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ENHANCED MONITORING PROGRAM: 2023 REPORT AND OTHER DEVELOPMENTS

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EXECUTIVE SUMMARY

The management measure for bigeye tuna (BET) catch thresholds per vessel, established in Resolution C-21-04, utilizes the Enhanced Monitoring Program (EMP) as a science-based support tool. This program implements a data collection protocol during catch unloading in port that allows for the estimation of the BET caught by a vessel during a fishing trip and a measure of precision on that catch estimate.

Between March and December 2023, the EMP sampled 75 trips from 30 purse-seine vessels, with a total of 529 wells sampled. The BET catch estimates per trip ranged from 2 to 519 t, with a decreasing temporal trend in the estimated BET catch per trip over the 9-month period. Meanwhile, the coefficients of variation (CVs) obtained for the trip-level BET catch estimates ranged from 0.05 to 0.88, with a median value of 0.19, and an increasing temporal trend over the 9-month period. The increase in CVs at a time when catches were decreasing reflects the fact that, for a number of sampled trips, only a few of the sampled wells contained significant amounts of BET catch, while most sampled wells had little or no BET catch. At the same level of sampling coverage of wells, such variability in BET catch among wells leads to higher estimated variance on the trip-level catch, and hence higher CVs.

The data collected by the EMP have created significant research opportunities, enabling studies that focus on maximizing the scientific benefits of data from other sources (observers, logbooks, and processing

plants). Similar decreases in the BET catch over the time period were also seen for the other data sources; however, on a vessel-by-vessel basis, the estimates from the other data sources could be higher or lower than those of the EMP, sometimes outside the confidence intervals on the EMP estimates. To better understand vessel-specific patterns, EMP and observer estimates of the proportion of BET in the catch, at the level of individual wells, are being analyzed. The 2024 EMP data will be very beneficial for these well-level comparisons because they will increase the number of trips sampled per vessel, for many of the vessels sampled by the EMP, leading to better statistical models, and thus, a better understanding of the relationship between the two data sources.

To provide information for planning EMP sampling beyond 2024, a cost-benefit analysis was conducted, presenting several implementation scenarios. The IATTC staff considers that, with the estimated annual budget of US$ 404,765 for Scenario A, the EMP could continue to implement the sampling protocol for estimation of BET catch per trip for a subset of vessels unloading in Manta, Ecuador, with the possibility of occasional sampling in Posorja, Ecuador. Additionally, within the budget proposed in Scenario A, in Ecuador the EMP could: 1) collect morphometric data to update the morphometric relationships used in the stock assessments; and, 2) collect high-frequency species composition sampling data for use in simulation studies to evaluate improvements to the traditional port-sampling protocol. Both of these activities would address recommendations of the 1st External Review of data used in stock assessments of tropical tuna in the EPO. For an additional US$ 80,000, the collection of morphometric and high-frequency sampling data could be expanded to Mexico. All these components of the EMP, in Ecuador, and additionally, in Mexico, would establish a foundation that can be expanded to collect additional types of data for scientific research, including but not limited to biological data for both tuna and non-tuna species (see Unfunded Project B.3.b).

1. BACKGROUND

In the context of conservation measures for tropical tunas in the Eastern Pacific Ocean (EPO), the Inter-American Tropical Tuna Commission (IATTC) adopted Resolution C-21-04 during its 98th meeting in October 2021. This resolution establishes annual catch thresholds for bigeye tuna (BET; *Thunnus obesus*) for individual purse-seine vessels (IVT) and mandates additional closure days for vessels exceeding these thresholds. To support the monitoring of purse-seine vessel catches relative to these thresholds, the resolution also established the Enhanced Monitoring Program (EMP). The EMP aims to collect data during the unloading of purse-seine vessels in port for estimation of trip-level BET catch. To this end, an EMP pilot study for data collection and sampling design development was conducted during September 2022 to February 2023. This pilot study focused on intensive sampling of wells that contained catches from floating-object (OBJ) sets, for a number of vessels, a task not previously undertaken by the IATTC staff. The results of this pilot study, including the sampling protocol that was developed, were presented in documents SAC-14-10 and SAC-14 INF-I. As of March 2023, the EMP began sampling activities in the ports of Manta and Posorja in Ecuador.

This document presents results of the EMP for 2023 and highlights opportunities for scientific research with EMP data identified during the program's implementation. Section 2 outlines the data collection and estimation processes conducted by the EMP, in compliance with Resolution C-21-04. Section 3 details scientific research carried out by the IATTC staff to date that uses data collected by the EMP. This research aims to improve data collection and analysis methods for the estimation of BET catch per trip and explore uses of EMP data to benefit estimation of fleet-level species catch composition for tropical tunas[1]. Section 4 addresses the requests made by the SAC at its 14th meeting, reporting on the progress in enhancing

[1] Tropical tunas refers to BET, yellowfin tuna (YFT; *Thunnus albacares*) and skipjack tuna (SKJ; *Katsuwonus pelamis*).

information exchange mechanisms between the IATTC staff and its Members. It also includes the cost-benefit analysis requested by the SAC in 2023, which presents potential scenarios based on the current objectives of the EMP. Section 5 expands on that cost-benefit analysis by proposing that the collection of morphometric and high-frequency sampling data be included among the tasks of the EMP. This collection of biological information aligns with the current research needs of the IATTC and follows the recommendations of the October 2023 External Review.

2. RESULTS OF THE ENHANCED MONITORING PROGRAM

2.1. Data collection

Between March and December 2023, the EMP sampled 75 fishing trips of 30 purse-seine vessels from the fleets of Ecuador, El Salvador, Spain, United States, Nicaragua and Panama. For 22 of these vessels, at least two trips were sampled (Figure 1). The number of trips sampled for the same vessel varied, based on several factors: the frequency with which the vessel unloaded in ports where the EMP operates; the availability of sampling technicians at the time of unloading; and, in the latter months of the year, the prioritization for sampling of vessels whose BET catch was approaching the thresholds of Resolution C-21-04.

The selection of trips for sampling was based on the extent to which fishing activity during a trip involved set types and areas that were considered a priority for data collection (SAC-14-10). Each well of a trip was assigned to a 'stratum', where strata are determined by the combination of fishing area(s) (Figure 2) and the set type(s) associated with the catch in the well. For each trip, six to eight wells were randomly selected from specific strata, with priority given to strata defined by OBJ sets made in the western area of the EPO (OBJ OFF and OBJ IN-west[2] strata). Wells with catch from OBJ sets made in the eastern EPO (OBJ IN-east stratum) and sets on unassociated schools of tuna (NOA strata) were only infrequently sampled due to their historically low or nonexistent BET catch (mixed set type and/or mixed area wells were not sampled). For each selected well, a team of two samplers sampled one unit[3] out of every 30 units of fish unloaded from the well, starting with a randomly chosen unit from the first 30 units, and continuing until the well was fully unloaded, as outlined in the EMP sampling protocol (SAC-14-10). For every unit sampled, all fish in the unit were identified to one of four species group (BET, YFT, SKJ, other fishes), and the weight of each tropical tuna was recorded. In total, the EMP sampled 529 wells in 2023.

2.2. Estimates of BET catch per trip and their coefficients of variation

The BET catch estimates from trips sampled by the EMP were obtained using the methodology described in document SAC-14-10. For each trip, this involved obtaining an estimate of the BET catch for each stratum of the trip, and summing those estimates to obtain the trip-level estimate. For strata of the trip that were not sampled by the EMP, estimates from observer Set Summary data, also known as Resumen De Lances (RDL) in Spanish, were used. For 65% of the sampled trips (49 out of 75), the trip-level BET estimate was based entirely, or almost entirely, on the species composition obtained from EMP data (Figure 3). For the remaining 35%, the RDL species composition data had to be used more extensively due to a higher number of strata per trip than could be sampled by the EMP (Figure 3).

BET catch estimates per trip for the 75 trips sampled in 2023 ranged from 2 to 519 t. There was a decreasing temporal trend in the estimates, with a notable change in mid-July (Figure 4). This trend was also observed in the estimates for the OBJ OFF and OBJ IN-west strata, but not for OBJ IN-east (Figure 5).

[2] OBJ OFF: OBJ sets made west of 110°W; OBJ IN-west: OBJ sets made between 110°W and 95°W; OBJ IN-east: OBJ sets made east of 95°W; NOA: non-associated sets. For further details of the strata used by the EMP, see Section A.4 of document SAC-14 INF-I.

[3] A unit of fish was defined as either a physical container filled with fish, or a fixed number of fish unloaded individually from the well, referred to as a 'virtual' container. For further detail see SAC-14-10.

The coefficients of variation (CV; Appendix B;) obtained for the trip-level BET catch estimates ranged from 0.05 to 0.88, with median of 0.19. Unlike the catch estimates, which showed a decreasing trend over time, the CVs exhibited an increasing trend, beginning around mid-July (Figure 6). This increasing trend in CVs was also observed at the stratum level, notably for OBJ OFF and, to a lesser extent, for OBJ IN-west (Figure 7). The median CVs for the stratum-level estimates were: 0.17 for OBJ OFF (range: 0.01 to 0.67); and, 0.26 for OBJ IN-west (range: 0.02 to 0.63).

The higher CVs during the period of lower estimated BET catches is the result of greater variability in the proportion of BET among the sampled wells of individual trips. The estimated BET catch for a trip, or stratum, is likely to be low when the proportion of BET per well is low for nearly all sampled wells. However, if a few sampled wells of a trip (or a stratum) have a significantly higher proportion of BET than the other sampled wells, this can lead to a higher estimated variance and thus a higher CV. For example, there is a clear temporal change in the variability of the proportion of BET, both within and among sampled wells of the same trip, for the OBJ OFF stratum (Figure 8). Sampled wells with catch from the OBJ OFF stratum, of trips that unloaded after July, typically had a lower overall proportion of BET compared to the earlier period (Figure 8). Nonetheless, for some of those trips, one or two wells had a much higher proportion of BET, resulting in higher CVs.

At the time of writing this document, it is not possible to establish whether the temporal pattern observed for CVs in 2023 is recurrent. Besides seasonal factors, other elements that may contribute to this pattern include: changes in fishing behavior, as a result of the Resolution, for vessels frequently sampled by the EMP, such as active avoidance of OBJ sets with higher BET catches towards the end of the year; possible sorting of catch among wells on board the vessel ; and, opportunistic fishing driven by an increase in the availability of skipjack tuna in the last months of 2023.

The temporal pattern in CVs will be studied further with data collected by the EMP in 2024. During the first three months of 2024, the EMP sampled 24 trips by 19 vessels from the fleets of Ecuador, El Salvador, Spain, Panama and Nicaragua. The EMP will continue to sample trips through December 2024.

3. SCIENTIFIC RESEARCH BASED ON EMP DATA

The port-sampling data collected by the EMP have significantly expanded research opportunities for IATTC staff to improve science for management. In addition to the use of EMP data for estimation of BET catch per trip, the EMP data are making possible studies aimed at maximizing the scientific benefits of other existing data sources, as well as studies on their potential use in estimating fleet-level catch of the three tropical tuna species.

In addition to the EMP data, the IATTC staff has access to data from three primary sources: the AIDCP observer program, fishing logbooks, and processing plants. As a first step towards developing a better understanding of all four data sources, the BET catch estimates from these sources can be compared at the trip level. Similar to the EMP estimates (Figure 4), the trip-level BET catch estimates from the other three sources showed a decreasing trend in 2023 (Figure 9), although this trend was slightly less evident in the logbook estimates. For each of the three primary data sources, there were some trips with estimates very similar to those of the EMP, and others with estimates outside the 95% confidence intervals on the EMP estimates, either above or below the confidence interval bounds.

A positive correlation was found between the EMP estimates and those of the three primary data sources (Figure 10). To statistically assess these relationships, simple linear regression models were fitted to the paired data points using weighted least squares, with weights equal to the inverse of the variance of the EMP estimates, to mitigate the impact of less precise EMP estimates on the fitted relationship. The estimated slopes for the three linear relationships—each with a p-value < 0.001 —are as follows: 0.71 (s.e. = 0.072) for EMP vs. RDL; 0.95 (s.e. = 0.045) for EMP vs. processing plant; and 0.89 (s.e. = 0.092) for

EMP vs. fishing logbook (Figure 10). Although statistical comparison of the slopes of the three linear relationships is feasible, interpreting the results is complicated due to the fact that IATTC staff did not have logbook and processing plant estimates for all 73 trips with EMP[4] and RDL estimates[5]. Specifically, there was a lack of processing plant and logbook data for 11 and 21 trips, respectively. This level of missing information poses a challenge to understand how the relationships between EMP and processing plant estimates, and EMP and logbook estimates, might change had the missing estimates from these two sources been available and included in the regression analyses. This is because the reasons why the information for these trips were not provided are not currently known, and therefore, it is not possible to assume that the information is missing at random. A detailed comparison of EMP and RDL data is presented in Section 3.1; additional information on logbook and processing plant data is provided in Section 4.1.

3.1. Research using detailed observer and EMP data

The detailed nature of the RDL data, and its availability for all trips sampled by the EMP, allows the EMP and RDL data to be compared at different levels, from the stratum level to the well level. A comparative analysis of EMP and RDL stratum-level estimates showed that the estimates from both sources display a similar behavior over time, following the same overall temporal trend, particularly for the OBJ OFF stratum, with estimates from both sources showing a reduction in BET catches starting in mid-July (Figure 11). For some trips, the stratum-level estimates of the two data sources were very similar, with the RDL estimate within the approximate 95% confidence interval of the EMP estimate. For other trips, the stratum-level estimates were different, with the RDL estimate above or below the confidence interval bounds on the EMP estimate (Figure 11).

Differences between the RDL and EMP estimates, computed by trip at the stratum level, were grouped by vessel to help understand the patterns shown in Figure 11. For vessels for which more than one trip was sampled, several types of patterns were identified (Figure 12). For some vessels, there were both positive and negative differences in the stratum level estimates, while for other vessels these differences could be almost entirely positive or negative. Thus, the patterns shown in Figure 11 appear to have both a temporal component and a vessel component.

For a better understanding of the patterns found at the vessel level (Figure 12), the estimated proportions of BET per well from both data sources were analyzed (Figure 13; Appendix A). The overall relationship between the proportion of BET per well for the EMP and the RDL showed a positive correlation, with both positive and negative differences (Figure 13). However, this overall relationship can be misleading. For some vessels, the difference between the two data sources at the well level was systematically positive or negative for almost all sampled wells and trips[6] (Figure 13; Appendix A), while for other vessels the pattern of well-level differences varies from trip to trip (Appendix A). These results indicate that the relationship between the EMP and the RDL is not simple. This is particularly true because RDL data for trips of the same vessel in 2023 were generally recorded by different observers. Therefore, for some vessels, the consistent pattern in well-level differences across trips may be related to vessel-specific factors, while for other vessels, where the pattern changes from trip to trip, other factors may be involved. Further analysis will be carried out later this year that includes data collected in 2024, to increase sample

[4] There were two trips sampled by the EMP for which variance could not be estimated.

[5] As of 9 April 2024

[6] Additionally, replacing the overall slope, β, in the simple linear model: EMP proportion BET = $\alpha + \beta$ x RDL proportion BET, with vessel-specific slopes reduced the Akaike Information Criterion (AIC) by -95 (from -618 to -713) and increased the adjusted R-squared from 62% to over 70%. (For both models, the p-value of the F-statistic for the test of model significance was < 0.001.) Given that the AIC for the model both vessel-specific intercepts and slopes was -733, the model with just an overall slope (and intercept) would not appear to be an adequate model.

sizes. This analysis will involve development of a model for the well-level relationship using covariates such as brailer capacity, set size, number of sets associated with the catch contained in the well, and the proportion of small yellowfin tuna in a set, among other factors. Although the IATTC staff does not currently have data on brailer size, this information will be collected by the EMP during 2024.

Successfully modeling the effects of various factors that lead to differences in EMP and RDL estimates at the well level has several potential scientific benefits. First, such a model would allow for adjustments to be made to observer catch estimates, which could lead to the incorporation of observer data in the future development of spatiotemporal models for fleet-level catch estimation. Second, it would allow observer data, with their broader coverage of vessels in space and time, to be used more extensively in the development of improvements to port sampling protocols, for both trip-level and fleet-level catch estimation. The 2024 EMP data will be very beneficial for the well-level comparison of the EMP and RDL estimates because it will increase the number of trips available for analysis from vessels sampled by the EMP, leading to better statistical models, and thus, a better understanding of the well-level relationship between the two data sources.

4. RESPONSE TO SAC-14 REQUESTS

4.1. Data transfer mechanisms

Since July 2023, every CPC has had access to a webpage on the IATTC website where BET catch estimates per trip from available primary data sources are presented, for Class 4-6 vessels under their flag. This is a dynamic table that is updated daily with information from the IATTC databases.

Table 1 presents a breakdown, in quantity and coverage, of the information available from each data source for trips by Class 4-6 vessels in 2023, as of 15 January 2024. In general, the AIDCP on-board observer program reported having data for 100% of the trips by Class-6 vessels operating in the EPO. Information from fishing logbooks was available for 70% of the trips. In the case of data from processing plants, although the submission of this information to the IATTC staff is established in paragraph 8 of Resolution C-21-04, as of 15 January 2024, the IATTC staff had received information for only 28% of the trips made in 2023. The low percentage of data received, particularly from processing plants, negatively impacts the IATTC staff’s ability to conduct analyses in a timely manner. However, this issue has highlighted an opportunity to work on improvements to procedures, formats and/or minimum requirements, that would allow for standardized management of the data received from processing plants, thereby minimizing the risk of errors in the information that cannot be identified and corrected, such as the potential reporting of incomplete or duplicate quantities.

4.2. Cost-benefit analysis

The cost-benefit analysis requested of the IATTC staff by the SAC is presented below (additional technical details are presented in Appendix B). The purpose of this cost-benefit analysis is to provide information to inform discussion on the level of sampling of a future EMP after 2024, specific to estimation of BET catch per trip. For this analysis, a simulation study was conducted to estimate the reduction in the CVs on the BET trip-level catch estimates that would occur with hypothetical increases in the number of wells sampled per trip.

4.2.1. Simulation methodology

This simulation evaluates the reduction in CVs that would be expected if the number of wells sampled for a stratum (trip) were increased. The variance on the estimated BET catch per stratum, and per trip, has two components: an among-well variance component, which is driven by variability in species composition among wells of the stratum (trip); and, a within-well variance component, which is driven by variability in species composition among units (containers) of fish unloaded from a well. Both are important to consider in order to reduce the variance on the estimated BET catch (SAC-14-10). However, the logistical challenges of reducing the within-well variance are considered greater than the logistical challenges of sampling more wells for the stratum (trip), given the current EMP within-well sampling protocol (SAC-14-10; SAC-14 INF-I). Thus, the simulation study focused on evaluating the reduction in variance, and hence CV, that can be achieved by increasing the number of wells sampled.

The simulation study focused on the OBJ OFF stratum due to its importance for BET catches and the clear increases in CVs in the latter part of 2023 (Figure 7). Although the simulation study focused on increasing sampling for the OBJ OFF stratum, both the CVs of the estimates for this stratum, and the CVs of the estimates per trip, were evaluated. Thus, for trips with catches from multiple strata, it was implicitly assumed that additional sampling would be more beneficial if conducted for wells with catches from the OBJ OFF stratum. It is also assumed that the among-well variance component on the estimated BET catch for the OBJ OFF stratum was adequately estimated with the number of wells actually sampled.

To estimate the reduction in CVs due to the simulated additional sampling, the data were divided into two periods: an early period, defined by trips that unloaded by 15 July; and a late period, defined by trips that unloaded after that date. These two periods were chosen because they are characterized by having different ranges of CV values (Figures 6-7). It was considered important to evaluate the benefit of additional sampling for each period separately, since, as mentioned in Section 2.2, the factors that led to differences in CVs over time are a subject of ongoing research and, therefore, at the time of writing this document, it is unknown what might be expected in future years. The simulations carried out for each period may delimit the possible distributions of estimated CV values that would be obtained from sampling in future years.

Within each period, the simulation was limited to trips for which not all wells in the OBJ OFF stratum had been originally sampled (because there would be nothing to improve for a specific trip if all possible OBJ OFF wells were originally sampled) and to trips for which the estimated CV of the OBJ OFF catch stratum was greater than 0.10 (assuming that if the original number of wells sampled resulted in a CV of 0.1 or less, then the original sampling level was adequate). For the early period, 21 trips were included in the simulation; six trips were not included since all OBJ OFF wells had been originally sampled and/or the original CV for the catch stratum was 0.1 or less. For the late period, 27 trips were included in the simulation, and eight trips were not included.

For the OBJ OFF stratum of an individual trip, the simulation details are as follows. The number of additional OBJ OFF wells that were simulated to have been sampled was: two, four, six, and eight wells. The variance on the BET catch estimate of the stratum was then recalculated with each of the simulated numbers of additional wells sampled. Finally, the corresponding CVs, for the stratum and the trip, were then recalculated using the simulated variances. These steps were only repeated for the OBJ OFF stratum of a trip up to the total number of OBJ OFF wells that could be sampled for that trip. For example, if a trip had 10 wells containing OBJ OFF catches and six wells were originally sampled, CVs would be evaluated with two additional wells sampled and four additional wells sampled, but not 6 or 8 additional wells sampled.

4.2.2. Simulation results

The simulation results of the OBJ OFF stratum CVs differ depending on the period (Figures 14-15), as would be expected given the differences in the original CVs of both periods (Figure 7). For the early period, the simulation results suggest that if the target CV for the OBJ OFF stratum is 0.20 or less, additional sampling of two OBJ OFF wells would likely achieve this target for each trip (Figure 14). If the target CV for the OBJ OFF stratum is 0.10, it would be necessary to sample six to eight additional OBJ OFF wells. For the late period, the simulation results suggest that it would be necessary to sample more than eight additional wells to achieve a target CV of 0.2 for all trips, and that a target CV of 0.10 for all trips is not realistic (Figure 15). However, by sampling two to four additional wells, the percentage of trips in the late period with CVs equal to or less than 0.20 or 0.25 increases significantly, compared to the original distribution of CV values (Figure 15). Thus, a limited amount of additional sampling can be expected to improve the CV results for the OBJ OFF stratum in the late period, as well.

Given the differences in simulation results between the early and late periods, the overall results were summarized separately for each period, based on the proportion of all sampled trips with catch in the OBJ OFF stratum for which the stratum CVs, and separately the trip CVs, were less than 0.10, 0.15, 0.20 and 0.25 (Figure 16). Following this approach, it is estimated that 100% of the CVs of the early period trips would be less than 0.20 if two additional wells were sampled for the OBJ OFF stratum (Table 2, Figure 16). For the late period, it is estimated that 49% and 69% of the trip-level CVs would be less than 0.20 and 0.25, respectively, if samples were collected from two additional wells for the OBJ OFF stratum (Table 2, Figure 16). It is estimated that these percentages would increase to 63% and 80%, respectively, if four additional wells were sampled for the OBJ OFF stratum.

4.2.3. Potential implementation scenarios

Based on the results presented in the previous section, three potential scenarios for a future EMP sampling protocol are proposed. These are based on the number of wells that would need to be sampled per trip, according to the expected CV (Table 2):

a) Scenario A (no increase): 6-8 wells sampled per trip.

b) Scenario B (+2): 8-10 wells sampled per trip.

c) Scenario C (+4): 10-12 wells sampled per trip.

For example, for the early period, if the desired CV is 0.20, under scenario A, 89% of the sampled trips could have CVs equal or less than 0.20; in scenarios B (+2) and C (+4) it would be expected that 100% of the trips would achieve this objective. However, for the late period these percentages are reduced to 40% for scenario A, 49% for scenario B (+2) and 63% for scenario C (+4) (Table 2, Figure 16).

The cost estimate for each scenario is derived from the number of sampling teams, with two people per team, required to sample the designated number of wells for each scenario, along with associated operating costs. The cost estimates are based on the 2023 EMP implementation budget and the actual level of sampling that occurred in the port of Manta in 2023, with an average of four trips sampled per month, totaling 48 trips per year. The annual and per-trip costs were then calculated for each of the three proposed scenarios (Table 3). Scenario A involves sampling the recommended minimum number of wells per trip (SAC-14-10), using six teams of samplers (12 people) to cover between six and eight wells per trip, which is the current protocol used by the EMP. This scenario would be estimated to achieve a CV of 0.2 or less for 89% of the trips in the early period and 40% in the late period, with an approximate annual cost of US$ 404,762.44. In scenario B (+2), which involves eight teams of samplers (16 people), the coverage is expanded to sample eight to ten wells per trip to obtain BET catch estimates with CVs estimated to be 0.20 or less for approximately 100% of the sampled trips in the early period, and 49% in the late period. The projected annual cost for this scenario is US$ 482,423.12 (Table 3).

The scenarios presented in this analysis take into account the requirement that the EMP should not disrupt the fleet's normal unloading times and procedures. It is possible that with additional cooperation on the part of the vessel and/or the unloading company, an increase in the number of wells sampled per trip could be achieved without increasing the number of samplers, thereby improving CVs without directly increasing the cost of the EMP. Moreover, the scenarios presented above assume occasional collaboration with personnel from the Vice-Ministry of Aquaculture and Fisheries of Ecuador, or another entity, to provide additional assistance when logistical challenges arise, while recognizing that the entities of the CPCs qualified to conduct this type of work have their own responsibilities to fulfill, making it difficult to assign permanent personnel to the EMP. Finally, the information provided in this section is intended to serve as an input to the decision-making processes of the SAC, as part of the strategies to improve data collection and analysis for trip-level and fleet-level species catch estimates related to conservation measures for tropical tuna species. In this regard, the next section provides information on the potential additional areas of action for the EMP, within the estimated costs of the scenarios proposed above, to support of the Commission's current sampling needs related to the recommendations of the October 2023 External Review.

5. EVOLVE THE EMP TO COLLECT DATA TO BETTER SUPPORT STOCK ASSESSMENTS AND MANAGEMENT

The experience gained by the EMP provides the infrastructure and expertise to support the Commission in meeting other current sampling needs identified by the October 2023 External Review for tropical tunas, thereby improving stock assessments. Among the recommendations of the External Review, there are two data collection needs that can be addressed by the EMP within the budget of Scenario A:

1) Improve morphometric relationships (Section 16.3 of the External Review): length-weight (L-W), weight-weight (W-W), and length-length (L-L) relationships are part of the foundation of a variety of research including stock assessments, ecological risk assessments, and catch estimation. However, current L-W relationships for the tropical tuna species are outdated (YFT: 1986, BET: 1966, SKJ: 1959), and are not representative of fish captured in the current fisheries.

2) Review of the IATTC traditional port-sampling protocol in light of results obtained from analysis of EMP pilot study data (Section 4.4 of the External Review): The IATTC staff has already initiated an exploratory simulation study on the potential for improvements to the IATTC traditional port-sampling protocol (SAC-15 INF-J), using observer data. This study aims to identify areas of future research to reduce the variance, and possibly bias, on the estimated fleet-level species catch. However, high-frequency port-sampling data are required to develop the detailed components of an improved port-sampling protocol.

The IATTC staff considers that, with the budget estimated for Scenario A (US$ 404,765), the EMP would be able to:

- Sample 6 to 8 wells per trip for IVT support, with an average of 48 trips sampled per year.
- Collect morphometric and high-frequency species composition data.

Scenario A includes the continued employment of 12 samplers, 6 two-person teams, which is the minimum number required to capture trip level sampling for the IVT (6 to 8 wells sampled per trip). Sampling teams will be based in Manta, Ecuador, and therefore sampling coverage will be mainly of vessels unloading in this port. It is, however, expected that samplers will make occasional trips to Posorja, Ecuador, to sample trips unloading there.

For an additional US$ 80, 000, the collection of morphometric and high-frequency sampling data could be expanded to Mexico. This would allow for an increase in the number of samplers to 16, providing 12 samplers based in Manta, Ecuador, to cover sampling requirements related to the IVT, and 4 samplers, two 2-person teams, with one team based in Ecuador (Manta – Posorja), and one team based in México (Mazatlán), which would be dedicated to the collection of morphometric data ((1) above) and species composition sampling data for use in simulation studies ((2) above). All these components of the EMP, in Ecuador, and additional, in Mexico, would stablish a foundation that can be expanded to collect additional types of data for scientific research, including but not limited to biological data for both tuna and non-tuna species (see Unfunded Project B.3.b).

There will be some limitations on the locations where the EMP collects data. Specifically, data collection will not be possible in ports without an IATTC field office. However, opportunities may exist to reduce these data gaps by strengthening capacity-building actions with staff of local governments and/or within the private sector to collaborate in data collection, which has already been taking place with the Ecuadorian government.

6. ACKNOWLEDGMENTS

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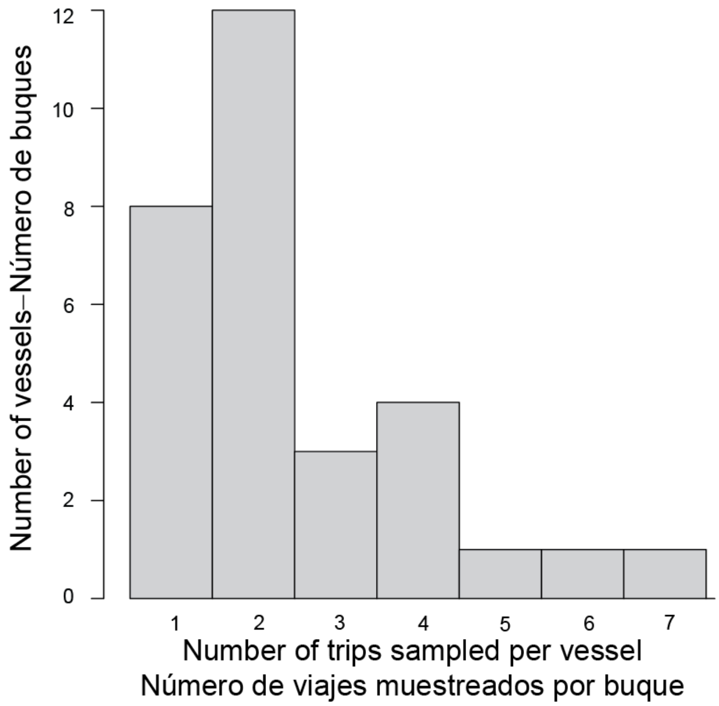

FIGURE 1. Number of trips sampled per vessel for the 75 trips sampled by the EMP in 2023.
FIGURA 1. Número de viajes muestreados por buque para los 75 viajes muestreados por el PRM en 2023.

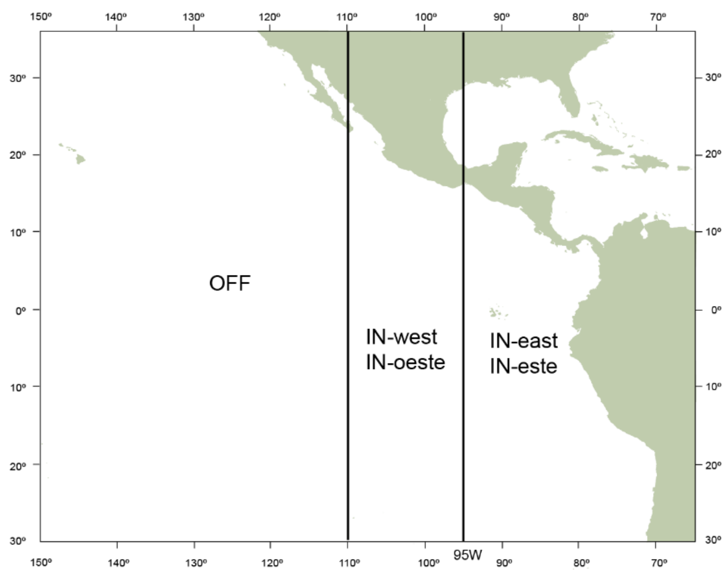

FIGURE 2. Fishing areas established by the EMP for estimates of BET catch per trip. OFF: sets made west of 110°W; OBJ IN-west: sets made between 110°W and 95°W; OBJ IN-east: sets made east of 95°W. The combination of the catch area and the set type used (NOA, OBJ or DEL) defines the strata established by the EMP.
FIGURA 2. Áreas de pesca establecidas por el PRM para las estimaciones de captura de BET por viaje. OFF: lances realizados al oeste de 110°O; OBJ IN-oeste: lances realizados entre 110°O y 95°O; OBJ IN-este: lances realizados al este de 95°O. La combinación del área de captura más el tipo de lance empleado (NOA, OBJ o DEL), definen los estratos establecidos por el PRM.

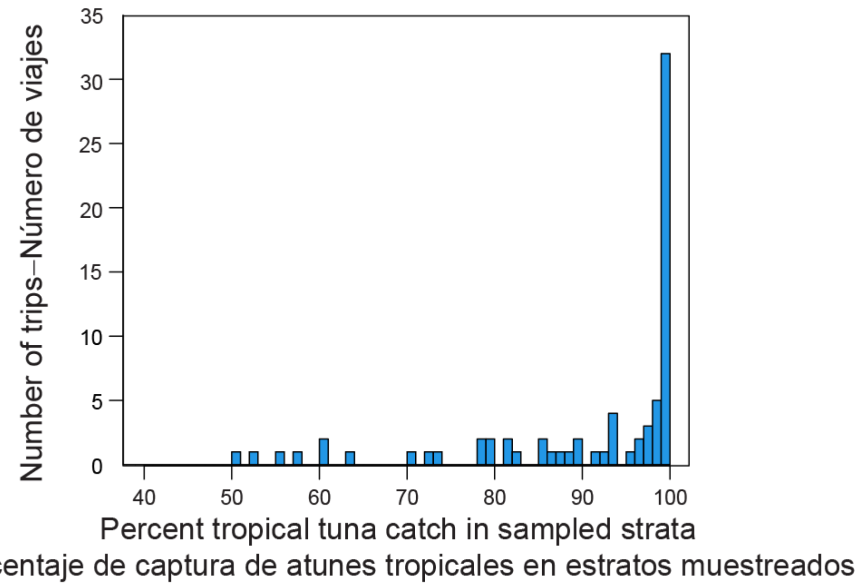

FIGURE 3. Frequency distribution of the percentage of tropical tuna catch of a trip that was present in the EMP-sampled strata for the trip (tropical tuna catch obtained from sets made outside the EPO is not considered in this figure; wells with catch from outside the EPO were not sampled by the EMP and did not factor into the EMP estimation). Not included are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 3. Distribución de frecuencia del porcentaje de captura de atunes tropicales, por viaje, presente en los estratos muestreados por el PRM (la captura de atunes tropicales obtenida de lances realizados fuera del OPO no fue considerada en esta figura, bodegas con capturas realizadas fuera del OPO no fueron muestreadas y por tanto no fueron un factor en las estimaciones del PRM). No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

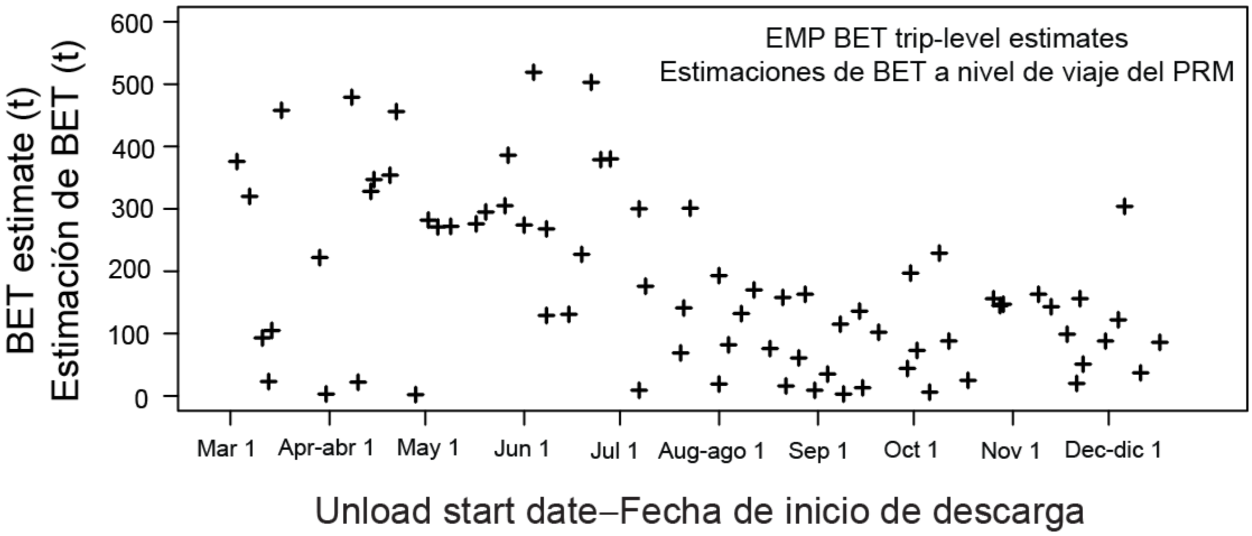

FIGURE 4. Trip-level estimates of BET catch (in metric tons), ordered according to the date of catch unloading in port, between March and December 2023. Every cross symbol represents an individual trip. For any trip with strata that were not sampled by the EMP, the RDL estimate of BET, by stratum, was added to the EMP estimates for sampled strata to obtain the trip estimate. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 4. Estimaciones de captura de BET a nivel de viaje (en toneladas métricas), ordenadas de acuerdo con la fecha de descarga en puerto, entre marzo y diciembre de 2023. Cada símbolo de cruz representa un viaje individual. Para cada viaje con estratos que no fueron muestreados por el PRM, la estimación de BET del RDL, por estrato, fue incluido a la estimación de estratos muestreados por el PRM para obtener la estimación a nivel de viaje. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

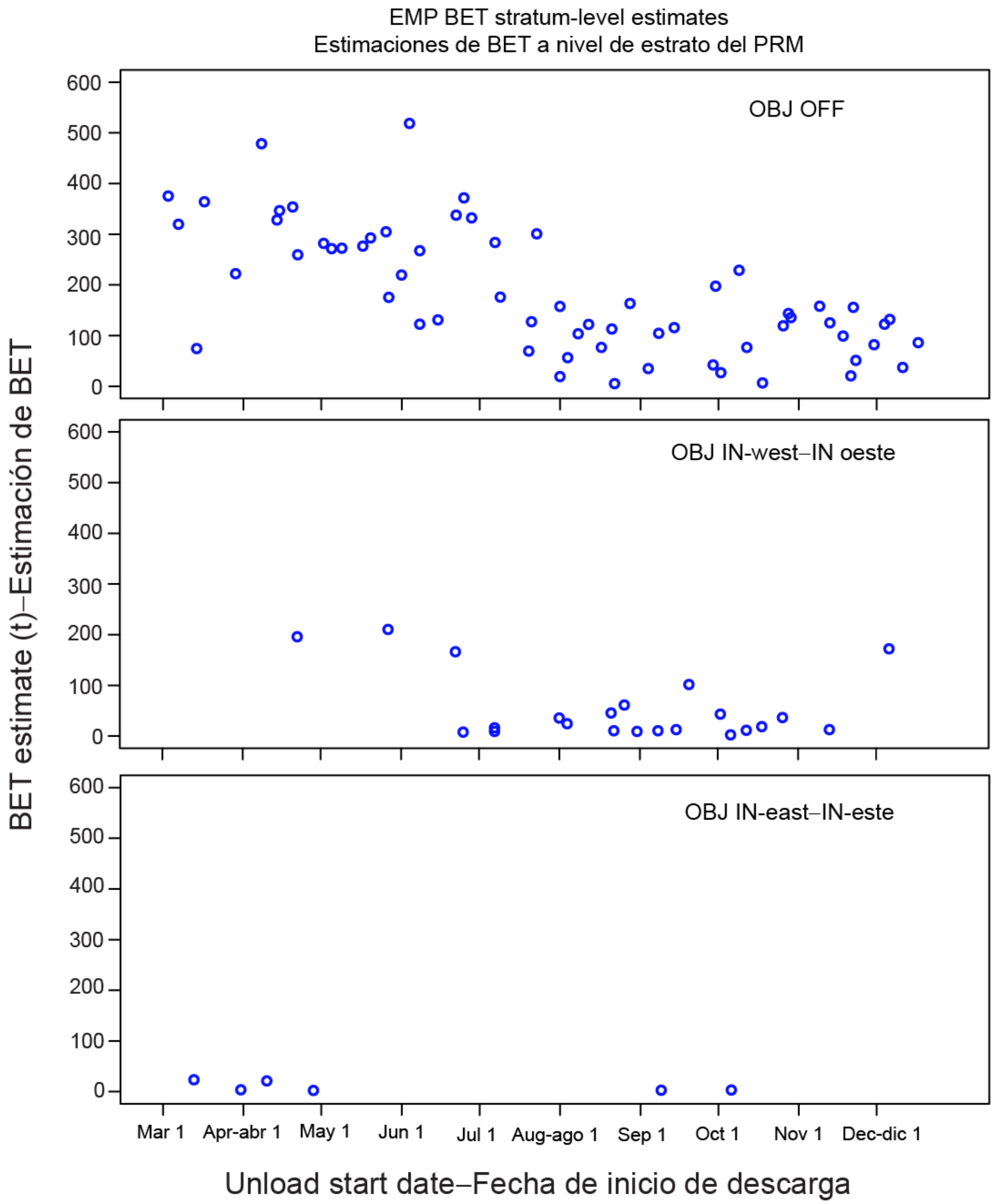

FIGURE 5. BET catch estimates (in metric tons) by sampled stratum. Each open blue circle represents one sampled trip. A trip may be represented in one or more panels, depending on whether one or more strata were sampled for the same trip. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 5. Estimaciones de captura de BET (en toneladas métricas) por estrato muestreado. Cada círculo azul hueco representa un viaje muestreado. Un viaje puede estar representado en una o más paneles, dependiendo de si uno o más estratos fueron muestreados para un mismo viaje. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

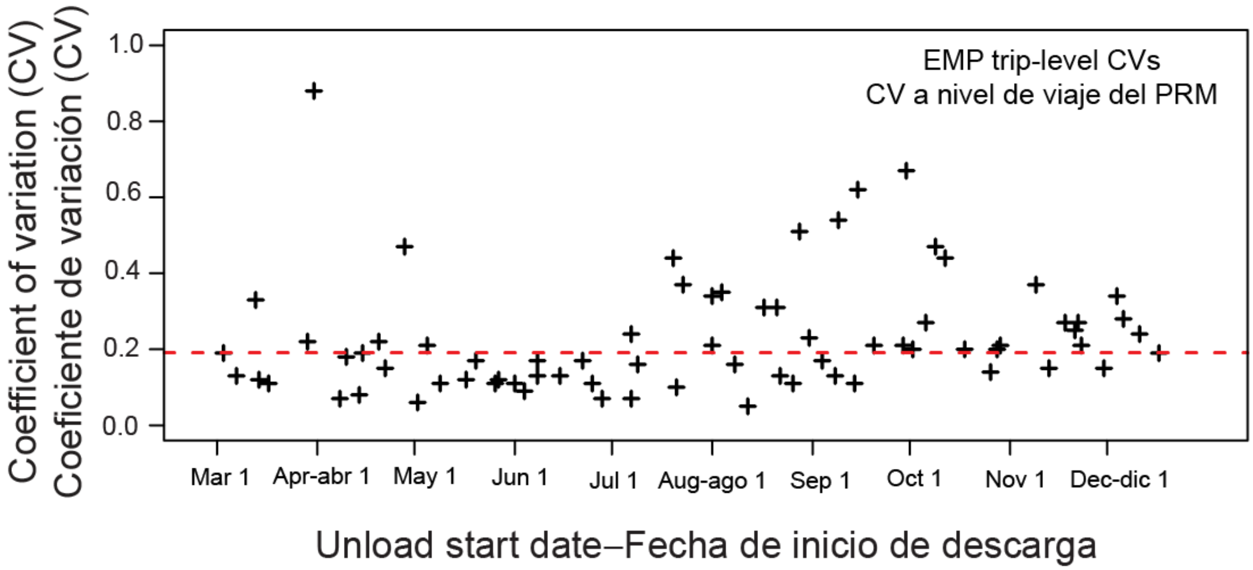

FIGURE 6. Coefficient of variation (CV) of BET catch estimates per trip sampled between March and December 2023. Each cross symbol represents a sampled trip. The red dashed line indicates the overall median CV value of 0.19. For trips where not all strata could be sampled, an approximation of the variance for each stratum that was not sampled was obtained using the method described in Appendix B. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 6. Coeficiente de variación (CV) de las estimaciones de captura de BET por viaje muestreado entre marzo y diciembre de 2023. Cada símbolo de cruz representa un viaje muestreado. La línea discontinua roja indica el valor mediano global de CV de 0.19. Para aquellos viajes en donde no todos los estratos pudieron ser muestreados, una aproximación de la varianza para cada estrato que no fue muestreado fue obtenida usando el método descrito en el apéndice B. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

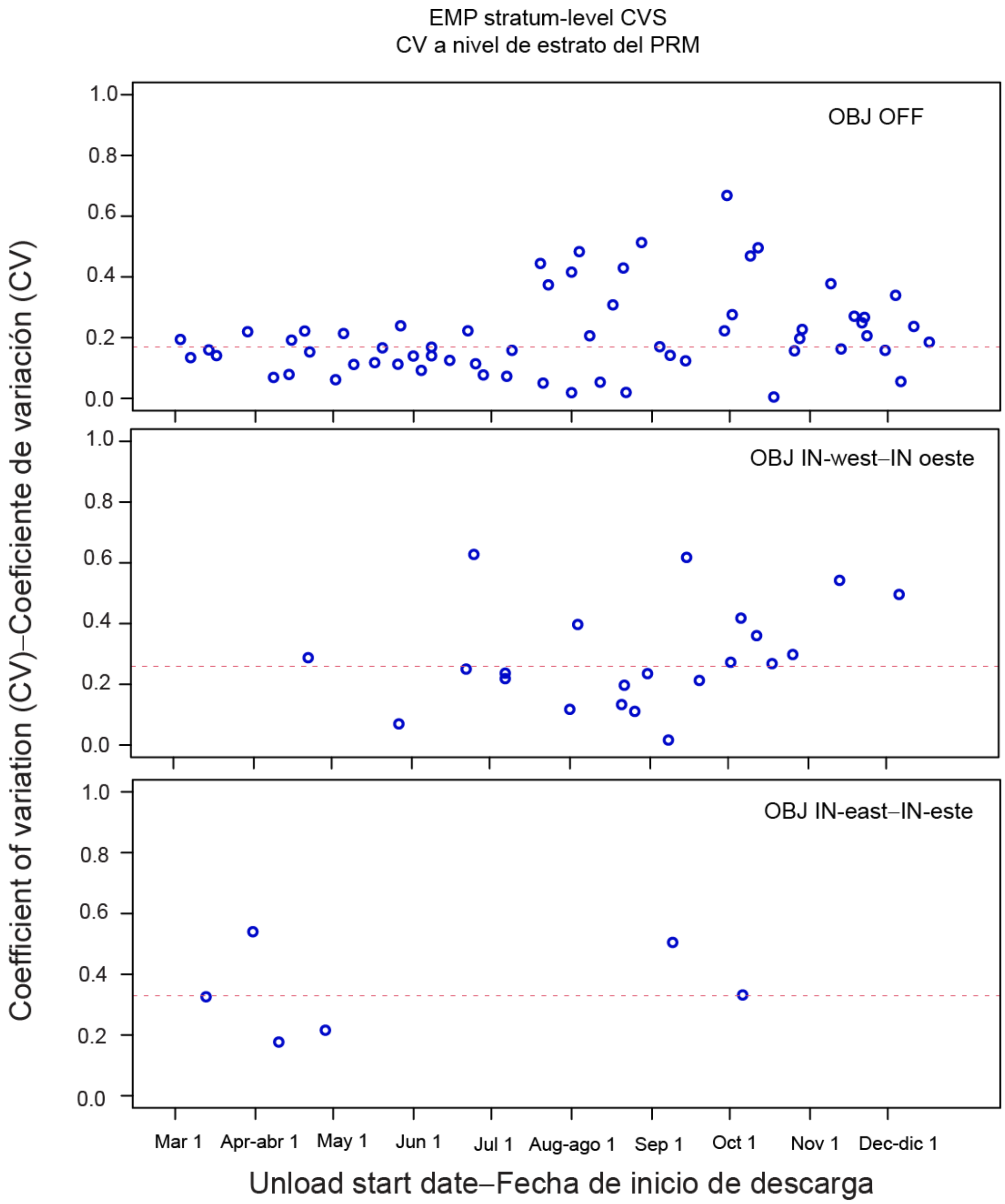

FIGURE 7. Coefficients of variation (CV) of BET catch estimates per catch stratum sampled. Each open blue circle represents a trip. A trip may be represented in one or more panels, depending on whether one or more strata were sampled for the same trip. The red dashed lines indicate the overall median CVs, by stratum; 0.17 for OBJ OFF; 0.26 for OBJ In-west; and, 0.33 for OBJ IN-east. These stratum-level CVs were estimated exclusively for EMP data. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level EMP catch estimates with EMP data.

FIGURA 7. Coeficientes de variación (CV) de las estimaciones de captura de BET por estrato de captura muestreado. Cada círculo azul hueco representa un viaje muestreado. Un viaje puede estar representado en uno o más paneles, dependiendo de si uno o más estratos fueron muestreados para un mismo viaje. La línea discontinua roja indica el valor mediano global de los CV, por estrato: 0.17 para OBJ OFF; 0.26 para OBJ In-oeste; y, 0.33 para OBJ IN-este. Estos CV a nivel de estrato fueron estimados exclusivamente para datos del PRM. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

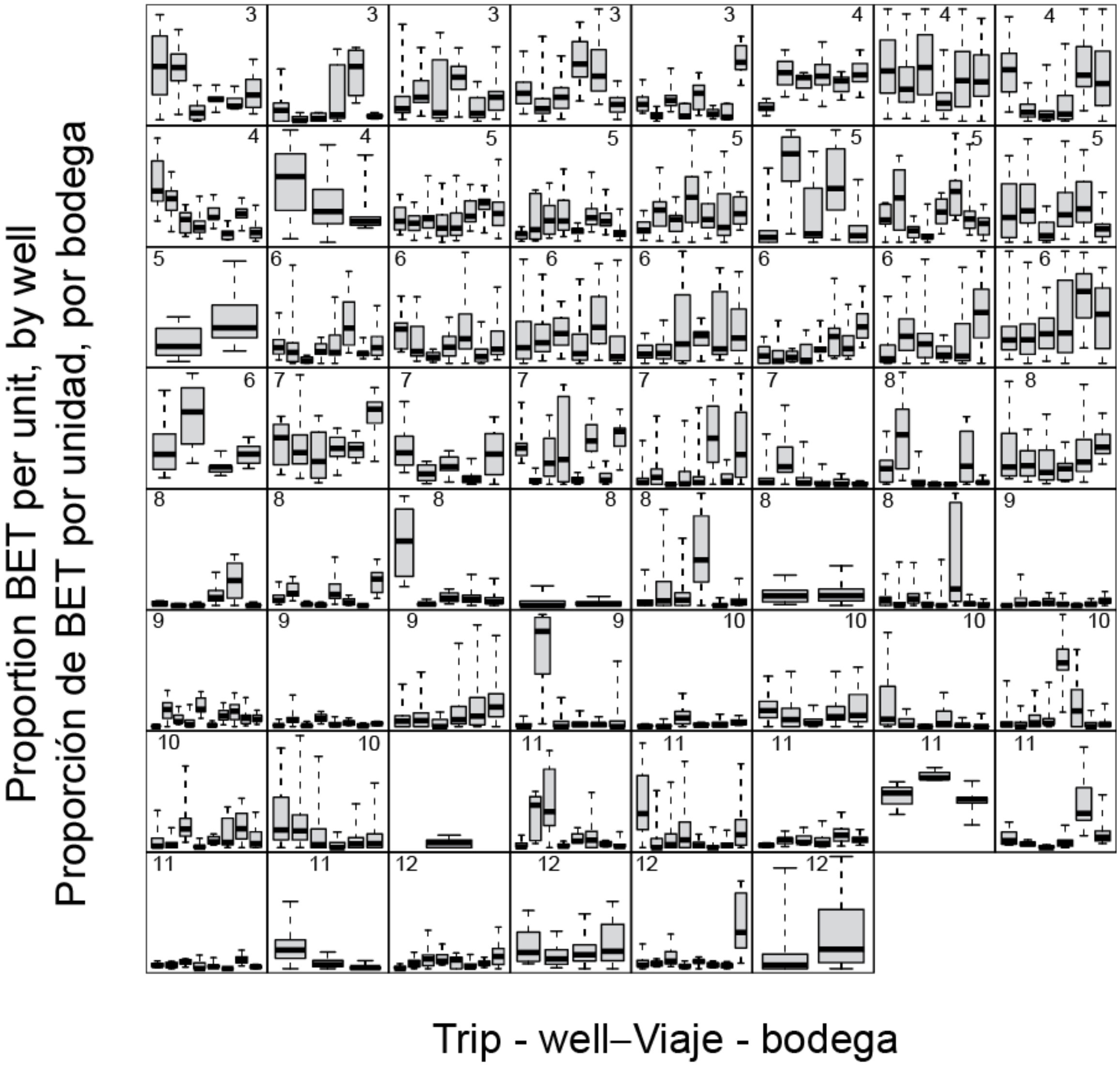

FIGURE 8. Box-and-whisker plots of the proportion of BET per unit, for wells with catches from the OBJ OFF stratum. Each panel represents a trip sampled between March and December 2023; the month in which the catch of the trip was unloaded is shown at the top of each panel. Each box-and-whisker plot represents a sampled well; the horizontal black bar shows the median proportion of BET per unit for the well, the gray box represents the middle 50% of the unit values for the well, and the whiskers extend to the extremes. The ranges of the x and y axes are the same for all panels (values between 0 and 1).
FIGURA 8. Gráficas de cajas y bigotes de la proporción de BET por unidad, para bodegas con capturas del estrato OBJ OFF. Cada panel representa un viaje muestreado entre marzo y diciembre de 2023, con el mes en el que se descargó la captura del viaje se muestra en la parte superior de cada panel. Cada gráfica de cajas y bigotes representa una bodega muestreada; la barra negra horizontal muestra la proporción mediana de BET por unidad para la bodega, la caja gris representa el 50% medio de los valores de la unidad para la bodega, y los bigotes se extienden hasta los extremos. Los rangos de los ejes ‘x’ y ‘y’ son los mismos para todos los paneles (tomando valores de entre 0 y 1).

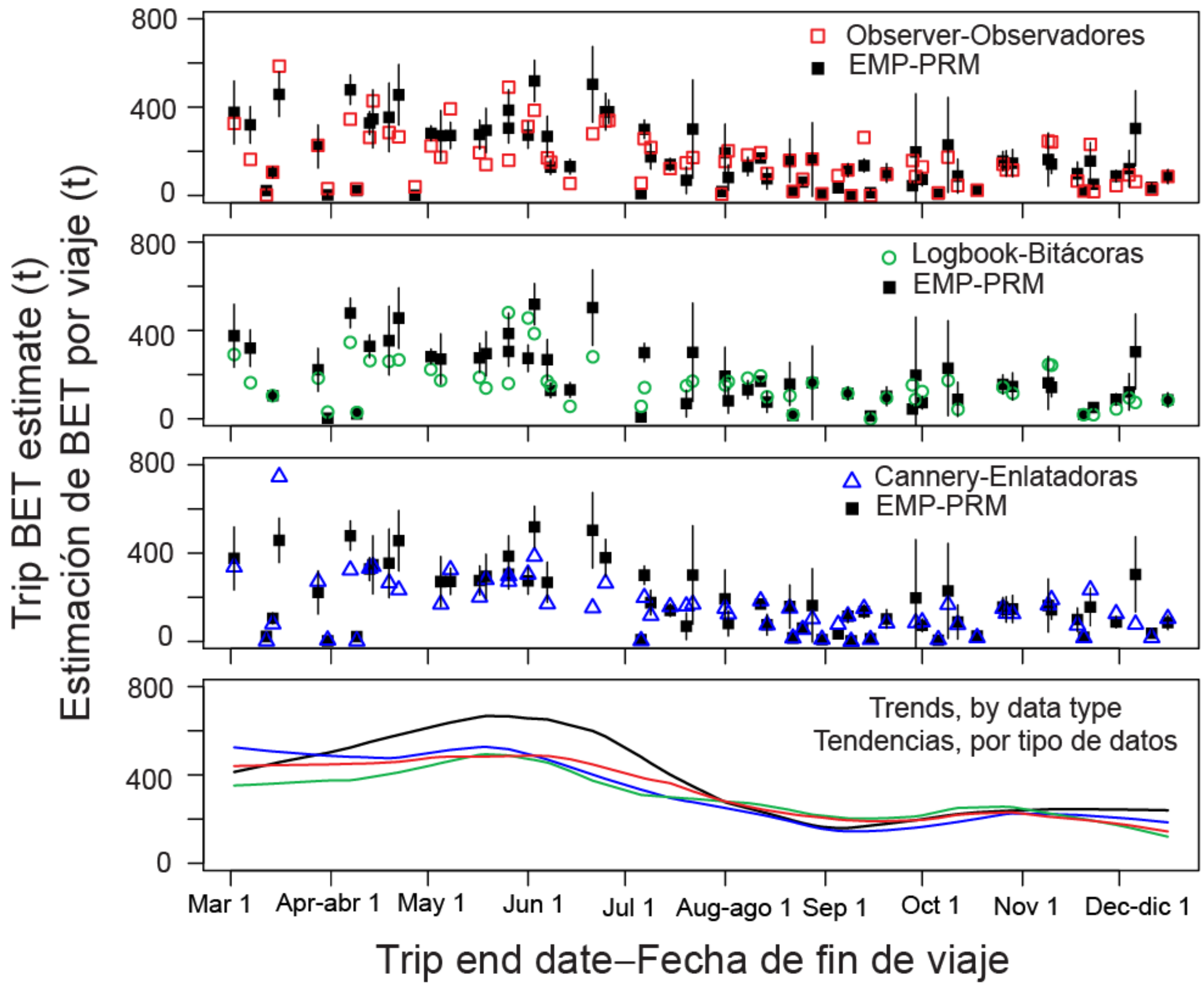

FIGURE 9. Estimated BET catch (in metric tons), by trip, for the EMP (black filled squares; vertical bars are the 95% confidence intervals), along with estimates from other data sources: observer (RDL; open red squares), first panel; logbook (open green circles), second panel; and, cannery (open blue triangles), third panel. The bottom panel shows a smoothed curve for the estimates from each data source to facility comparison of the large-scale patterns. The smooth curves were computed using a LOESS with a span of 1/3 and a degree of 1. The number of trips shown per panel differs, due to availability of the other data sources; top panel: 73 trips; middle panel: 52 trips; bottom panel: 62 trips. Not shown in any panel are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 9. Estimación de captura de BET (en toneladas métricas), por viaje, para el PRM (cuadrados negros; las barras verticales son los intervalos de confianza del 95%), junto con las estimaciones de las otras fuentes de datos: observadores (RDL; cuadrados rojos huecos), primer panel; bitácoras (círculos verdes huecos), segundo panel; y enlatadoras (triángulos azules huecos), tercer panel. El panel inferior muestra una curva suavizada de las estimaciones de cada fuente de datos para facilitar la comparación de los patrones a gran escala. Las curvas suavizadas se calcularon utilizando LOESS con un intervalo de 1/3 y un grado de 1. El número de viajes mostrado por panel difiere debido a la disponibilidad de las otras fuentes de datos: panel superior, 73 viajes; panel central, 52 viajes; panel inferior, 62 viajes. No se incluyen en ningún panel los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

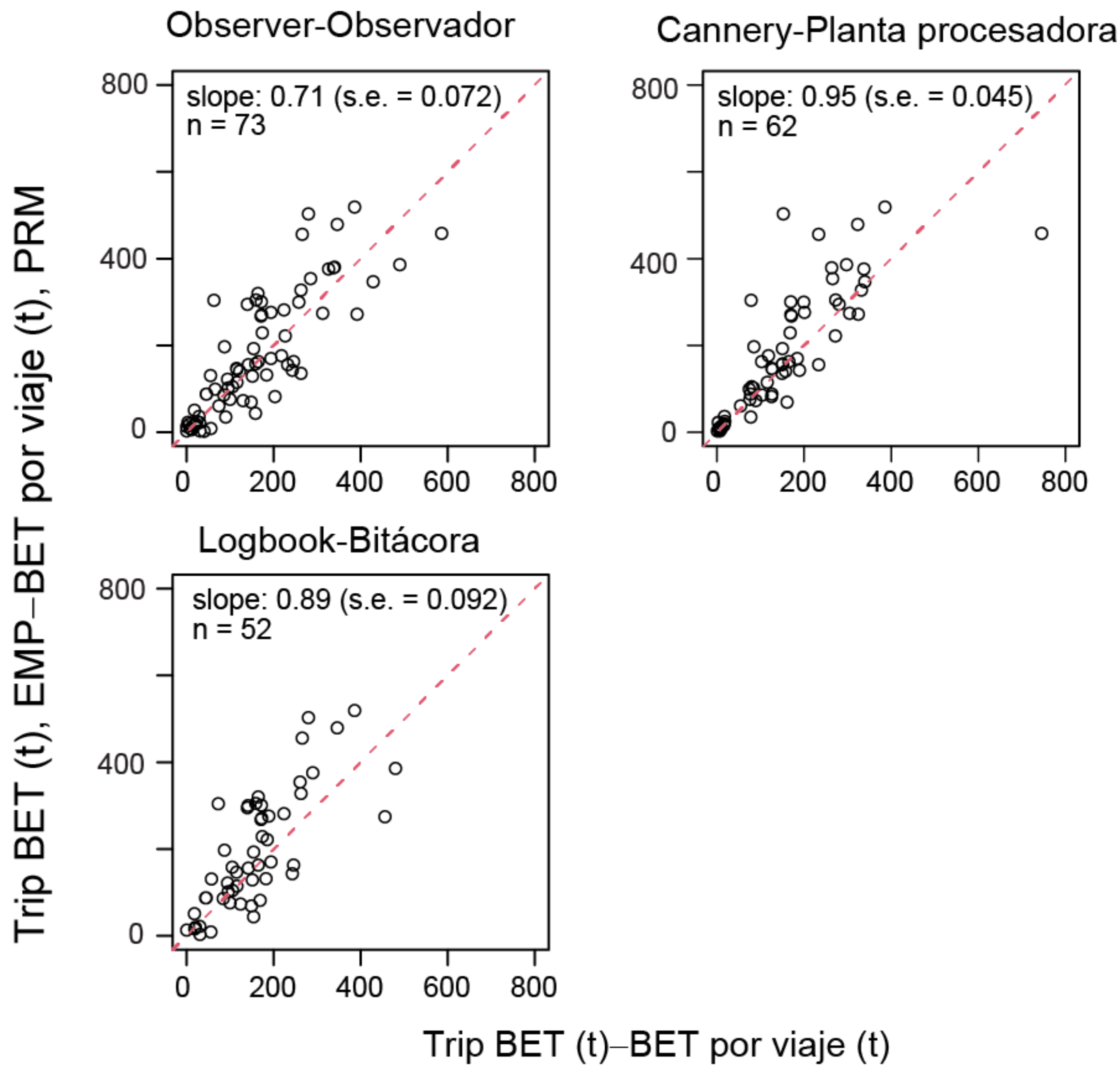

FIGURE 10. BET catch estimates (in metric tons), by trip, from the EMP versus estimates from the other three data sources, where available (observer: upper left; cannery: upper right; logbook: lower left). Each open circle is an individual trip. “slope”: slope estimate for the relationship (based on weighted least squares, with variance on the EMP estimates used as weights). “s.e.”: standard error on the estimated slope. “n”: number of trips shown in each plot. The red dashed line is the 1-to-1 line. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 10. Estimaciones de captura de BET (en toneladas métricas), por viaje, del PRM versus estimaciones de las otras tres fuentes de datos, conforme a su disponibilidad (observador: superior izquierdo; planta procesadora: superior derecho; bitácora: inferior izquierdo). Cada círculo hueco es un viaje individual. “pendiente”: pendiente estimada para la relación (basado en mínimos cuadrados ponderados, con la varianza de la estimaciones del PRM utilizada como peso). “s.e.”: error estándar de la pendiente estimada. “n”: número de viajes mostrados en cada gráfico. La línea discontinua roja es la línea 1 a 1. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

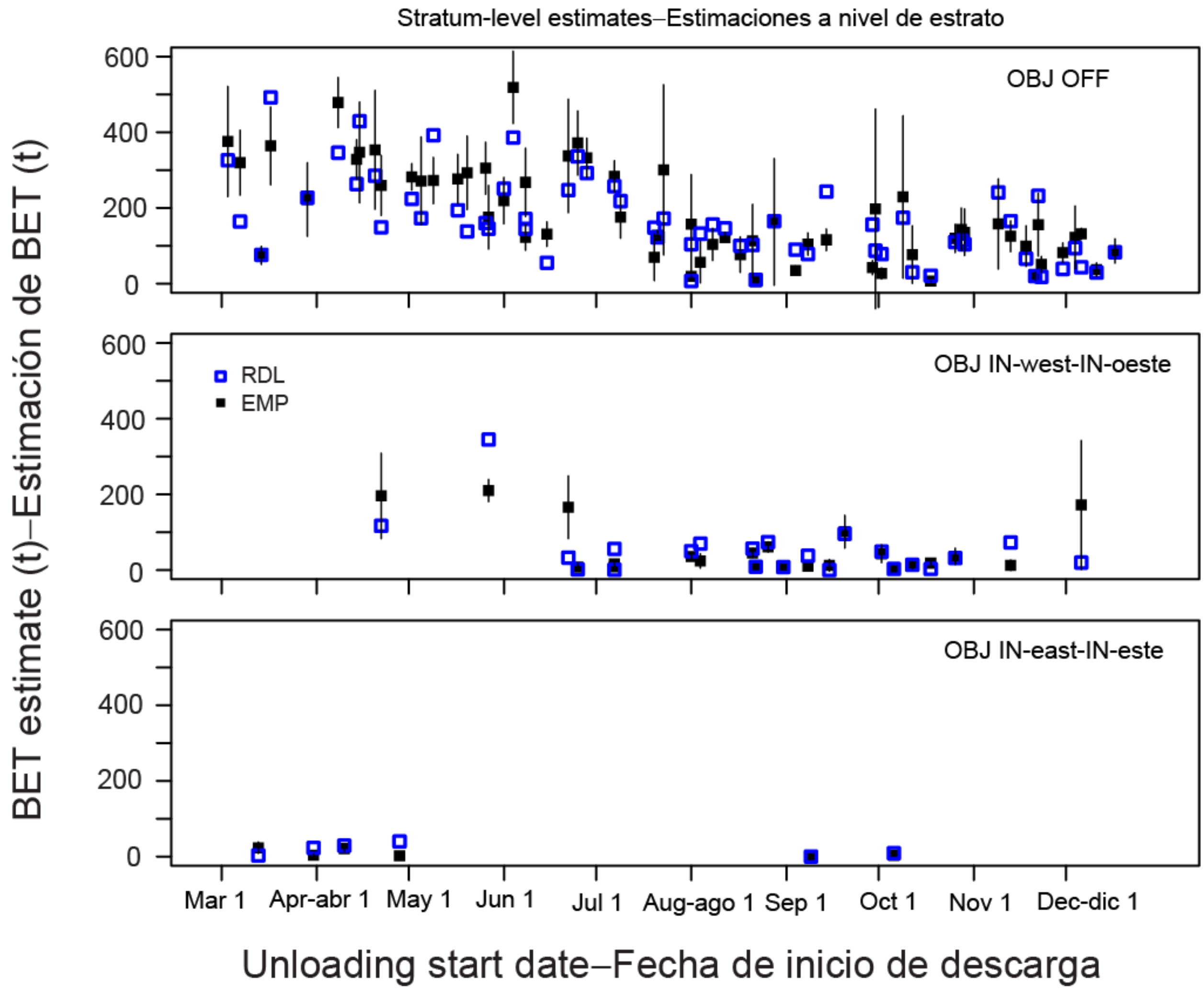

FIGURE 11. BET stratum-level catch estimates (in metric tons) for the three main strata, for EMP and observer (RDL). EMP estimates with 95% confidence interval are represented by filled black squares and vertical lines, respectively, and RDL estimates are represented by open blue squares. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 11. Estimaciones de captura de BET a nivel de estrato (en toneladas métricas) para los tres principales estratos, para el PRM y el RDL. Las estimaciones del PRM con el 95% de intervalo de confianza están representadas por los cuadros negros y la línea vertical, respectivamente, y las estimaciones del RDL están representadas por los cuadros azules huecos. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

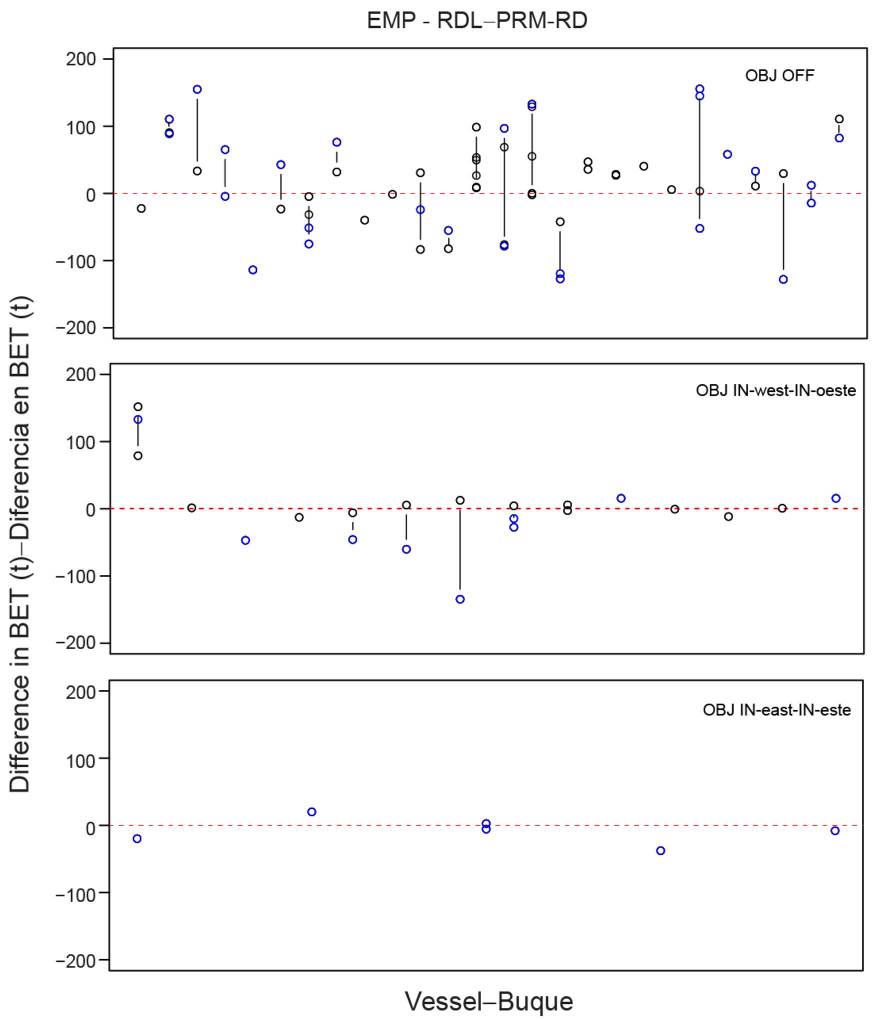

FIGURE 12. Differences in EMP and RDL stratum-level catch estimates (EMP – RDL; in metric tons), by trip, grouped by vessel. Each open circle is the difference in stratum-level estimates from the two data sources for a trip; trips are grouped by vessel (a black vertical line connects stratum-level differences of those trips from the same vessel). Open blue circles represent stratum-level estimates for which the RDL estimate was outside the 95% confidence interval on the EMP estimate. The red dashed lines indicate a difference value of 0 t. If the same vessel appears in more than one panel, it is not necessarily in the same position along the x-axis. Not shown are the data of two trips (out of 75) for which it was not possible to make any stratum-level catch estimates with EMP data.

FIGURA 12. Diferencias en las estimaciones de captura a nivel de estrato del PRM y el RDL (PRM – RDL; en toneladas métricas), por viaje, agrupadas por buque y estrato. Cada círculo hueco es la diferencia en las estimaciones a nivel de estrato de las dos fuentes de datos para un viaje; los viajes están agrupados por buque (una línea vertical negra conecta las diferencias a nivel de estrato de aquellos viajes del mismo buque). Los círculos azules huecos representan estimaciones a nivel de estrato para las que la estimación del RDL estuvo fuera del 95% de intervalo de confianza de la estimación del PRM. Las líneas discontinuas rojas indican un valor de diferencia de 0 t. Si el mismo buque está presente en más de un panel, no es necesariamente en la misma ubicación a lo largo del eje x. No se incluyen los datos de dos viajes (del total de 75) para los que no fue posible realizar estimaciones de captura a nivel de estrato con los datos del PRM.

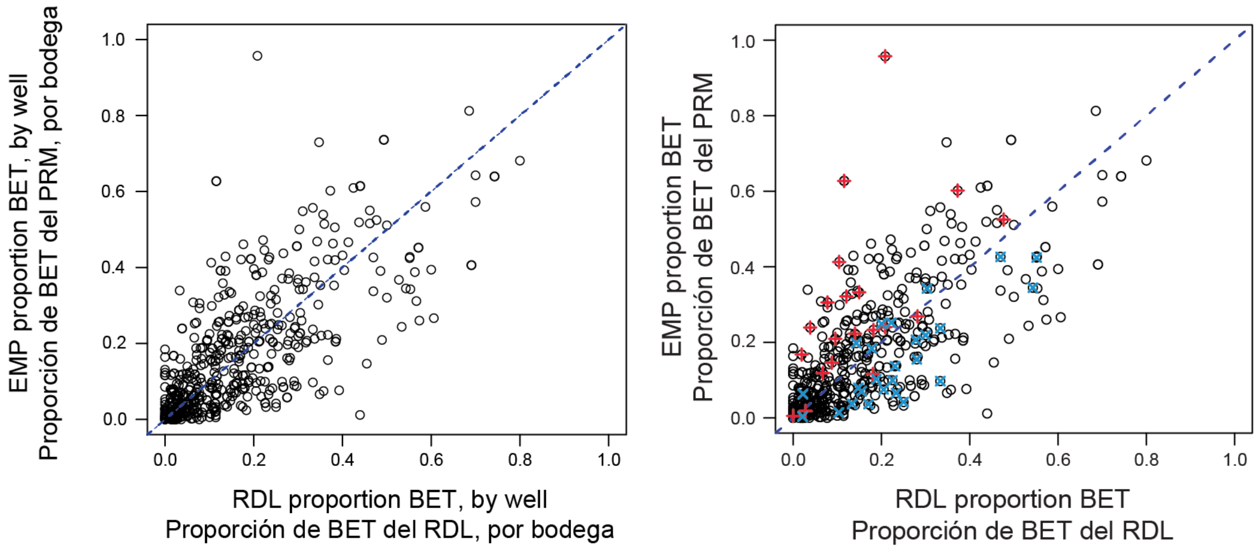

FIGURE 13. Comparison of EMP and RDL well-level estimates of the proportion of BET. Each open circle represents an individual well. The two figures show the same estimates, but in the figure on the right, estimates for several vessels have been highlighted to illustrate vessel-specific patterns. The red and blue crosses represent two different vessels, where for the wells of the vessel shown in red, the EMP estimates mostly higher than those of the RDL, and for wells of the vessel shown in blue the RDL estimates were mostly higher than those of the EMP.

FIGURA 13. Comparación PRM – RDL de las estimaciones a nivel de bodega de la proporción de BET (cada círculo hueco representa una bodega individual. Las dos figuras muestran las mismas estimaciones, pero en la figura de la derecha, las estimaciones para varios buques han sido resaltadas para ilustrar patrones específicos por buque. Las cruces rojas y azules representan dos buques diferentes, donde para las bodegas del buque que se muestra en rojo, las estimaciones del PRM fueron en su mayoría mayores que las del RDL, y para las bodegas del buque que se muestra en azul las estimaciones del RDL fueron en su mayoría mayores que las del PRM.

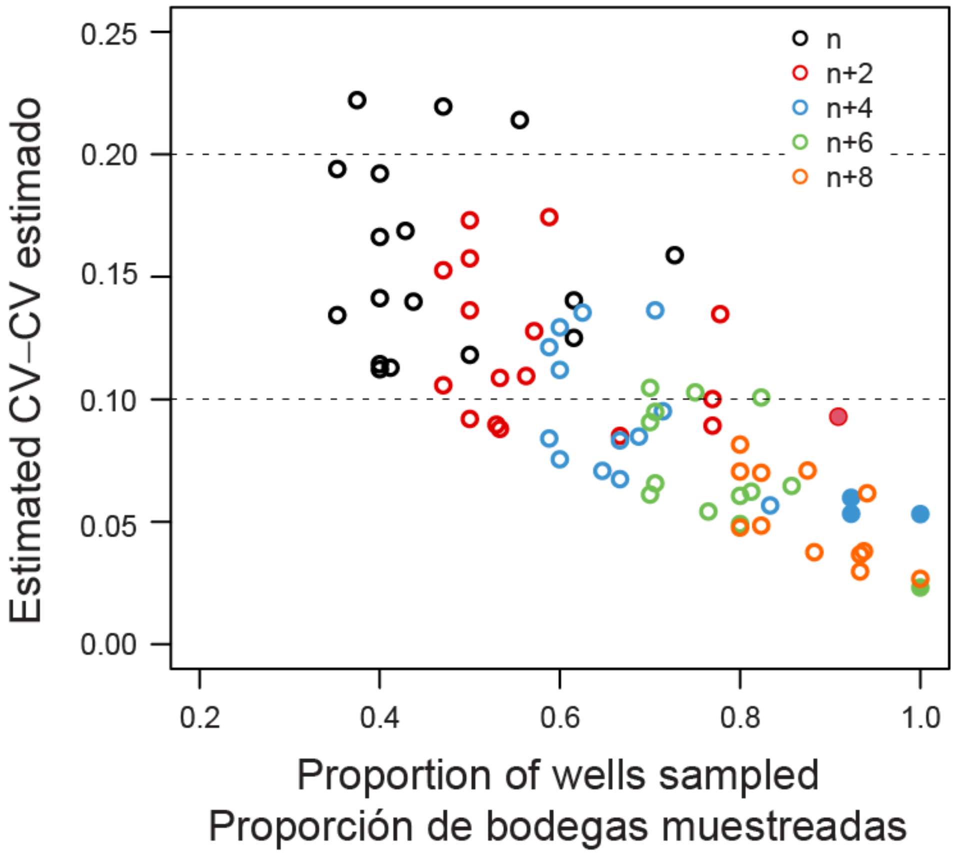

FIGURE 14. Estimated CVs at different hypothetical numbers of wells sampled for BET catch by trip, OBJ OFF stratum, for the early period (trips unloading prior to July 16, 2023). ‘n’: original number of wells sampled for the trip in this stratum. Black open circles: original CV; red open circles: original number of wells + 2; blue open circles: original number of wells + 4; green open circles: original number of wells + 6; open orange circles: original number of wells + 8. Filled circles indicate trips with CVs that could not be improved further in the simulation because at the step indicated by the color of the filled circle, almost all wells of the stratum were already sampled (e.g. if there were 9 total wells with catch from OBJ OFF for a trip, and 6 of those wells were originally sampled, then a change in CV could be simulated for n+2 wells, i.e. 7 out of 9 wells sampled, but not n+4 since that would imply sampling 10 out of 9 wells).

FIGURA 14. CV estimados con diferentes números hipotéticos de bodegas muestreadas para la captura de BET por viaje, estrato OBJ OFF, para el periodo temprano (viajes descargando antes del 16 de julio de 2023). ‘n’: número original de bodegas muestreadas para el viaje en este estrato. Círculos negros: CV original; círculos rojos: número original de bodegas + 2; círculos azules: número original de bodegas + 4; círculos verdes: número original de bodegas + 6; círculos anaranjados: número original de bodegas + 8. Los círculos rellenos indican viajes con CV que no pudieron mejorarse más en la simulación porque en el paso indicado por el color del círculo relleno, casi todas las bodegas del estrato ya estaban muestreadas (por ejemplo, si había 9 bodegas totales con captura de OBJ OFF para un viaje, y 6 de esas bodegas estaban muestreadas originalmente, entonces podría simularse un cambio en el CV para n+2 bodegas, es decir, 7 de 9 bodegas muestreadas, pero no n+4 ya que eso implicaría muestrear 10 de 9 bodegas).

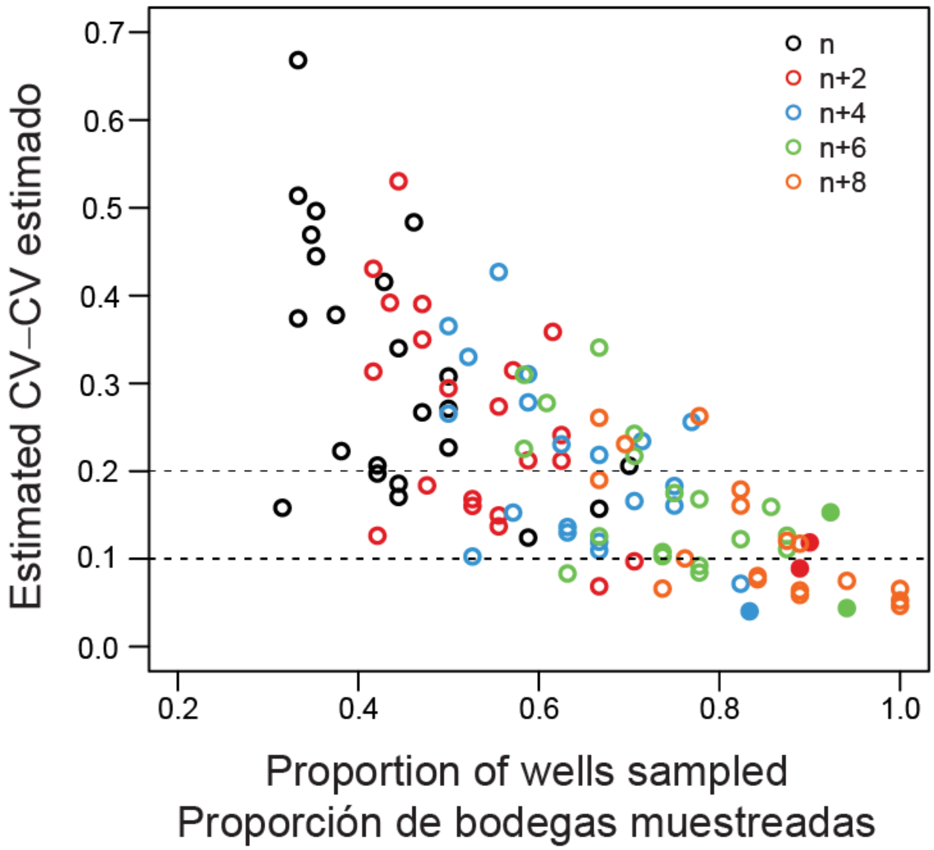

FIGURE 15. Estimated CVs at different hypothetical numbers of wells sampled for BET catch by trip, OBJ OFF stratum, for the late period (trips unloading after July 15, 2023). 'n': original number of wells sampled for the trip in this stratum. Black open circles: original CV; red open circles: original number of wells + 2; blue open circles: original number of wells + 4; green open circles: original number of wells + 6; orange open circles: original number of wells + 8. Filled circles indicate trips with CVs that could not be improved further in the simulation because at step indicated by the color of the filled circle, almost all wells of the stratum were already sampled (e.g. if there were 9 total wells with catch from OBJ OFF for a trip, and 6 of those wells were originally sampled, then a change in CV could be simulated for n+2 wells, i.e. 7 out of 9 wells sampled, but not n+4 since that would imply sampling 10 out of 9 wells).

FIGURA 15. CV estimados con diferentes números hipotéticos de bodegas muestreadas para la captura de BET por viaje, estrato OBJ OFF, para el periodo tardío (viajes descargando después del 16 de julio de 2023). 'n': número original de bodegas muestreadas para el viaje en este estrato. Círculos negros: CV original; círculos rojos: número original de bodegas + 2; círculos azules: número original de bodegas + 4; círculos verdes: número original de bodegas + 6; círculos anaranjados: número original de bodegas + 8. Los círculos rellenos indican viajes con CV que no pudieron mejorarse más en la simulación porque en el paso indicado por el color del círculo relleno, casi todas las bodegas del estrato ya estaban muestreadas (por ejemplo, si había 9 bodegas totales con captura de OBJ OFF para un viaje, y 6 de esas bodegas estaban muestreadas originalmente, entonces podría simularse un cambio en el CV para n+2 bodegas, es decir, 7 de 9 bodegas muestreadas, pero no n+4 ya que eso implicaría muestrear 10 de 9 bodegas).

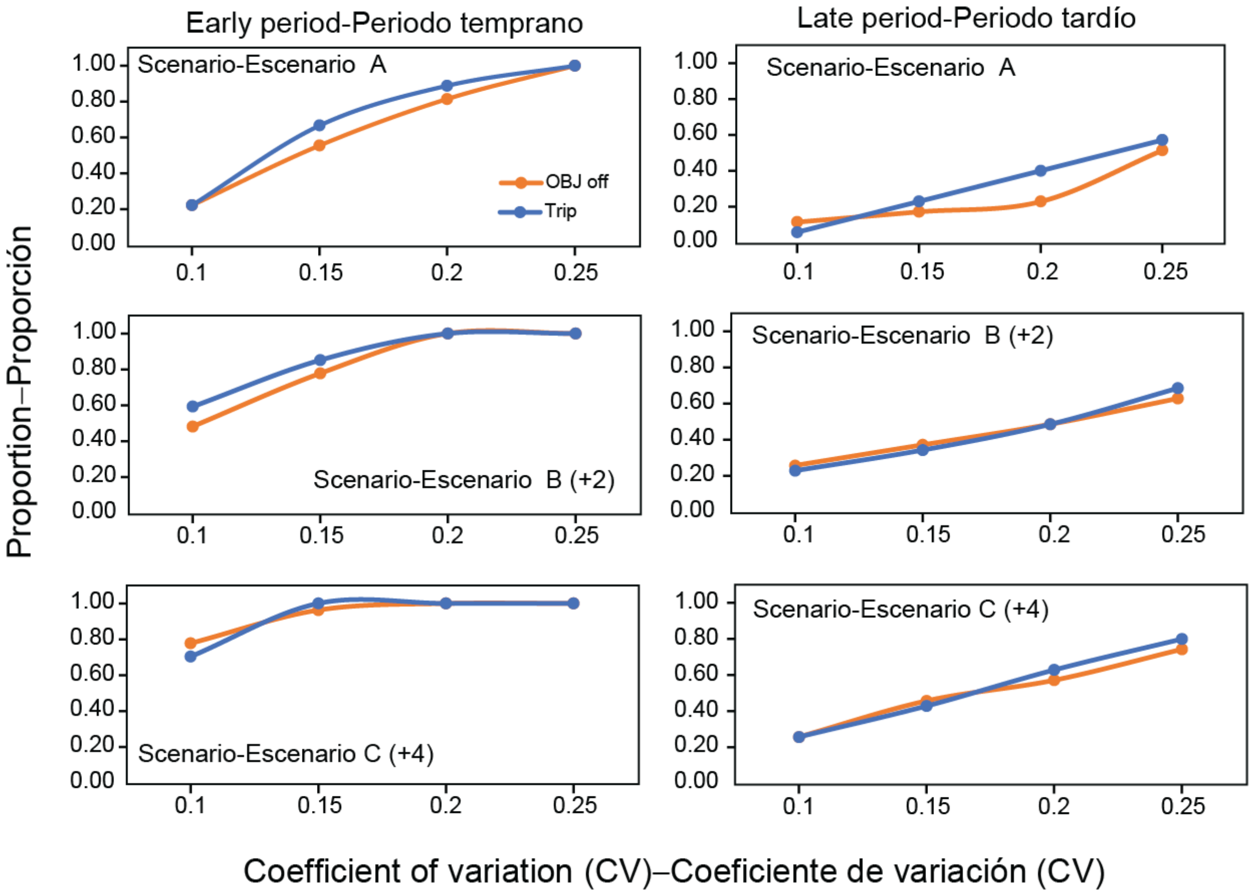

FIGURE 16. Summary of the results of the simulation study conducted for the cost-benefit analysis, with the proportion of all trips sampled by the EMP in 2023 with catch from the OBJ OFF stratum for which the stratum CVs (orange line) and trip CVs (blue line) were below 0.10, 0.15, 0.20 and 0.25. The figures on the left show the results for the early period and the figures on the right show the summary of the simulation results for the late period. For each period, results are presented for three scenarios: scenario A, original CVs obtained by the EMP in 2023; scenario B: simulation of results with two additional wells sampled per trip; scenario C: simulation of results with four additional wells sampled per trip.

FIGURA 16. Resumen de resultados del estudio de simulación realizado para el análisis costo-beneficio, con la proporción de todos los viajes muestreados por el PRM en 2023 con captura en el estrato OBJ OFF para los que los CV del estrato (línea naranja) y CV del viaje (línea azul) estaban por debajo de 0.10, 0.15, 0.20 y 0.25. Las figuras en la izquierda presentan los resultados para el periodo temprano y las figuras de la derecha presentan el resumen de resultados de la simulación para el periodo tardío. Para cada periodo se presentan los resultados en tres escenarios; escenario A: CV originales obtenidos por el PRM en 2023; escenario B: simulación de resultados con el muestreo de 2 bodegas adicionales por viaje; escenario C: simulación de resultados con el muestreo de 4 bodegas adicionales por viaje.

TABLE 1. Information available by trip from the main data sources (logbook, processing plant and observer) for trips made in 2023 by Class 4-6 vessels (as of 15 January 2024).

TABLA 1. Información disponible por viaje de las fuentes de datos primaria (bitácora de pesca, planta procesadora y observador) de los viajes realizados en 2023 por buques clase 4, 5 y 6 (al 15 de enero del 2024).

Vessel class	2023 trips	Logbook		Plant		Observer	
		Trips	%	Trips	%	Trips	%
4	159	148	93%	16	10%	53	33%
5	148	129	87%	25	17%	105	71%
6	926	586	63%	308	33%	926	100%
TOTAL	1233	863	70%	349	28%	1084	88%

TABLE 2. Cost-benefit analysis. Summary of the results of the simulation study conducted, with the proportion of all trips sampled by the EMP in 2023, with catch from the OBJ OFF stratum, with CVs below 0.10, 0.15, 0.20 and 0.25. For scenario A: original CVs obtained by the EMP in 2023; scenario B: simulation of results with two additional wells sampled per trip; scenario C: simulation of results with four additional wells sampled per trip.
TABLA 2. Análisis costo-beneficio. Resumen de resultados del estudio de simulación realizado, con la proporción de todos los viajes muestreados por el PRM en 2023, con captura en el estrato OBJ OFF, con CV por debajo de 0.10, 0.15, 0.20 y 0.25; para el escenario A: CV originales obtenidos por el PRM en 2023; escenario B: simulación de resultados con el muestreo de 2 bodegas adicionales por viaje; escenario C: simulación de resultados con el muestreo de 4 bodegas adicionales por viaje.

Early period									
Scenario	**Wells per trip**	**Proportion below target CV**							
		OBJ OFF				**Trip**			
		0.1	**0.15**	**0.2**	**0.25**	**0.1**	**0.15**	**0.2**	**0.25**
A	6 to 8	0.22	0.56	0.81	1.00	0.22	0.67	0.89	1.00
B (+2)	8 to 10	0.48	0.78	1.00	1.00	0.59	0.85	1.00	1.00
C (+4)	10 to 12	0.78	0.96	1.00	1.00	0.70	1.00	1.00	1.00
Late period									
Scenario	**Wells per trip**	**Proportion below target CV**							
		OBJ OFF				**Trip**			
		0.1	**0.15**	**0.2**	**0.25**	**0.1**	**0.15**	**0.2**	**0.25**
A	6 to 8	0.11	0.17	0.23	0.51	0.06	0.23	0.40	0.57
B (+2)	8 to 10	0.26	0.37	0.49	0.63	0.23	0.34	0.49	0.69
C (+4)	10 to 12	0.26	0.46	0.57	0.74	0.26	0.43	0.63	0.80

TABLE 3. Cost-benefit analysis, presentation of estimated costs by scenarios of coverage of wells sampled per trip (Table 2). For the cost estimation, an average of four sampled trips per month was considered, based on EMP activities in the port of Manta in 2023.
TABLA 3. Análisis costo-beneficio, presentación de costos estimados por escenarios de cobertura de bodegas muestreadas por viaje (Tabla 2). Para la estimación de costos se ha considerado un promedio de 4 viajes muestreados por mes, basado en las actividades del PRM en el puerto de Manta en 2023.

Scenario	**Wells per trip**	**Sampling teams**	**Logistics costs**		**Administrative costs**		**Total costs**	
			Trip	**Year**	**Trip**	**Year**	**Trip**	**Year**
A	6 to 8	6	$ 4,993.76	$239,700.36	$ 3,438.79	$ 165,062.08	$ 8,432.55	$ 404,762.44
B (+2)	8 to 10	8	$ 6,611.69	$317,361.04	$ 3,438.79	$ 165,062.08	$ 10,050.48	$ 482,423.12
C (+4)	10 to 12	10	$ 8,356.22	$401,098.72	$ 3,438.79	$ 165,062.08	$ 11,795.02	$ 566,160.80

APPENDIX A.

Examples of patterns in well-level estimates of the proportion of BET, EMP versus RDL, by vessel, pooled over trips (Figure A-1), and by-trip for several vessels (Figure A-2).

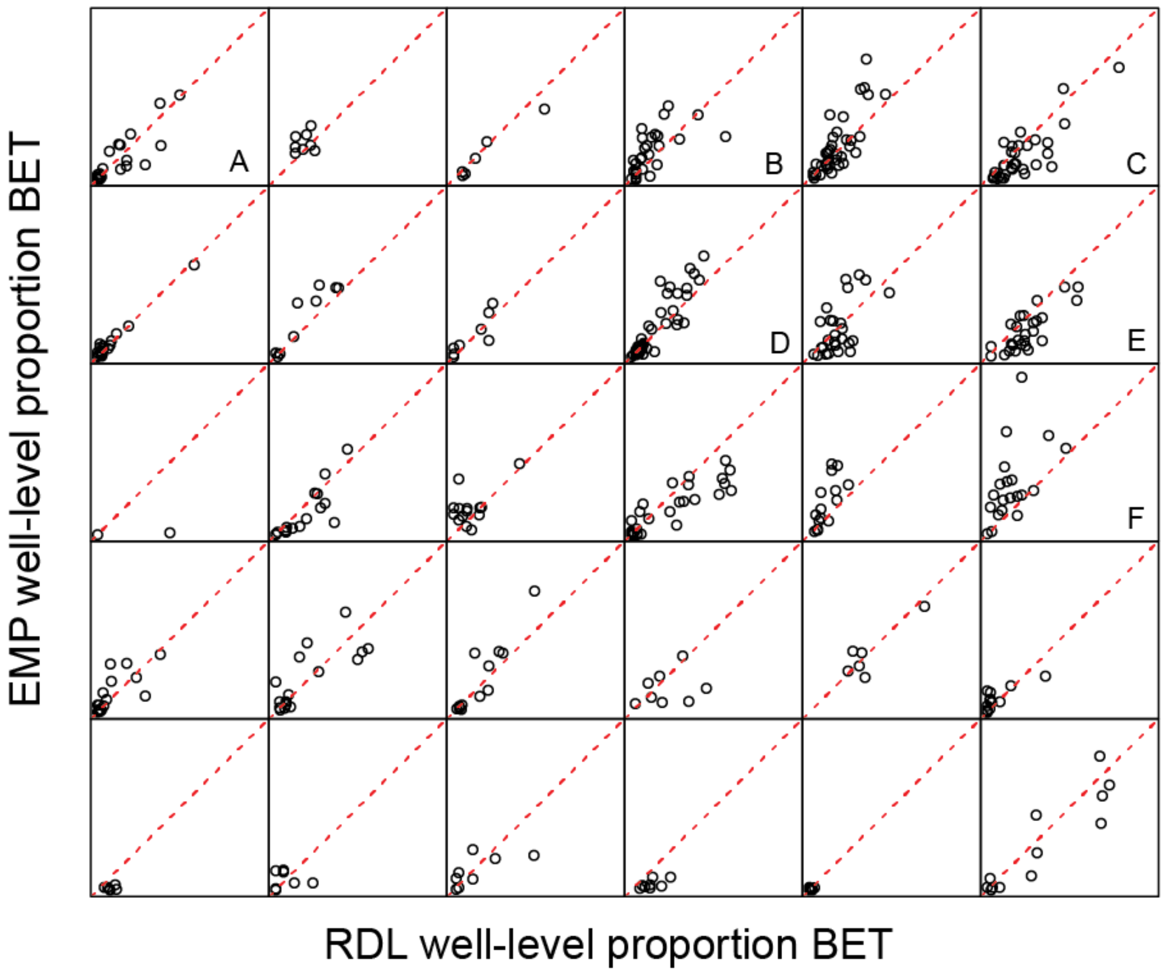

FIGURE A-1. Relationship between the RDL and EMP estimates of the proportion of BET per wells, by vessel. Each panel corresponds to the data of one vessel, each open black circle corresponds to the estimate for one well. The red dashed line is the 1-to-1 line. The letters in the lower-left corner of some panels correspond to trip-by-trip graphs shown in Figure A-2.

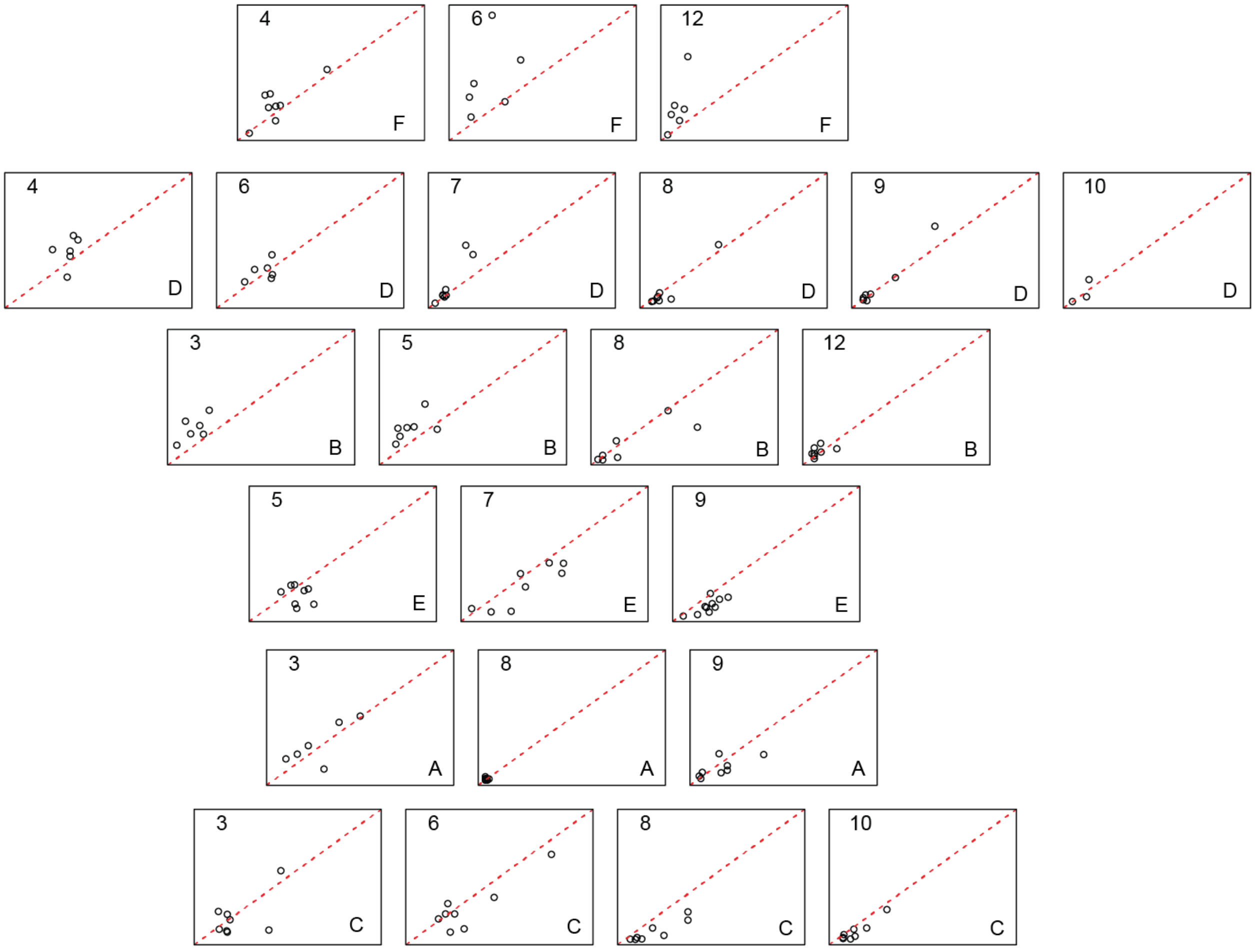

FIGURE A-2. Relationship between the RDL and EMP estimates of the proportion of BET per wells, by trip, for several of the vessels shown in Figure A-1. Each row corresponds to the data of one vessel; each panel of a row corresponds to the data of one trip for that vessel; and, each open black circle corresponds to the estimate for one well. The red dashed line is the 1-to-1 line. The letters in the lower-left corner of each panel indicate the corresponding vessel of Figure A-1.

APPENDIX B.

This appendix contains details of the methodology used to obtain the variance on the estimated BET catch per trip (for trips sampled by the EMP) and the coefficient of variation (CV). All statistical analyses were performed with the statistical freeware R (R Core Team (2021).

Variance estimation

This section provides a brief description of the methodology used to obtain the variance on the EMP trip-level estimates of BET catch. The details of the methodology depend on whether or not all strata of the trip were sampled by the EMP. This is because the RDL data were used as the estimate of the BET catch for strata that were not sampled by the EMP (Section 2.2 above).

1) All strata of the trip were sampled by the EMP

The variance on the BET estimate for each stratum is given by (from eq. (7) of Lennert-Cody et al. *Submitted*), adapted for estimating the variance of the BET stratum catch):

$$\left[\left(\frac{N}{n}\right)\delta^2_{among}\right](N(1-f_1)+\gamma) \qquad \text{(B-1)}$$

where N is the total number of sampleable wells for the stratum, n is the number of wells sampled for the stratum, f_1 is equal to (n/N), δ^2_{among} is the among-well variance (first component of eq. (6) of Lennert-Cody et al. *Submitted*). γ, which is the ratio of the within-well variance to the among-well variance, was assigned a value of 0.50. This approximation is based on the results of simulation studies conducted with EMP pilot study data (Lennert-Cody et al. *Submitted*). The value represents the average of trimmed mean values[7] from each synthetic data type (linear interpolation, loess plus error) for the 1-out-of-30 simulation (for a graphical summary of values of γ see Figure 14 of Lennert-Cody et al. *Submitted*). γ cannot be estimated directly from EMP data because only one systematic sample is collected per well, and thus, the within-well variance is not estimable.

If a trip had catch from more than one stratum, the variance for the trip is the sum of variances for each stratum. In the unusual situation where only one well was sampled for a stratum, the variance for the stratum was obtained by the method described below in (2).

2) Not all strata of the trip were sampled by the EMP

The approach to obtain an approximate measure of error for each catch stratum of a trip that was not sampled can be summarized as follows:

1) Use the RDL BET estimate as an approximation for the EMP estimate. This was typically necessary for low priority strata (e.g. OBJ IN-east, NOA). On occasion the RDL was used for priority strata (e.g., OBJ IN-west) represented by very few wells (i.e. representing little trip catch of tropical tunas). By doing this, more wells could be sampled for the dominant priority stratum (e.g. OBJ OFF), leading to a catch estimate for that stratum with smaller variance.

2) Obtain an approximation to the standard error (s.e.) on the stratum BET catch estimate using the fitted relationship between EMP BET estimates and their unscaled s.e.'s (described below) to predict the s.e. for the unsampled stratum. This approximation was not scaled for sampling coverage of wells in the stratum nor was an adjustment for within-well variance applied. This approach will be improved as more EMP data become available in 2024 and a better

[7] Trimming the lowest and highest values.

understanding of the well-level relationship between EMP and RDL estimates is obtained (as described in Section 3.1 above).

The relationship between the EMP BET estimate and its unscaled among-well s.e. (i.e., the square root of δ^2_{among}) was estimated using a generalized additive model (GAM) for 75 EMP stratum-level estimates (all strata; data available as of early December 2023). This increasing relationship (Figure B-1), which had increasing dispersion at higher BET catch amounts, was fitted using a Tweedie distribution with a parameter *p* of 1.6 for the relationship between the mean and variance of the response variable (i.e., the s.e.), and a power function for the link function with parameter 0.7; i.e. the relationship between the s.e. and the BET catch was assumed to be: s.e. = (BET catch)$^{0.7}$. This model was fitted using the *mgcv* library (and function *Tweedie*) in R (Wood 2017). The parameter for the Tweedie variance-mean relationship and the exponential of the power function were determined from inspection of diagnostic plots (provided by the function *gam.check*) and the GCV and adjusted R^2 values. The model summary statistics are:

```
Family: Tweedie(1.6)

Link function: mu^0.7

Formula:

se ~ s(BET.sampling.est, k = 4)

Parametric coefficients:

            Estimate Std. Error  t value Pr(>|t|)

(Intercept)   3.8783    0.2025   19.15   <2e-16

---

Approximate significance of smooth terms:

                     Edf    Ref.df  F      p-value

s(BET.sampling.est) 2.841  2.981 49.28  <2e-16

---

R-sq.(adj) =  0.475   Deviance explained = 59.5%

GCV = 0.77729  Scale est. = 0.84734   n = 75
```

A s.e. was predicted for each stratum of each sampled trip for which the s.e. could not be estimated from EMP sample data. The predicted s.e. was then squared to get the predicted variance. When the RDL BET catch estimate was 0, the s.e. was predicted assuming a catch value of 0.10 t. To note that the GAM predicts a s.e. greater than zero at 0 t catch. Forcing the intercept of the model through zero led to model convergence issues. In addition, because the fitted GAM was primarily used to make predictions of the s.e. for strata that were not of primary importance, the relationship was used for predicting at the left-hand part of the fitted curve, where there is less dispersion.

Estimation of the CV on the trip BET catch

The general formula for the CV is given by: CV = s.e. / estimate. Estimation of the CV for the BET catch of a trip involved the following steps: a) estimate the s.e. on the catch of each stratum and square those values to obtain variance estimates on the catch for each stratum; (b) compute the s.e. on the BET catch of the trip as the square root of the sum of stratum variances; and c) divide the trip s.e. by the trip BET catch estimate (equal to the sum of stratum BET catch estimates).

For the cost-benefit analysis simulation study (Section 4.2), the simulated variance at increased sampling coverage of wells of a stratum was computed by replacing the actual number of wells sampled (n of equation B-1) with the simulated increased number of wells sampled (e.g. n+2 or n+4). Computing the simulated variance in this way assumes that the among-well variance, δ_{among}^2, was well-estimated at the actual sampling coverage.

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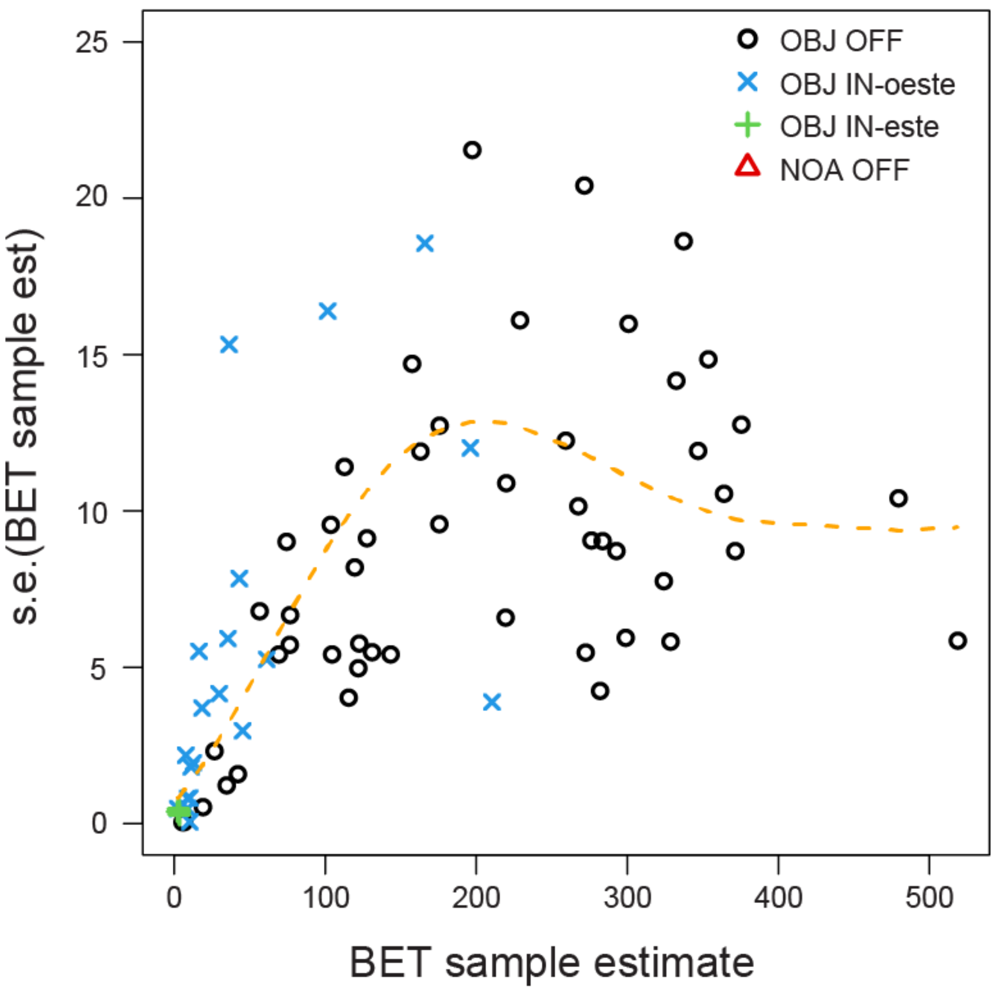

FIGURE B-1. Relationship between stratum-level EMP BET estimates and their standard errors. The orange dashed line is the fitted GAM curve. Black circles: OBJ OFF; blue ‘x’s: OBJ IN-west; green crosses: OBJ IN-east; and, red triangles: NOA OFF.