EEZ, N=2) were removed from the study sample. The final study sample contained 6,574 sets that were made in the Palau EEZ. The study sample contained 604 sets made by 18 Okinawa-based vessels, and 5,970 sets by 38 locally-based vessels. The sets were conducted between 2 January 2016 and 12 September 2017.

In all sets of the study sample without EM, the maximum recorded catch was 1 individual capture for each species per set. Fishers recorded retaining 22 sharks in sets conducted in the Palau EEZ, this despite Palau laws, regulations and license conditions prohibiting shark retention (Palau OEK, 2003; Gilman et al., 2016). Discarding was recorded in 678 sets, 10.3% of the study sample, which is similar to the logbook records with EM coverage. Again, the lack in almost 90% of sets of reported capture of stingrays and sea turtles, and lack of records of any discarded catch, is likely due to misreporting (Gilman e al., 2016; Section 3.2).

Magnitude and Statistical Significance of Differences in Mean Catch Rates for Sets with vs. without EM:
There was no significant difference between mean catch rates with vs. without EM for tunas, other teleosts, combined retained catch, combined discarded catch ($P>0.05$, two-sample t-test for equal variances), and elasmobranchs ($P>0.05$, two-sample t-test for unequal variances). The magnitudes in differences in mean catch rates were relatively small for tunas (5% higher for sets with EM than without EM), other teleost (16% higher for sets without EM than sets with EM), and combined retained species (<1% higher for sets with EM than without EM), where the latter finding is due to retained species being mainly tunas and other teleosts. Magnitudes in differences in catch rates were relatively high for elasmobranchs (36% higher for sets without EM than sets with EM) and combined discarded species (33% higher for sets without EM than sets with EM), where the latter finding is due to discarded species being mainly sharks.

3.2. Catch Rates from EM, Logbook and Port Sampling Data for Trips with EM Coverage

Table 2 summarizes catch rates from sets that occurred in the Palau EEZ from EM data and retained catch rates from port sampling data from sets in the Palau EEZ with EM systems. Summary statistics are presented by groupings of tunas, other teleosts and elasmobranchs. Table 2 also reports the number caught and percent retained for EM data, and the number retained for port sampling data, by individual species and higher taxonomic group. For the EM data, the total number of discarded and retained organisms is less than the total catch because some of the catch escaped and for some catch events the office observer was unable to determine if the organism was retained or discarded.

Table 2. Catch rates, sample sizes and percent retained for sets with EM systems from EM data and port sampling data for locally-based and distant-water pelagic longline vessels making sets in the Palau EEZ, 2016. Summary statistics from logbook data from trips with EM coverage are presented in Table 1.

	Electronic monitoring data				Port sampling data		
Common Name	**Mean catch rate (no.*10^{-3} hooks)**	**95% CI**	**% retained**	**N (total caught)**	**Mean retained catch rate (no.*10^{-3} hooks)**	**95% CI**	**N (total retained)**
Tunas	14.3	4.9	95.14	1,461	8.0	14.6	190
Albacore			97.14	35	0	NA	0
Bigeye			95.87	387	2.1	0.7	46
Bluefin (Atlantic)			100.00	1	0	NA	0
Skipjack			80.00	45	0	NA	0
Yellowfin			95.47	993	5.8	14.3	144
Other Teleosts	6.3	1.1	34.34	661	No data	NA	No data
Black marlin			100.00	3	0	NA	0
Blue marlin			100.00	7	0	NA	0
Escolar			85.00	100	No data	NA	No data
Gemfish (southern or silver kingfish)			0.00	3	No data	NA	No data
Great barracuda			100.00	3	No data	NA	No data
Lancetfishes			3.33	90	No data	NA	No data
Longsnouted lancetfish			0.00	6	No data	NA	No data
Mahi mahi			85.71	7	No data	NA	No data
Marlins, sailfishes, spearfishes unidentified			60.00	5	0	NA	0
Moonfish			83.33	6	No data	NA	No data
Ocean sunfish			50.00	2	No data	NA	No data
Oilfish			80.00	25	No data	NA	No data
Opah			100.00	1	No data	NA	No data
Pomfrets and ocean breams			0.00	2	No data	NA	No data
Rainbow runner			100.00	1	No data	NA	No data
Sailfish (Indo-Pacific)			94.12	17	0	NA	0
Sharptail mola			0.00	2	No data	NA	No data
Short-billed spearfish			100.00	1	0	NA	0
Sickle pomfret			62.50	16	No data	NA	No data
Snake mackerel			8.45	71	No data	NA	No data
Striped marlin			100.00	19	0	NA	0
Swordfish			94.12	17	0	NA	0
Unspecified			2.92	240	No data	NA	No data
Wahoo			82.35	17	No data	NA	No data
Elasmobranchs	10.8	2.1	0.09	1,139	No data	NA	No data
Blue shark			0.00	14			
Long finned mako shark			0.00	2			
Mako sharks			0.00	5			
Oceanic whitetip shark			0.00	4			

Pelagic stingray			0.12	826			
Pelagic thresher shark			0.00	1			
Rays, stingrays, mantas NEI			0.00	60			
Requim sharks NEI			0.00	169			
Short finned mako shark			0.00	12			
Silky shark			0.00	30			
Spinetail mobula			0.00	1			
Thresher shark (vulpinas)			0.00	1			
Thresher sharks			0.00	13			
Tiger shark			0.00	1			
Sea Turtles	0.5	0.2	0.00	45	No data	NA	No data
Green			0.00	30			
Hawksbill			0.00	9			
Leatherback			0.00	2			
Unidentified			0.00	4			
Total retained	15.8	4.7	100.00	1618	No data	NA	No data
Total discarded	15.5	2.4	0	1639	NA	NA	No data

Figs. 1-3 present catch rates for retained tunas from EM, logbook and port sampling data, retained catch rates from EM and logbook data, and discarded catch rates from EM and logbook data, respectively.

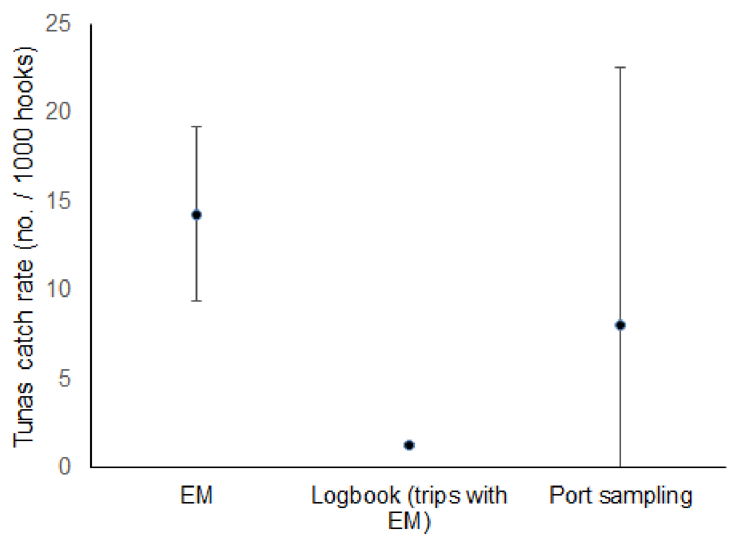

Fig. 1. Mean catch rates and 95% CIs of combined tunas from EM, logbook and port sampling data, Palau EEZ longline fisheries, 2016.

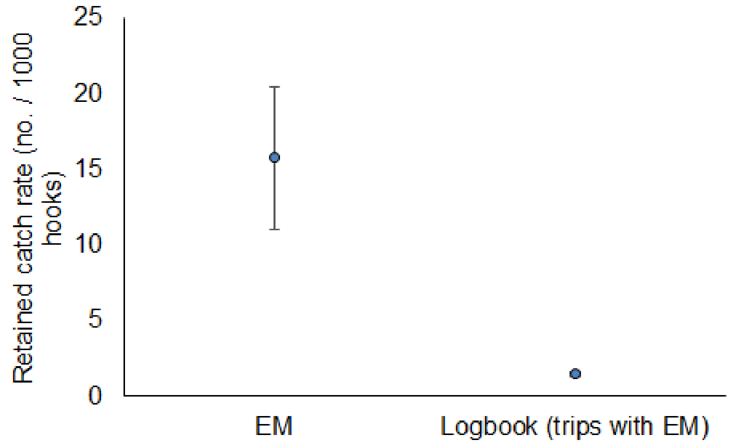

Fig. 2. Mean retained catch rates and 95% CIs from EM and logbook data, Palau EEZ longline fisheries, 2016.

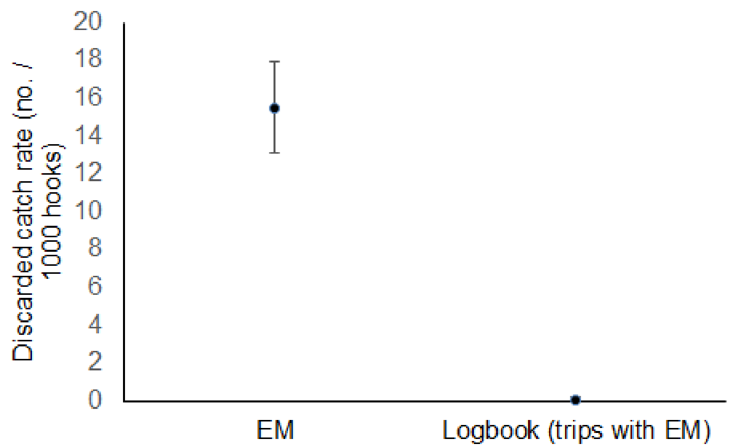

Fig. 3. Mean discarded catch rates and 95% CIs from EM and logbook data, Palau EEZ longline fisheries, 2016.

EM data: EM data were available for 70 sets in 10 trips by four vessels. Of these, 64 sets were made by 3 locally-based vessels, and 6 sets were by 1 Okinawa-based vessel. One set had to be removed from the study sample because it lacked a value for the number of hooks that were deployed. The sample used for the study contained 69 sets made of 6 sets made by the one Okinawa-based vessel, and 63 sets made by 3 locally-based vessels. The locations of the start of sets were within the Palau EEZ. The sets were conducted between 30 September and 26 December 2016. Because it was not possible to match records of a unique trip and set between the EM and logbook databases (see Methods section), it was not possible to determine with certainty that all of the 67 sets included in the study sample from the logbook with EM dataset were included in the 69 sets from the EM dataset.

In 66 of the 69 sets, an office observer recorded >1 capture for one or more individual species; i.e., only in 3 of 69 sets was there a maximum of 1 individual capture of a single species. This suggests that there is substantial underreporting in logbooks, where fishers recorded a maximum of 1 capture of an individual species per set in all sets included in the logbook study sample (Section 3.1).

All caught elasmobranchs except for 1 pelagic stingray were observed to be discarded, consistent with the logbook data from sets with EM, but not with the logbook data without EM where fishers recorded retaining 2% of caught sharks (Section 3.1). Consistent with the logbook data, there was high retention of all billfishes, mahi mahi and opah. Discarding was observed to have occurred in each of the 69 sets, suggesting that there was underreporting of discards in logbooks, where fishers recorded discarding in a small proportion of sets (Section 3.1).

The species richness from the EM data, even with the relatively limited sample size (69 sets) compared to the combined logbook study sample (6,641 sets), was substantially larger than that of the logbook data, with 22 non-tuna teleost species in the EM study sample compared to 12 in the combined (EM and non-EM) logbook study sample, 14 elasmobranch species/groups in the EM study sample versus in the combined logbook study sample, and no sea turtle or ray species in the logbook data sample. This suggests that the fishers likely have poor species identification skills relative to the EM office observers. Given larger EM sampling effort, it is likely that a larger number of rarer species would be observed caught in the Palau longline fisheries.

There may have been misidentification of sea turtle species by the EM office observers based on evidence from analyses of the historical Palau observer program data that found that olive Ridleys make up a very large proportion of the sea turtle catch by the locally-based longline fishery (Gilman et al., 2016). The EM data record of an Atlantic bluefin tuna was likely a data entry error.

Compared to human observer data for the locally-based Palau longline fishery from 1999-2011, the catch rates observed here were 60, 25, 66 and 33% higher for tunas, other teleosts, elasmobranchs and sea turtles, respectively (Gilman et al., 2016). In the current study, the sets with the highest catch rates were made by the distant-water vessel, which may partially explain the extremely large differences in catch rates between the two observer data samples, this in addition to the numerous potentially significant explanatory variables (variability in environmental conditions, gear designs, fishing methods, relative abundance), that can affect catch rates (e.g., Gilman and Hall, 2015). Similarly, the catch and discard rates determined from the EM data was substantially higher for all groups than the logbook data (Section 3.1).

Port sampling data: Port sampling data were available from three trips with EM coverage conducted by two locally-based vessels, which departed port on 30 Sept, 25 Nov. and 23 Dec. 2016. For all three trips, all retained tunas were offloaded and measured, and for one of the three trips, all retained billfishes were offloaded and measured. No information was available on whether all retained catch of other teleosts and elasmobranchs was offloaded and measured. Based on information in EM dataset records for the three trips in the port sampling study sample, all sets of the three trips occurred in the Palau EEZ. Data on hooks per trip for the three trips in the port sampling study sample were obtained from EM data.

For the one trip where the port sampling record indicated that all retained billfishes were offloaded and measured by the Palau government port sampler, 0 billfishes were recorded as being landed (Table 2). However, the EM data for this same trip recorded 6 retained billfishes. The port sampling data for the three trips indicated that a total of 190 tunas, made up of 46 bigeye and 144 yellowfin tunas, were retained, while the EM data for the same trips recorded 45 bigeye, 172 yellowfin, and 11 other tuna species were retained. The port sampling data for the three trips with EM coverage lacked information on the total retained catch of non-tuna and non-billfish species, while the EM data recorded 22 species other than tunas and billfishes were retained in the three trips.

Magnitude and Statistical Significance of Differences in Mean Catch Rates and Mean Retained Catch Rates for Sets with EM from EM, Logbook and Port Sampling Data

Mean catch rates for combined tunas, other teleosts, combined elasmobranchs, combined retained catch, and combined discarded catch from EM data were significantly higher than rates from logbook data with EM coverage ($P<0.05$, two-sample t-test for unequal variances). The mean combined tunas, other teleosts, combined elasmobranchs, combined retained catch, and combined discarded catch from EM data were 92, 95, 99, 91 and 99% higher than the rates from logbook data with EM, respectively.

No sea turtle or ray species captures were recorded in the logbook with EM study sample. There was a combined sea turtle catch rate of 0.5 turtles (±0.2 95% CI) per 1000 hooks and ray catch rate of 8.3 rays (±2.1 95% CI) per 1000 hooks from EM data. Discussed above, this discrepancy was likely due to misreporting in the logbooks.

The mean retained tunas catch rate from EM data was not significantly different than from port sampling data from trips with EM coverage ($P>0.05$, two-sample t-test for equal variances). This was likely due to the port sampling study sample having only 3 records, resulting in a large 95% CI of 14.6 tunas per 1000 hooks. Not shown in Table 2, from EM data, the tuna and combined billfishes mean retained catch rates were 13.6 (±4.7 95% CI) per 1000 hooks and 0.6 (±0.2 95% CI) per 1000 hooks, respectively. The port sampling data with EM coverage retained catch rate for billfishes, from 1 record (1 trip) was 0 billfishes per 1000 hooks. The mean retained tuna catch rate from EM data was 41% higher than that from port sampling data.

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Appendix 1

Table A1 summarizes attributes and potential biases of three fisheries monitoring approaches that were assessed in the study plus human onboard observers.

Table A1. Information collected and potential biases of different data fields collected by alternative monitoring programs for pelagic longline fisheries.

Data field	Attribute			
	Logbook	**Port sampling**	**Human onboard observer**	**Electronic monitoring**
Fishing effort				
What is collected	All vessels are required to submit logsheets for all trips, covering all sets within a trip, and all hooks per set. However, there is partial reporting, where (i) fishers do not submit logsheets for some trips, and (ii) fishers partially complete fields, including on amount of fishing effort, within logsheets.	Most vessels and trips. No information collected on number of sets or hooks per trip. In some fisheries, there may be a lack or low coverage of vessels that transship at sea.	Low coverage rates (<1% of trips) in some pelagic longline fisheries. In some fisheries, the observer monitors a subset of fishing effort during a set/haul, usually close to 100% of hooks within sets.	Currently, EM data for 100% of effort (all trips and sets within trips) are analyzed. Currently, covers a small sample of vessels active in the fishery. In some fisheries, only domestically-based vessels have EM coverage (i.e., some EM programs exclude distant-water vessels that are authorized to fish in the EEZ)
Accuracy of estimate	High for number of sets, medium for number of hooks	High for number of trips, no data collected for other units of effort	High for number of sets, medium for number of hooks	High for number of sets, medium for number of hooks
Incentives for bias	No known incentives for misreporting	No known incentives for misreporting	Observer effect: The presence of an observer onboard can cause fishers to alter their conventional fishing effort per trip (e.g., they may reduce the number of sets per trip, and number of hooks per set) No known incentives for misreporting	Not known if an observer effect occurs for EM programs. If EM equipment is installed for a fixed and short period, the same effect of placement of a human observer may occur. If the EM equipment is in perpetuity, then there may be no effect on fishing practices. No known incentives for misreporting
Spatial resolution of records				
What is collected	The SPF/FFA Regional Longline	The SPC/FFA Regional	SPC/FFA longline observer form calls for	Same as for human onboard observer.

	Logsheet Form calls for fishers to record the latitude and longitude at the start of each set, but not coordinates of the end of the set, or coordinates at the start and end of hauls. Discussed under 'fishing effort' there can be partial logbook records.	Longline Port Sampling Form calls for port samplers to record a latitude and longitude range for the fishing grounds of a trip.	observers to record the coordinates of the starts and ends of sets and hauls, and coordinates for other fishing activities.	
Accuracy of estimate	High (use vessel GPS)	Don't know (don't know what data source the port sampler uses to make the estimate)	High (observer uses GPS)	High (some EM systems can record coordinates using vessel GPS)
Incentives for bias	Fishers may misreport location of effort if occurred in a prohibited area	No known incentives for misreporting	Presence of observer onboard can cause fishers to alter their conventional location of effort Observer may be influenced by fishers to misreport the location of effort if fishing occurred in a prohibited area	Not known if an observer effect occurs for EM programs. If EM equipment is installed for a fixed and short period, the same effect of placement of a human observer may occur. If the EM equipment is in perpetuity, then there may be no effect on fishing practices. No known incentives for misreporting by office-based EM reviewer
Temporal resolution of records				
What is collected	Date and time of start and end of trip; date and time of start of set. Discussed under 'fishing effort' there can be partial logbook records	Date of start and end of trip	Date and time of start and end of each fishing activity, including sets and hauls	Same as for human onboard observer.
Accuracy of estimate	High	High	High	High
Incentives for bias	Fishers may misreport dates of sets when they	None	In some fisheries, vessels may undertake shorter trips when	Not known if an observer effect occurs for EM

	occurred during a closed period		observer onboard. And the presence of observer onboard can cause fishers to alter their conventional time-of-day of fishing operations, but this is unlikely. Observer may be influenced by fishers to misreport dates of sets if they occurred during a closed period	programs. No known incentives for misreporting by office-based EM reviewer
Retained catch				
What is collected	Number, weight and species of each retained organism Discussed under 'fishing effort' there can be partial logbook records	Number, length, weight, and species of each retained organism	Number, length, weight and species of each retained organism	Same as for human onboard observer.
Accuracy of estimate	Medium (species ID accuracy is low for some groups, estimates of number high, estimates of length and weight are low)	High	High Relative to logbook data, observer program data have been documented to be more robust relative to logbook data. Previous studies have documented that the quality of data from human onboard observer programs and from EM systems are similar	High Relative to logbook data, observer program data have been documented to be more robust relative to logbook data. Previous studies have documented that the quality of data from human onboard observer programs and from EM systems are similar
Incentives for bias	Fishers may misreport retained catch that they illegally transship at sea or illegal sell in port, and that they land at ports that charge an export tax	Government port samplers may be influenced to misreport landed catch in ports that charge an export tax	Observer effects on fishing methods and gear may affect catch rates of retained species Observers may be influenced by fishers to underreport retained catch for fisheries that land in ports where there is an export tax	Not known if an observer effect occurs for EM programs. No known incentives for misreporting; office-based observers are unlikely to be influenced by fishers as they might not interact with each other
Discarded catch (i.e., all catch that is not retained, that is both released alive and that is discarded				

dead)				
What is collected	Number by species Discussed under 'fishing effort' there can be partial logbook records	No data are collected on non-retained catch	Number, length, weight and species of each non-retained organism	Same as for human onboard observer.
Accuracy of estimate	Low	Not applicable - no data are collected on non-retained catch	Same as for retained catch	Same as for retained catch
Incentives for bias	Fishers may misreport non-retained catch, especially of endangered, threatened and protected (EPT) species when there are seasonal bycatch limits in place, and because the catch sector may fear managers putting more stringent measures in place to manage discards and catch of ETP species.	Not applicable - no data are collected on non-retained catch	Observer effects on fishing methods and gear may affect catch rates of non-retained species Fishers may influence the observer, causing the observer to misreport ETP catch, especially in fisheries with bycatch caps	Not known if an observer effect occurs for EM programs. No known incentives for misreporting; office-based observers are unlikely to be influenced by fishers as they might not interact with each other