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AN EXPLORATORY SIMULATION STUDY ON THE POTENTIAL FOR IMPROVEMENTS TO THE IATTC TRADITIONAL PORT-SAMPLING PROTOCOL FOR FLEET-LEVEL SPECIES CATCH ESTIMATION

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EXECUTIVE SUMMARY

This document presents results of an exploratory simulation study on the potential for improvements to data collection and estimation for the tuna purse-seine fleet-level species catch composition of the floating-object fishery in the eastern Pacific Ocean (EPO). This work was motivated by the results from analyses of data collected during the Enhanced Monitoring Program (EMP) pilot study, which identified pronounced within-well patterns in the proportion of bigeye tuna (BET) per container during catch unloading from individual wells. Results from the exploratory simulation study suggest that there is the potential for improvements to be made to the IATTC traditional port-sampling protocol to reduce variance on the estimated fleet-level BET catch, and also to potentially reduce bias. It is anticipated these improvements could be achieved through adoption of a probability sampling protocol for data collection, so that sampling probabilities are known and can therefore be used to estimate in the species catch composition. It is expected that this protocol would include increased within-well sampling, relative to the current traditional port-sampling protocol. The details of a revised sampling protocol remain to be determined through further simulation work. Plans for future simulation studies, which will incorporate data collected by the EMP in 2023 – 2024, are briefly discussed.

1. BACKGROUND

Analysis of data collected by the IATTC Enhanced Monitoring Program (EMP) pilot study in 2022 identified large-scale within-well patterns in tropical tuna species composition that may have implications for estimation of fleet-level species catch (SAC-14-10; Lennert-Cody et al. *Submitted*). In particular, for wells with catch from floating-object (OBJ) sets, the proportion of bigeye tuna (BET) per unloading container was often found to vary considerably over the course of catch unloading from individual wells. These patterns in species composition were identified with the EMP pilot study data because the pilot study sampled the entire unloading of individual wells, at a regular interval. Such patterns are unlikely to be detected when the unloading of only a section of a well is sampled, as is currently done by the IATTC traditional port-sampling program (Appendix of Suter 2010). The IATTC traditional port-sampling program collects data for estimation of fleet-level catch composition, but given its within-well sampling protocol, those data cannot be used to evaluate any effects of large-scale within-well patterns on fleet-level estimation.

As a first step towards evaluating any potential impact of large-scale within-well patterns in species composition on fleet-level BET catch estimation for the OBJ fishery, an exploratory simulation study was conducted. This simulation study used the same methodology as the fleet-level simulations described in Lennert-Cody et al. (*Submitted*). This methodology allows for a comparison of the accuracy of fleet-level estimates generated by different within-well sampling protocols. As part of this exploratory work, the study presented here also evaluated whether there may exist modifications to the current catch estimation methodology (Tomlinson 2002, 2004; Suter 2010; WSBET-02-06) that could lead to improvements in the species composition estimates. In particular, given that the OBJ fishery has evolved since that methodology was developed, this study sought to determine if there is potentially an advantage to explicitly incorporating 'trip' into the estimation methodology by raising the sample data to the trip, for individual sampled trips, when computing the fleet-level BET species catch estimates. The current estimation methodology does not explicitly raise the sample data to the trip level, but instead assumes that once the sample data for a year are stratified by area, month, set type and vessel size class category, the well-level species composition estimates can be considered to be a random sample from all wells of the fleet for that stratum.

With respect to estimation of fleet-level BET catch, there were three questions considered in this study: 1) could it be beneficial to sample more than one section of a well?; 2) is there any advantage to using a probability sampling protocol that covers all levels of sampling (trips, wells, fish within a well) so that sample data can be raised to the trip level as part of the catch estimation methodology?; and, 3) would it be preferable to sample more wells for fewer selected trips, or more trips and fewer wells per trip? This document presents the results from this exploratory work, as well as plans for future, more comprehensive simulation studies.

2. EXPLORATORY SIMULATION STUDY

2.1. Data

Observer Set Summary[1] (Resumen De Lances, or RDL in Spanish) data from Class-6 vessels for 2010 – 2019 were used in this study. The RDL data were used because they contain set-level species composition information, by well, in addition to having complete coverage of Class-6 vessel fishing activity in both space and time. The RDL data had to be reconstructed from different observer data

[1] This observer data type is also referred to as observer 'well plan' data.

tables[2] because, although RDL data are recorded on data forms by all AIDCP observers, those data forms are only keypunched for some trips[3]. To reconstruct the RDL data set for the entire Class-6 vessel fleet, different types of observer data were linked using trip numbers and fishing locations and dates (set numbers were not available in all required data tables). For the 2010 – 2019 period, about 2% of wells could not be linked to specific sets, and data of those wells were excluded from the simulation. The RDL data contain information on set type, dates and locations of fishing, and observer estimates of catch amounts, by species, for the catch from every set loaded into each well of a trip.

The simulation study was limited to trips that made at least one OBJ set in the EPO west of 110°W and north of 10°S. This area corresponds to Areas 1 – 2 of the 2019 benchmark stock assessment for BET (Xu et al. 2022) (hereafter referred to Area A1; Figure 1), although relatively little purse-seine catch occurred in Area 1. OBJ sets made in Area A1 have historically generated a considerable percentage of the EPO BET catch (Xu et al. 2022). For trips that made at least one OBJ set in Area A1, their data associated with any fishing activity that took place outside of Area A1 were excluded from the simulation study. As compared to the current catch estimation methodology, the simulation focused on annual, instead of monthly, estimates. However, the simulation study was otherwise largely consistent with the stratum-level estimation of the current catch estimation methodology, in the sense that the simulation focused on a single set type, vessel size class category and spatial region of the EPO.

2.2. Simulation methodology

Where possible, aspects of the simulation methodology were based on the sampling protocol currently used by the IATTC traditional port-sampling program and on statistics related to the sampling coverage achieved by that program during 2010 – 2019. The sampling protocol of that program specifies that a well is only sampled if all the sets associated with the well catch were from the same stratum. Of particular relevance for the simulation is that wells that contain catch from multiple set types and/or areas are not sampled (Suter 2010). For the EPO, about 50 – 60% of trips of Class-6 vessels were sampled annually. Similarly, about 50% of Class-6 vessel trips with OBJ-set wells[4] that had catch from Area A1 were sampled annually. Among sampled trips that had at least one Area A1 OBJ-set well, on average, about 67% of those trips had one such well sampled; 27% of those trips had 2 such wells sampled (94% had either 1 or 2 sampled). For each well sampled, the sample was collected from a distinct section of the well; on average, 36%, 40%, 19% and 5% of the samples came from the 1st, 2nd, 3rd, and 4th quarters of the well, respectively. Where possible, these aspects were used in structuring the simulation. However, the selection of trips and wells in the simulation was based on probability sampling. By contrast, the selection of trips and wells by the IATTC traditional port-sampling program is largely opportunistic, an aspect of the protocol that would be difficult to replicate in a simulation.

In this simulation study, within-well variability in species catch composition arises from differences in species composition at the level of sets within a well[5], which is the finest resolution of catch composition in the RDL data. For Area A1, annually about 67% – 75% of OBJ-set wells contained catch from 2 or more sets (Figure 2). This suggests that samples from different quarters of the well could correspond to catch

[2] Permanent observer database and Tuna Tracking form database.

[3] RDL data are considered a preliminary data source and are ultimately replaced with fully edited observer data once those data become available.

[4] Hereafter, the term 'OBJ-set well' will be used to refer to a well filled with catch exclusively from OBJ sets.

[5] It is assumed that the composition of set(s) selected from a well was known exactly; i.e., no error was added to the observers' estimates of set-level catch composition values.

from different sets. If two wells, with catch from several sets, had identical distributions of species composition, but different quarters of those wells were sampled, the estimated species composition of the wells might be quite different, depending on how different the species composition was among sets. In the simulation, sampling a set from a well (described below) is intended to approximate sampling a section of the well and can be compared to a census of the entire well catch. In practice, sampling catch from individual sets in a well would be difficult because the boundaries in the well between catch of different sets are not known. Thus, the within-well sampling protocol implemented in this simulation is for illustrative purposes and is not intended to be a protocol that would necessarily be implemented in the field.

For each of years 2010 – 2019, the simulation methodology, which was limited to trips of Class-6 vessels with OBJ sets made in area A1, consisted of the following steps:

- Create 200 synthetic data sets. Each synthetic data set consisted of the same number of trips as the original data, drawn at random with replacement, from among that year's trips which had at least one OBJ set in Area A1.
- For each of the 200 synthetic data sets:
    - Repeat the following steps 30 times to generate 30 estimates of the fleet-level proportion of BET for the stratum:
        - Sample a fixed percentage of trips (at random without replacement) that had at least one well containing only OBJ-set catch; 25% and 50% of trips were used.
        - Sample a fixed number of wells (selected at random without replacement); 1 well (for 25% and 50% of trips) and 2 wells (25% of trips) were used.
        - Select set(s) (two options): 1) use the species catch amounts of all sets in the well ('census'); and, 2) use the species catch amounts from only one set in the well, where that set is selected at random ('1 set at random'). The 'census' option amounts to using the catch composition of the entire well catch, while the '1 set at random' option amounts to using the catch composition from only one set in the well. For wells that contained catch from only one set, these two options will give the same outcome.
    - Summarize the performance of each combination of sampling options (percentage of trips; wells per trip; sets within a well) by:
        - Bias = $\bar{\acute{p}} - p^*$
        - Relative Bias = $\frac{(\bar{\acute{p}} - p^*)}{p^*}$
        - Variance = $\left(\frac{1}{29}\right) \sum_{samples} \left(\acute{p} - \bar{\acute{p}}\right)^2$

        Where $\acute{p}$ is the estimated fleet-level proportion of BET for the stratum based on a single sample (estimators described below), $\bar{\acute{p}}$ the average of the 30 sample estimates, and p^* is the true fleet-level proportion of BET for the stratum (computed as the sum of all BET catch divided by the sum of all tropical tuna catch (= BET + yellowfin tuna + skipjack tuna) from the same sets).
- Summarize the bias, relative bias and variance estimates from the 200 synthetic data sets, for a particular combination of sampling options, by the minimum, median and maximum of the estimates.

Two different estimators of $\acute{p}$ were used in the simulation: (1) a probability sampling estimator (Lohr 2022); and, 2) a method similar to the current fleet-level catch estimation methodology (Tomlinson 2002, 2004; Suter 2010; WSBET-02-06).

For estimating a proportion, estimator (1) raises the BET and tropical tuna amounts in the sample data from each trip to the trip level, based on the probability of obtaining each sample, before computing the estimate of the fleet-level proportion of BET for the stratum. Estimator (1) has the following general form:

$$\acute{p}_1 = \frac{BET\ stratum\ estimate}{Tropical\ tuna\ stratum\ estimate} = \frac{\left(\frac{N}{n}\right)\sum_i \left(\frac{M_i}{m}\right)\sum_j \left(\frac{L_{ij}}{l_{ij}}\right)\sum_k BET_{ijk}}{\left(\frac{N}{n}\right)\sum_i \left(\frac{M_i}{m}\right)\sum_j \left(\frac{L_{ij}}{l_{ij}}\right)\sum_k Tropical\ tuna_{ijk}}$$

where *n* trips are selected by simple random sampling (SRS) out of *N* total sampleable trips in the stratum (note that the factor N/n cancels from the equation when estimating a proportion), *m* is the number of wells selected by SRS for the i^{th} trip, out of M_i sampleable wells. For the '1-set-at-random' option, l_{ij} sets are selected by SRS out of the L_{ij} sets in the j^{th} well of trip *i* (l_{ij} =1 in the simulation above). For the 'census' option, $l_{ij} = L_{ij}$.

An example for an individual trip is provided to illustrate the sample weighting shown in the equation above. Suppose that a sampled well had three sets that could be sampled, and that this well was one of two possible wells to sample for the trip. Then sampling using the '1-set at random' option, the BET catch for the trip (in sampleable wells) would be equal to 2 x [3 x BET catch for the selected set], where $\frac{M_i}{m} = \frac{2}{1}$ and $\frac{L_{ij}}{l_{ij}} = \frac{3}{1}$. These weights reflect the fact that the probability that the specific set was selected from the well is 1/3, and the probability that the specific well was selected from the trip is 1/2. For the 'census' option, the BET catch for the well would only be raised by a factor of 2, instead of 2 x 3 $\left(\frac{L_{ij}}{l_{ij}} = 1\right)$. The same weights would be used to raise the tropical tuna catch from the sample to the trip.

On the other hand, estimator (2) assumes that within a stratum the distribution of species composition among wells is fairly homogeneous. That is, the method assumes that the sampled wells for a stratum represent a simple random sample of all wells in the stratum, without regard for trip. This means that, using estimator (2), the sample data are not raised to the trip level before estimating the fleet-level proportion of BET for the stratum. This can be seen by rewriting the equations of estimator (2) from Tomlinson (2002, 2004), which shows that estimator (2) can be equivalently expressed as weighted average of the well-level proportions, with weights equal to the total well catch of tropical tunas (WSBET-02-06). Thus, using the weighted-average simplification, for the '1 set at random' option, estimator (2) of the fleet-level proportion of BET in the stratum is given by:

$$\acute{p}_{2_{1\ set\ at\ random}} = \frac{\sum_j Tropical\ tuna_{j.} \left(\frac{BET_{j_{selected\ set}}}{Tropical\ tuna_{j_{selected\ set}}}\right)}{\sum_j Tropical\ tuna_{j.}}$$

where the 'j.' subscript denotes the sum of all set amounts in the j^{th} well.

For the census option, estimator (2) of the fleet-level proportion of BET in the stratum is given by:

$$\acute{p}_{2_{census}} = \frac{\sum_j Tropical\ tuna_{j.} \left(\frac{BET_{j.}}{Tropical\ tuna_{j.}}\right)}{\sum_j Tropical\ tuna_{j.}} = \frac{\sum_j BET_{j.}}{\sum_j Tropical\ tuna_{j.}}$$

The simulations and statistical testing were all implemented with the statistical freeware R (R Core Team 2021).

2.3. RESULTS AND DISCUSSION

2.3.1. Sampling within a well

The ‘census’ option led to somewhat better bias properties but mostly improved variance, compared to the ‘1 set at random’ option (Figure 3). This result was consistent across all 10 years and both estimators of the fleet-level proportion of BET for the OBJ fishery of Class-6 vessels in area A1. This suggests that sampling only a section of the well catch, even if that section is selected at random, could lead to increased variance, and possibly somewhat higher bias, on the estimated fleet-level BET catch, as compared to sampling all sections of the well.

2.3.2. Use of a probability sampling estimator

The probability sampling estimator (estimator (1)) had less bias, and less relative bias, than estimator (2) for the stratum considered in this study (Figure 3). This outcome would be consistent with the presence of heterogeneity in the proportion of BET among trips (vessels) that is not addressed by estimator (2). In principle, such heterogeneity will be better addressed using estimator (1) because the individual well samples are raised to the trip level, as part of the estimation methodology, using the probability that each sample was included in the data collected. This is not the case for estimator (2). To address such heterogeneity with estimator (2), the factors that lead to the heterogeneity would need to be used to define the strata, which means all such factors must be known and measured. This simulation result, which will be evaluated in more detail in the future, may arise because of differences in operational characteristics among vessels, and hence trips, combined with large differences in the number of OBJ-set wells per trip for Class-6 vessels of the OBJ fishery operating in area A1. Specifically, the frequency distribution of the number of OBJ-set wells per trip is right skewed (Figure 2), with about 25% of trips having 1-2 OBJ-set wells but some trips having 18 or more OBJ-set wells per trip. Sampling only a few OBJ-set wells per trip could lead to some trips (vessels) being under-represented in the sample data, compared to their prevalence in the OBJ fishery of Area A1. If the vessels that have many OBJ-set wells per trip fish differently from the rest of the fleet, and those fishing practices affect the species composition of their catch, this could lead to increased bias with estimator (2), depending on the stratification used with that estimator.

Although estimator (1) had less bias than estimator (2), it had larger variance (Figure 3). This outcome could arise from the same process that would lead to increased bias for estimator (2). Specifically, sampling only a few wells per trip may lead to less variability among estimates of different samples because the trips of vessels with many OBJ-set wells (and perhaps different species catch composition) are under-represented in the sample data. With estimator (2), this would lead to lower variance, compared to estimator (1), because estimator (2) does not raise the sample data to the trip level. But it will also lead to greater bias, as compared to estimator (1), if the ‘true’ fleet-level proportion of BET is highly influenced by those trips (vessels) with many OBJ-set wells.

2.3.3. Sampling coverage of trips and wells

Using estimator (1), sampling 50% trips and 1 well per trip led to considerably smaller variance than sampling 25% of trips and 2 wells per trip, although the bias associated with the two protocols was very similar (Figure 4). The increase in variance may have occurred because sampling fewer trips would decrease the diversity of vessels in individual samples, thereby potentially increasing the variability among samples from the same population.

2.3.4. Caveats

There are several caveats worth mentioning as regards interpretation of these results. First, as noted in Section 2.2, the simulation study assumed the set catch composition information for each well was known without error. It is expected that large within-well sampling error (e.g. due to inadequate sampling coverage of the well catch) would reduce the differences in simulation outcomes found for the two set-sampling options. Second, the accuracy of observer data and port-sampling data are influenced by different factors, which may affect the extent to which these simulation results based on RDL data can be extended to a port-sampling situation. Third, it is noted that in this simulation study the 'true' fleet-level proportion BET for each synthetic data set is known, which will not be the case in an actual sampling situation. Thus, the actual bias and variance that would be achieved under different sampling protocols will need to be evaluated. Fourth, this simulation study focused on yearly estimates for the OBJ fishery of Class-6 vessels in area A1, whereas the current fleet-level estimation methodology computes monthly estimates, and the current fishery definitions used in the BET stock assessment are different than those shown in Figure 1. Some differences in results may occur with different poststratification of the data, which is an aspect that will be evaluated in future simulation studies. Finally, because the IATTC regular port-sampling protocol involves opportunistic selections of trips and wells, which will be difficult to replicate in any simulation study, simulation outcomes can only provide a guide as to improvements in bias and variance that may be achieved through improved sampling protocols.

2.4. CONCLUSIONS AND FUTURE WORK

In conclusion, results of the simulation study presented in this document indicate that there is likely room for improvement to the IATTC traditional port-sampling protocol, to reduce variance on the estimated fleet-level BET catch estimates, and potentially bias. These improvements might be achieved through increased within-well sampling and adoption of a probability sampling protocol so that sampling probabilities are known and can therefore be used in the species catch estimation.

Several areas for future simulation research into potential improvements to the IATTC traditional port-sampling protocol include:

1. Reducing variance
    a. Test the performance of sampling protocols that sample more sections of the well catch, such as the within-well sampling protocol currently used by the EMP (SAC-14-10; SAC-14 INF-I).
    b. Evaluate the performance of a broader range of sampling coverage options for trips and wells per trip, within the framework of a practical probability sampling protocol, that takes into consideration historical patterns in the frequency of vessel arrivals at ports where sampling is feasible to conduct. Some vessels unload in ports where sampling is not currently feasible. Thus, simulations testing different levels of coverage that take into consideration logistical constraints are necessary to provide a realistic appraisal of costs and benefits.
2. Reducing bias
    a. Develop and test practical probability sampling protocols and their corresponding estimators, so that inclusion probabilities are known and can be used for species catch estimation.

Future simulations studies will incorporate EMP data into the within-well sampling component, so that within-well sampling protocols can be more effectively evaluated. The EMP data can be used to generate synthetic within-well composition data, which can then be sampled with various well-level systematic (and random) sampling protocols.

Finally, in the future, simulation studies will also be possible for other set types due to the collection of high-frequency within-well sample data for unassociated (NOA) set wells and dolphin-associated (DEL) set wells. Collection of this high-frequency data in 2024 is the purpose of Project C.1.b (SAC-15 INF-E) and one component of the proposed workplan for future EMP data collection (SAC-15 INF-H; Unfunded Proposal B.3.b). These data will allow IATTC scientists to extend the work of Wild (1994) on port-sampling of NOA and DEL set catch.

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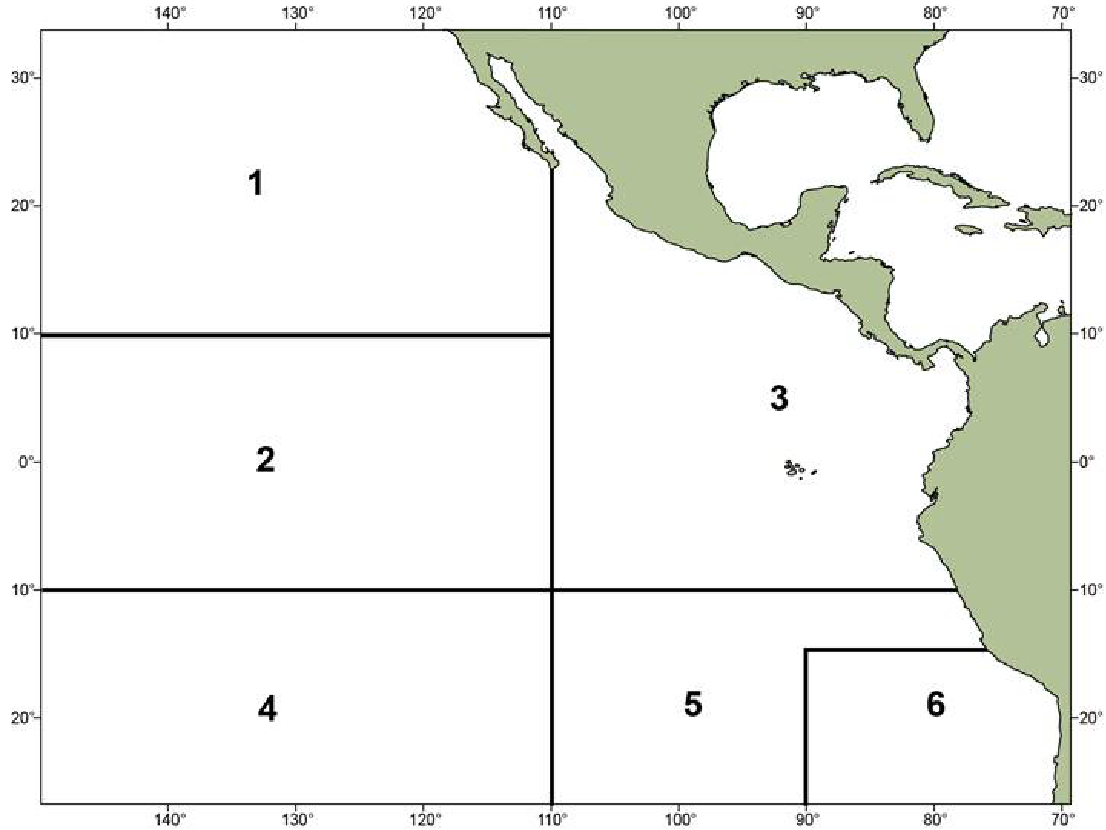

FIGURE 1. Fisheries used in the 2019 BET benchmark stock assessment (figure from Xu et al. 2022). Area A1 used in the simulation study is the combination of Areas 1 and 2 shown here.

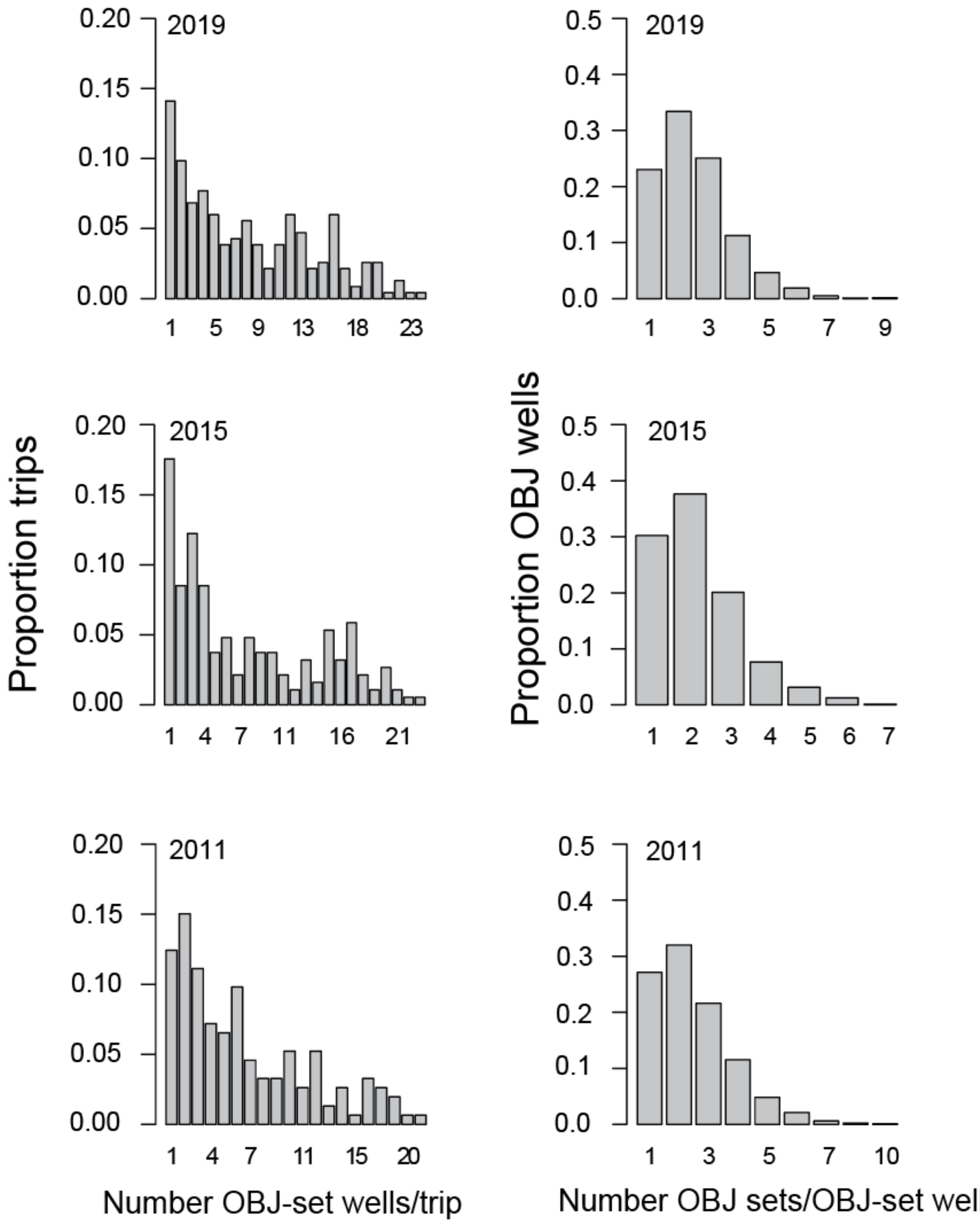

FIGURE 2. Examples of frequency distributions of the number of OBJ-set wells per trip (left column of panels) and the number of OBJ sets per OBJ-set well (right column of panels), for Area A1 in 2011, 2015 and 2019.

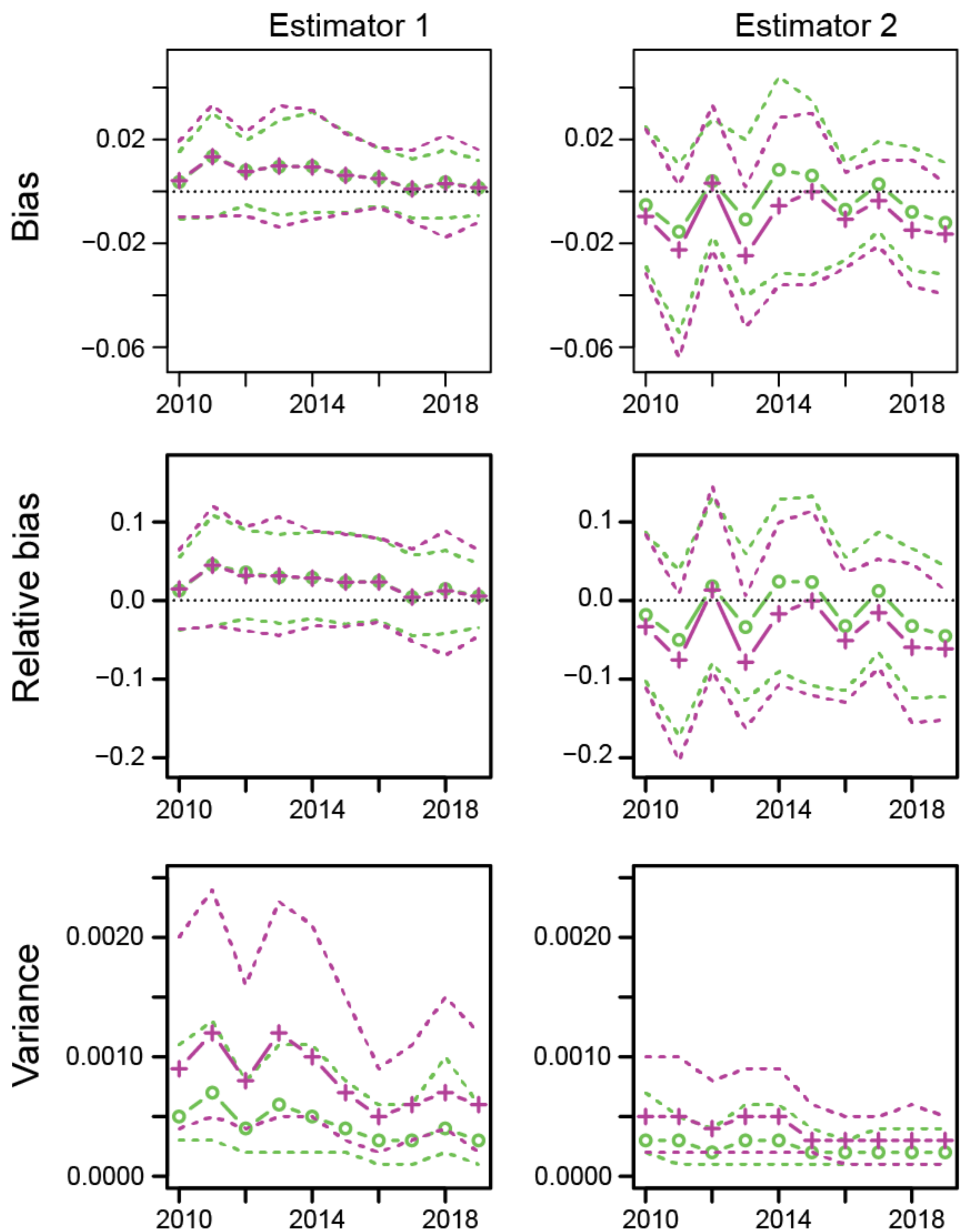

FIGURE 3. Bias, relative bias and variance, for the estimated fleet-level proportion of BET for the OBJ fishery in area A1, by year, from the simulation based on 50% coverage of trips and 1 well sampled per trip, using the 'census' option (green) and the '1 set at random' option (pink). For each year, results from the 200 synthetic data sets are summarized by the median (open green circles; pink crosses) and the minimum and maximum values (dashed lines).

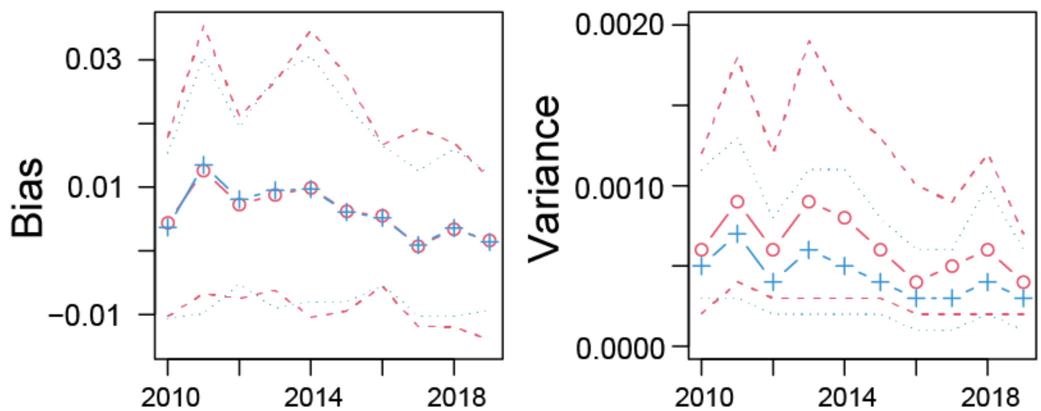

FIGURE 4. Bias and variance, by year, for the estimated fleet-level proportion of BET for the OBJ fishery in area A1, using estimator (1), for 25% coverage of trips and 2 wells sampled per trip (red) and 50% coverage of trips and 1 well sampled per trip (blue), both using the 'census' option. For each year, results from the 200 synthetic data sets are summarized by the median (open red circles; blue crosses) and the minimum and maximum values (dashed lines).