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1 Estimating tag-reporting rates for Atlantic tropical tuna fleets using 2 coincidental tag return and tag seeding experiment data

3 Akia S^{1,2,3*}, Amandé M². and Gaertner D^{1,3}.

5 Abstract

6 One of the most important biases to consider in tagging capture-recapture data for stock
7 assessment studies is the proportion of reported tags among the actual recaptures, i.e., the tag-
8 reporting rate. In this study, we used the model developed by Kimura (1976) and adapted in a
9 Bayesian framework by Carruthers et al. (2015) to estimate the reporting rates for thirteen
10 Atlantic Ocean tuna fleets using coincidental tagging data and catch data disaggregated by
11 species, school-type (Fish Aggregating Device and Free Swimming Schools), location and
12 time. The method was applied on recaptures and tag seeding experiments conducted during
13 the Atlantic Ocean Tropical Tuna Tagging Program (AOTTP) of the ICCAT (International
14 Commission for the Conservation of Atlantic Tunas). Tag seeding consists of secretly
15 planting tags on fish by observers onboard fishing vessels to estimate how many tags are
16 found during later stages (landing, processing, etc.) and reported to scientific authorities. Our
17 results showed that the tag-reporting rate was as large as 84.70% (80.58% – 88.39%) for the
18 European Union purse seiner fleet (Spain and France) but decreased for several surface fleets
19 from 72.79% (67.49%-77.77%) for the Spanish baitboats (operating off Senegal or in Canary
20 islands) to 22.83% (15.26% - 31.24%) for the Ghanaian mixed purse seiner-baitboat fishery.
21 Overall, we conclude that given the very low reporting rate for several important fleets
22 operating in the Atlantic Ocean, it is crucial to account for the reporting rate estimates to
23 avoid highly biased results in future stock assessment using tagging data.

24 **Keywords:** Tag reporting rate, Tag seeding experiments, Bayesian analysis, Tropical tuna,
25 Atlantic Ocean.

27 Highlights

- 28 • The reporting rate of the “observed” (European purse seiner) fleet was estimated at
29 84.70% from tag seeding data.
- 30
- 31 • The tag-reporting rates for the others twelve fleets were estimated by using
32 coincidental tagging data and catch data disaggregated by species, school-type (FAD,
33 free school, location and time.
- 34
- 35 • Estimates of the other fleets inferred from the reporting rate of the European purse
36 seiner fleet were lower and ranged from 22.83% to 72.82%.

37 1. Introduction

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39 Tagging programs remain valuable sources of information for research on highly migratory
40 species (HMS). Since the “Rio de Janeiro conference” in 1966, ICCAT has been responsible
41 for coordinating research on Atlantic tuna and the regional management of its fisheries
42 (Carroz and Roche, 1967). As part of this mission, ICCAT has implemented several tagging
43 programs in the Atlantic Ocean over the years. However, most of these programs were limited
44 to one species, and for practical reasons, they were not carried out on an Atlantic Ocean
45 basin-wide scale. The long-awaited project of an Atlantic Ocean basin-scale tagging program
46 started in June 2016 under the "Atlantic Ocean Tropical Tuna Tagging Program (AOTTP)".
47 The AOTTP objective is to improve the estimation - derived from capture-recapture data - of
48 key parameters in stock assessment, namely growth, natural and fishing mortality, movement,
49 and stock structure. From 26 June 2016 to 28 December 2020, 120 679 fish were tagged using
50 conventional, internal electronic and chemical (OTC) tags. As of 29 July 2021, 17 669 tags
51 have been recovered, implying an empirical recapture rate (assuming 100% reporting) of
52 14.64%. The main target species of AOTTP were the three principally harvested tropical
53 tunas (skipjack, *Katsuwonus pelamis*; yellowfin, *Thunnus albacares* and bigeye, *Thunnus*
54 *obesus*). Assessing exploitation and mortality rates with AOTTP's tagging data requires a
55 good estimate of the proportion of recaptured tags that are returned, i.e. the tag-reporting rate
56 (Hillary et al., 2008). However, the rate of fisher underreporting is usually unknown.
57 Several methods have been used to estimate the tag-reporting rate. Some include the use of
58 tagging data alone, angler or port surveys, high reward tagging, and observer programs in
59 multi-component fisheries with a 100% reporting rate in one component (Pollock et al., 2002,
60 2001). However, these methods assume spatio-temporal invariance of the reporting rate and
61 100% reporting of all fish recovered from a portion of the fishery, which can be considered
62 major assumptions (Berger et al., 2014). On the other hand, the tag seeding experiments
63 estimate tag reporting rates for the fishery components that conform to the experimental
64 tagging plan (gear, fleet, landing location, etc.). Tag seeding consists of secretly planting tags
65 in fishers' catches by observers onboard fishing vessels to verify that the tag is found during
66 later stages (landing, processing, etc.) (Hearn et al., 2003). However, sometimes tag seeding is
67 compromised, or seeding experiments cannot be conducted for all fleets operating in the
68 tagging area to infer an overall reporting rate. In such situations, we can proceed another way
69 by defining an observed fleet whose reporting rate is largely known and better controlled.
70 The concept of estimating all the fishing operators' reporting rates by using the knowledge of
71 one operator's reporting rate (i.e., the “observed fleet”), developed initially by Kimura (1976),
72 was extended by Carruthers and McAllister (2010) to a Bayesian estimator that operates on
73 data disaggregated in time, space, and size of the species. This method is divided into three
74 steps: (1) selection of the observed fleet and calculation of the reporting rate associated with
75 this fleet from seeding experiments, (2) construction of comparison strata of the observed
76 fleet's catch data and recaptured tags with that from the other fleets and (3) inference of the
77 reporting rate of the other fleets from the reporting rate of the observed fleet. In this study the
78 observed fleet is the European purse seiner fleet (France and Spain flags) operating in the
79 Atlantic Ocean. The other fleets' reporting rate estimation is done by comparing the catches
80 and recaptures made simultaneously in the same strata by these fleets and the observed fleet
81 (coincidental tagging data). Carruthers et al. (2015) used time, space and tuna size factors to
82 construct these strata.
83 In our case, we based strata construction on time, space and school type factors. The school
84 types considered were unassociated schools (i.e., free school; or not associated with structure)
85 where large yellowfin tuna dominate, and schools associated to floating objects, mainly
86 drifting fish aggregative devices (dFAD), attracting skipjack and juvenile bigeye and

87 yellowfin. Indeed, there are different sizes of fish by school type, and reporting rates would be
 88 expected to vary by size (Hearn et al., 1999; Pollock et al., 2002), so “it is essential to
 89 consider fleet fishing strategies as a source for heterogeneity.” It is important to note that the
 90 choice of the school type variable versus the size variable is related to the reliability and
 91 quality of the catch at size data available for this study.
 92 Therefore, this study estimates the tag-reporting rates of the major surface fleets (i.e., purse
 93 seine, hook and line, and baitboats) operating in the Atlantic Ocean that have recovered at
 94 least thirty tags during the AOTTP. Small-scale artisanal fleets and longline fleets, which
 95 report low recaptures, were not included in the analysis.

96
97
98

99 2. Materials and methods

100

101 2.1. Theory

102 As mentioned in the Introduction section, Kimura (1976) developed a method to infer the
 103 unknown tag-reporting rate of a commercial fleet from an observed fleet with a known tag-
 104 reporting rate. By defining an observed fleet (*obs*) for which we have simultaneously the
 105 amount of fish caught (C_{obs}) and the number of tags recovered (T_{obs}) in a given spatio-
 106 temporal stratum, the following relationship can be established:

$$107 \lambda_{com} = \frac{T_{com} C_{obs} \lambda_{obs}}{T_{obs} C_{com}} \quad (1)$$

108

109 where T is the number of tags, C is the number of fish caught, and the subscripts *obs* and *com*
 110 refer to the data of an observed fleet assumed to have a known reporting rate of λ_{obs} and a
 111 commercial fleet with unknown reporting rate λ_{com} .

112 For the sake of generalization and to be able to use this method to infer the tag-reporting rates
 113 of other fleets that do not overlap with the observed fleet in a given spatio-temporal stratum,
 114 we can rephrase it in terms of mark rate m (the probability of catching a tag given a fish is
 115 caught).

$$116 m = \frac{T_{obs}}{\lambda_{obs} C_{obs}} = \frac{T_{com}}{\lambda_{com} C_{com}} \quad (2)$$

117 and therefore:

118

$$119 T_{com} = m \lambda_{com} C_{com} \quad (3)$$

120

121 We then assume that tagged fish are fully mixed in each stratum (see discussion section for
 122 more details on the tag mixing assumption).

123 Note that where λ_{obs} is known, for any strata in which T_{obs} and C_{obs} are reported, m is
 124 informed. Any fleet that reports T_{com} and C_{com} in the same strata may be assumed to be
 125 operating on the same population of marked fish of mark rate m . It follows that these
 126 coincidental observations inform the reporting rate of the commercial fleet. If reporting rates
 127 can be assumed constant over time and space, this commercial reporting rate will then serve

128 to inform other fleets' reporting rates with coincidental data (even if they do not overlap
 129 directly with the observed fleet). In this way, commercial reporting rates flow from the
 130 observed fleet through a network of mark rates and overlapping tag recovery observations. In
 131 this study, the observed fleet is composed of French and Spanish purse seiners for which there
 132 are independent tag seeding data with which to estimate the tag-reporting rate.

133 The tag-reporting rate of the observed fleet can be quantified from tag seeding data by
 134 assuming a binomial probability of reporting a seeded tag (Carruthers and McAllister, 2010):

$$135 \quad P(R | \lambda_{obs}, S) = \binom{S - 1}{R} \lambda_{obs}^R (1 - \lambda_{obs})^{S-R} \quad (4)$$

136
 137 where S is the number of seeded tags and R is the number of seeded tags reported by the
 138 observed fleet. For any strata s , the tags reported by a fleet f can be assumed to be distributed
 139 according to the negative binomial distribution:

$$141 \quad P(T | C, \lambda, m) = \prod_f \prod_s \binom{C_{f,s} - 1}{T_{f,s}} (\lambda_f m_s)^{T_{f,s}} (1 - (\lambda_f m_s))^{C_{f,s} - T_{f,s}} \quad (5)$$

142
 143 In this study, a stratum (see "Strata considered" section for more details on strata
 144 construction) is a division in time, space and fishing mode (FAD vs free school) for which a
 145 population of fish can be assumed to have the same mark rate m . For the commercial fleets,
 146 reporting rates were assigned a uninformative beta(1,1) prior. In this analysis, we used the
 147 same beta prior for the mark rate of each stratum. Using the Gibbs sampler, we used a
 148 Bayesian statistical approach to estimate reporting rates distribution with Markov Chain
 149 Monte Carlo (MCMC) simulation. The MCMC was undertaken using R 3.6.3 (R
 150 Development Core Team, 2020), the package 'R2WinBUGS' (Sturtz et al., 2005) and
 151 WinBUGS 1.4 (Lunn et al., 2000) with three chains of 50 000 iterations and a 'burn-in' of 5
 152 000 samples. In addition, the R packages ggmcmc (Fernández-i-Marín, 2016) and coda
 153 (Plummer et al., 2006) was used to process the MCMC simulation obtained from WinBUGS
 154 and assess the convergence of the MCMC algorithms.

155

156 2.2. Presentation and pre-processing of the study data

157

158 From 26 June 2016 to 28 December 2020, 120 679 fish (tropical tuna) had been tagged
 159 (during AOTTP) using both conventional, electronic and chemical (OTC) tags, of which 41
 160 015 (36.53%) were yellowfin, 46 989 (41.85%) were skipjack, and 24 217 (21.62%) were
 161 bigeye. As of 29 July 2021, 17 669 tags concerning the three tropical tuna have been
 162 recovered, of which 8 423 were yellowfin, 3 576 were skipjack, and 5 021 were bigeye. Data
 163 missing key information at recapture (i.e. gear type, fleet code, date or position) were
 164 removed from the analysis. We considered fleets that recaptured at least 30 tags during the
 165 AOTTP and tuna tagged with a conventional tag (yellow spaghetti tag) according to the flag
 166 and fishing gear type. We split the data according to the gear type, i.e. purse seine catch and
 167 recapture data vs other gears (baitboats and handline) catch and recapture data.

168 Catch and fishing effort statistics for each species by area (1x1 degree squares by month for
 169 purse seiners, 5x5 degree squares by quarter for baitboats and handlines), gear, flag, raised to
 170 the total landing of Atlantic fishing fleets were extracted from the ICCAT website. Indeed, the

171 spatio-temporal data called "Task 2" used in this analysis, which in general area incomplete,
172 are raised to the total annual catches reported in "Task 1" by each ICCAT contracting party
173 (CPC) and assumed to be complete. These spatio-temporal datasets were used as the data
174 source to calculate the catch rate m (See equation 2).

175 Since the purse seine catch and effort statistics of the tropical tuna fishery operating in the
176 Atlantic Ocean are only available through 2019, we selected the purse seiners capture-
177 recapture data that occurred through 31 December 2019. Likewise, since the other fleets'
178 catch and fishing effort data raised to total landings are only available through 2018, we
179 selected the baitboats and handline capture-recapture data that occurred through 31 December
180 2018. This preprocessing allowed us to obtain 12 288 recaptures, representing 72.19% of the
181 initial data.

182 A tag seeding experiment had been conducted on board some fleets and some unloading
183 locations. Scientific observers or voluntary skippers secretly tagged some tunas before the fish
184 were placed in the vessel's well. The probability of detecting these seeded tags was
185 comparable to those used in an actual tagging operation. After preprocessing the tag-seeding
186 data, there were 338 tags seeded on the French and Spanish purse seiner fleet for the three
187 target tuna species (Yellowfin, Bigeye, and Skipjack).

188

189

190 2.3. Definitions of fleets for which reporting rates were estimated

191

192 We initially planned to estimate the tag-reporting rate of 15 fleets (fleets that recaptured at
193 least 30 tags during the AOTTP) according to the flag and fishing gear type. Unfortunately,
194 two of them, i.e. the Ivorian artisanal fleet and the Brazilian baitboats, did not overlap well
195 with the observed fleet, making it impossible to use this method to estimate their reporting
196 rate (see **Fig.Sup 1** to **Fig.Sup 4**). Furthermore, we initially intended to estimate other gears
197 reporting rates, such as some longlines operating in the Atlantic Ocean. However, we could
198 not do that due to poorly documented catches and small areas of operation of these fleets (e.g.,
199 the networks of anchored FADs in the Ivorian EEZ or catches concentrated near the coast).
200 For all of these reasons, it is difficult or impossible to estimate the tag-recovery rate of these
201 fleets using this method. After all the validation and verification steps of the model's
202 assumptions, we defined twelve fleets (in addition to the European purse seiner fleet), some of
203 those as the result from the grouping of others (see **Table 1** for a complete presentation). The
204 "BB_Dakar" and "PS_BB_GHA" represented the baitboat vessels of Spain, France, and
205 Senegal based in Dakar-Senegal and the purse seiner and baitboat vessels of Ghana,
206 respectively. For the Ghanaian fleet (composed of two different gears), the ICCAT tropics
207 working group concluded that the estimation of catch and efforts data should be considered
208 baitboat and purse seine in the same fleet segment (Chassot et al., 2016). Consequently, we
209 put the two Ghanaian gears together in the same fleet ("PS_BB_GHA"). However, because
210 more than 85% of Ghanaian recaptures are from purse seiners (see **Table 2** and **Table 3**) we
211 performed then a sensitivity analysis to estimate the reporting rate for the Ghanaian purse
212 seiner fleet alone ("PS_GHA").

213

214 2.4. Strata considered

215 In the development of the methodology, selecting the observed fleet and estimating its
216 tag-reporting rate using seeding data is followed by the construction of strata to compare the

217 mark rates m between the observed fleet and the other fleets. Disaggregating the data into
 218 strata to estimate the reporting rate corrects some bias generated by assuming that the
 219 reporting rate is homogeneously distributed throughout the study area. Besides, this process
 220 significantly reduces the number of overlapping recaptures used to infer the other fleets'
 221 reporting rates. This phase is crucial because it is the basis of the reporting rates estimation
 222 with this method. For it to be useful, it is necessary to construct strata large enough to have
 223 data meaningful for analyses, but small enough to minimize potential bias. In addition, it is
 224 essential to know what spatio-temporal resolution is appropriate for comparing different
 225 fleets' return rates.

226

227 **Table 1**

228 The disaggregation of fishing fleets operating in the Atlantic Ocean for which individual
 229 reporting rates were estimated. We defined twelve ‘fleets’ (in addition to the Spanish and
 230 French “observed fleet”) according to different combinations of flags and gears. In some
 231 cases, these ‘fleets’ are grouping multiple flags or gear types; for example, the baitboat of
 232 Spain, France, and Senegal based in Dakar and operating off Senegal were aggregated under
 233 the term ‘BB_Dakar’.

234 * The Ghana PS fleet is used as a sensitivity approach to analyze Ghanaian PS and BB's
 235 pooling on the reporting rate estimate.

Flag	Gear	Fleet code	Description
Panama	Purse seiner	PS_PAN	Purse seiners of Panama
Salvador	Purse seiner	PS_SLV	Purse seiners of Salvador
Curaçao	Purse seiner	PS_CUW	Purse seiners of Curaçao
Guatemala	Purse seiner	PS_GTM	Purse seiners of Guatemala
Senegal	Purse seiner	PS_SEN	Purse seiners of Senegal
Cabo Verde	Purse seiner	PS_CPV	Purse seiners of Cape Verde
Brazil	Handline HL	HL_BRA	Handline vessels of Brazil
Ghana	Purse seiner	PS_GHA	Purse seiners (only) of Ghana*
Ghana	Purse seiner and Baitboat	PS_BB_GHA	Purse seiners and Baitboats of Ghana
Spain,France & Senegal	Baitboat	BB_Dakar	Baitboats based in Dakar Senegal
Spain	Baitboat	BB_SPA_CAN	Baitboats of Spain based in the Canary Islands
Portugal	Baitboat	BB_PRT	Baitboats of Portugal based in Madeira and Azores
Spain & France	Purse seiner	Ref_PS_FR_SPA	Purse seiners of Spain and France

236

237 Where possible, we added species and school type (which approximate the size-structure of
238 the catch data) factors in the strata's construction. In the catch and effort data, sometimes the
239 school type is missing or the variable itself does not exist for some fleets. When it was not
240 possible to estimate the proportion of catches by school type, we simplified the calculation by
241 removing the school type variable in the strata construction with the aim to compare them
242 with the observed fleet. For most cases, the strata constructed are thus of the type: spatio-
243 temporal structure*year*species*school type. To overcome the situations where catch and
244 effort data have missing information for the school type variable, we considered some simpler
245 models without the school type. In cases recapture (tagging) and catch data have missing
246 values for the school-type variable, we used the known proportion of catches and recapture by
247 strata and by school type to reallocate this data with missing values on school type
248 (assignment based on averages). We estimated the tag reporting rates from these strata and
249 tested the hypothesis that the tag reporting rate of the observed fleet is higher than those of the
250 other fleets. This condition allowed us to validate the choice of the spatio-temporal structure
251 or to use a larger resolution to obtain more consistency between the data of the fleet under
252 consideration and those of the observed fleet. We proposed two other spatio-temporal
253 structures for the purse seiners and one other structure for the baitboats. The base case model
254 proposed ensures that the spatio-temporal strata construction depends on the species and the
255 fishing mode. Situations that required data restructuring, distribution of recaptures without
256 school type information, and simplification of strata construction (strata with catch data
257 without defining school type) were addressed to ensure the estimation of the tag-reporting rate
258 of the 12 fleets. The final models used for the estimation of each tag reporting are specified in
259 the result section.

260

261

262 2.5. Convergence of the MCMC algorithms (Gelman and Rubin's diagnostics tools)

263 The Markov Chain Monte Carlo (MCMC) algorithms are widely used to fit complicated
264 statistical models in situations where the traditional estimation techniques are challenging to
265 apply. However, it is difficult to determine the algorithm's convergence, because it is not a
266 scalar quantity to a point but a distribution to another distribution. Therefore, MCMC
267 diagnostic tools are needed for deciding the convergence of Markov chains to stationarity.
268 There are many MCMC diagnostics tools in the literature, but we used the Gelman-Rubin
269 diagnostic tools (parameters and plot) in this paper. Gelman and Rubin's (1992) approach to
270 monitoring convergence is based on detecting when the Markov chains have forgotten their
271 starting points by comparing several sequences drawn from different starting points and
272 checking that they are indistinguishable. There are many ways to compare parallel sequences.
273 The most obvious approach is to look at overlaid traceplots and see if the two sequences can
274 be distinguished. A quantitative approach is based on the analysis of variance. The Gelman-
275 Rubin diagnostic measures whether there is a significant difference between the variance
276 within several chains and between several chains by a value called "scale reduction factors".
277 The `gelman.diag` function in the R package `coda` gives the scale reduction factors for each
278 parameter. A factor equal to one means that between-chain variance and within-chain
279 variance are equal; larger values mean that there is still a notable difference between chains.
280 Convergence is achieved when the scale reduction factor is below 1.1. The R package `coda`'s

281 gelman.plot function shows the development of the scale-reduction over time (chain steps),
 282 which is helpful to see whether a low chain reduction is also stable.

283

284

285 **Table 2**

286 Total nominal catch of fish (tons) and recaptures numbers by fleet, average recapture rate and
 287 simple reporting rate for purse seiner. The average recapture rate is the number of tags
 288 recaptured per tons of fish caught. Assuming a single mixed strata, an approximate point
 289 estimate of reporting rate can be calculated for the seven purse seiner fleets ('Simple reporting
 290 rate estimate') by multiplying their recapture rate by the assumed reporting rate of the
 291 observed fleet (84.95%; 290 tags seeded, 247 reported) and dividing this by the recapture rate
 292 of the observed fleet.

Fleet code	Catch (tons)	Number of recaptures	Average recapture rate	Simple reporting rate estimate (%)
PS_PAN	41036.5	443	10.79	85.34
PS_SLV	86443.2	554	6.4	50.66
PS_CUW	1100063.4	724	6.57	52
PS_GTM	46883.8	65	1.38	10.96
PS_SEN	113640.7	1975	17.37	137.4
PS_GHA	178580.7	379	2.12	16.77
PS_CPV	37449.3	90	2.40	18.99
Ref_PS_FR_SPA	371491.9	3990	10.74	84.91

293

294 **Table 3**

295 Total nominal catch of fish (tons) and recaptures numbers by fleet, average recapture rate and
 296 simple reporting rate for baitboats. The average recapture rate is the tags recaptured per tons
 297 of fish caught. Assuming a single mixed strata, an approximate point estimate of reporting
 298 rate can be calculated for the five other fleets ('Simple reporting rate estimate') by
 299 multiplying their recapture rate by the assumed reporting rate of the observed fleet (84.95%;
 300 290 tags seeded, 247 reported) and dividing this by the recapture rate of the observed fleet.

Fleet code	Catch (tons)	Number of recaptures	Average recapture rate	Simple reporting rate estimate (%)
PS_BB_GHA	227351.4	402	1.76	10.99
BB_Dakar	34127.5	1948	57.08	354.8
BB_SPA_CAN	17524	545	31.09	193.30

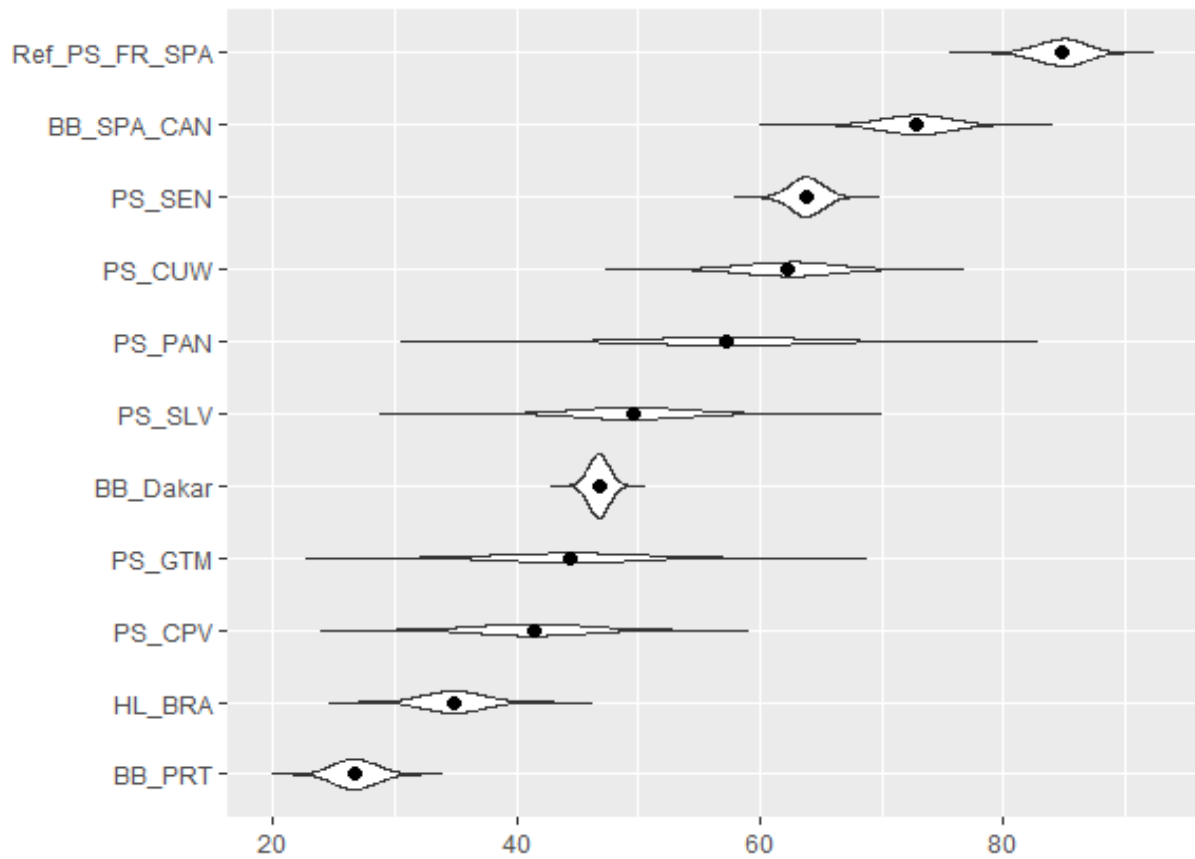
BB_PRT	16506.8	335	20.29	126.15
HL_BRA	65634.1	197	3	18.65
Ref_PS_FR_SPA	274012.9	3745	13.66	84.95

301

302 **3. Results**

303 The data structure allowed us to estimate two types of modelling procedure (i.e., omitting
304 catch data without declared school type vs reallocation of the catch with unknown school type
305 based on known proportions by school type) with two types of strata construction in each
306 modelling option. The specification-retained strata by fleet are presented in **Table 4**.
307 Reporting rate estimates in this study are detailed in **Table 4** and illustrated in **Fig. 1** and **Fig.**
308 **2**. The analysis of the Gelman Rubin diagnostics (**Table 5** and **Fig.Sup 7**) ensured that
309 convergence was achieved for all models. The posterior estimates of reporting rates varied
310 widely among the different fleets. The effective sample size (ESS) used to draw posterior
311 distributional conclusions was approximately 4 500 by chain (mean ESS). The ESS is the
312 equivalent number of independent samples that would contain the same posterior accuracy as
313 the correlated samples from an MCMC. Based on tag seeding experiment data, the reporting
314 rate of the EU purse seiner fleet was estimated to be 84.72%. The mean reporting rate
315 estimates of the twelve other fleets were between 22% and 72%. The Ghanaian fleet
316 composed of baitboats and purse seiners showed the lowest reporting rate. The sensitivity
317 analysis showed no differences between the reporting rate of purse seiners alone and purse
318 seiners combined to baitboats, and reinforced the advice to consider these two gears in the
319 same fleet.

320



321
 322 **Fig. 1.** MCMC posterior probability and 95% credible intervals for the estimated reporting
 323 rates of the 11 fleets (the Ghanaian fleets are presented in figure 2). The central range
 324 depicted by a solid black violin is the 50% probability interval. The most central range is the
 325 95% (97.5 - 2.5%) credible intervals.

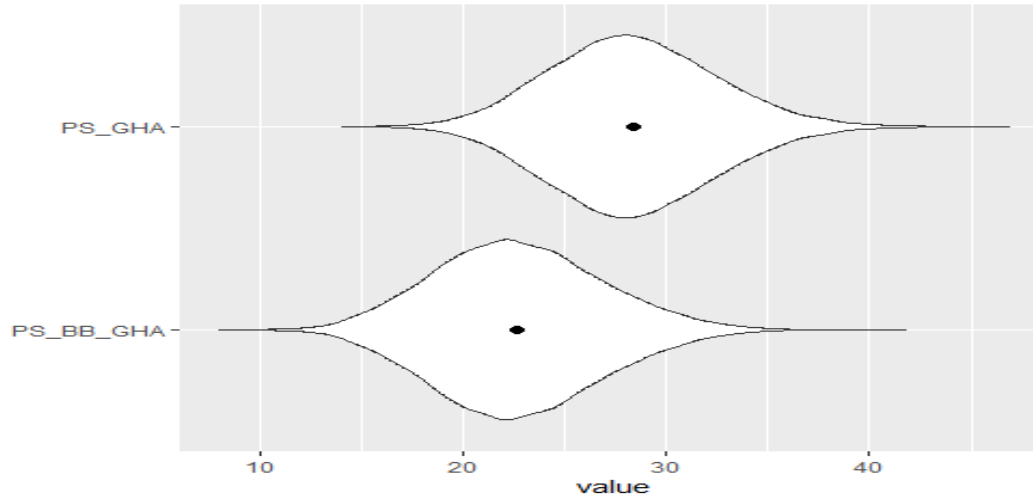
326 **Table 4**

327 Posterior probability distributions of AOTTP reporting rates (percentages) and structure of the
 328 stratification used in each case for different tropical tuna surface fleets operating in the
 329 Atlantic Ocean. sd: standard deviation.

Fleet code	Models components (variables)	MCMC posterior probability and credible intervals				
		2.50%	50%	97.50%	Mean	sd
PS_PAN	School-type; specie; year & [1° x Month]	44.93	57.37	69.50	57.29	6.31
PS_SLV	School-type; specie; year & [1° x Month]	40.83	49.62	58.17	49.62	4.39
PS_CUW	School-type; specie; year & [1° x Month]	54.77	62.37	69.39	62.28	3.70
PS_SEN	School-type; specie; year & [5° x Bimonthly]	61.18	63.81	66.42	63.81	1.34
PS_CPV	School-type; specie; year & [10° x Quarter]	33.10	41.34	50.12	41.12	4.36
PS_GTM	School-type; specie; year & [10° x Quarter]	33.91	44.35	55.54	44.49	5.47
BB_Dakar	School-type; specie; year & [5° x Quarter]	45.15	46.76	48.38	46.76	0.82

HL_BRA	Specie; year & [20° x Semester]	30.26	34.87	39.61	34.88	2.37
BB_SPA_CAN	Specie; year & [20° x Semester]	67.49	72.85	77.77	72.79	2.65
BB_PRT	Specie; year & [20° x Semester]	23.49	26.73	30.26	26.77	1.72
PS_GHA	School-type; specie; year & [5° x Bimonthly]	20.77	28.23	36.72	28.35	4.07
PS_BB_GHA	School-type; specie; year & [5° x Quarter]	15.09	22.51	31.11	22.69	4.10
Ref_PS_FR_SPA	Directly obtained from tag seeding data	80.74	84.78	88.39	84.72	1.96

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332 **Fig. 2.** MCMC posterior probability and 95% credible intervals for the estimated reporting
333 rates of the Ghanaian fleet, depending on whether we consider the purse seiners only or the
334 mixed purse seine and baitboat fishery. The central range depicted by a solid black violin is
335 the 50% probability interval. The most central range is the 95% (97.5 - 2.5%) credible
336 intervals.

337 **Table 5**

338 Gelman-rubin convergence diagnostics (Convergence rule: parameter < 1.1)

Parameters	Point estimate	Upper Confidence interval
PS_PAN	1.001	1.000
PS_SLV	1.000	1.000
PS_CUW	0.999	1.001
PS_SEN	1.000	1.000
PS_CPV	1.000	1.001
PS_GTM	1.000	1.001
BB_Dakar	0.999	1.000
HL_BRA	1.000	1.000
BB_SPA_CAN	1.000	1.001
BB_PRT	1.000	1.001
PS_GHA	1.000	1.000
PS_BB_GHA	0.999	1.000
Ref_PS_FR_SPA	1.000	1.001

Multivariate potential scale reduction factor	1.002
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342 **4. Discussion**

343 This study aimed at estimating the tag-reporting rate of the main surface fleets catching
344 tropical tunas in the Atlantic Ocean, based on a theoretical approach proposed by Kimura
345 (1976) combined with a Bayesian method proposed by Carruthers and McAllister (2010). The
346 approach is to infer the tag-reporting rate of other fleets from an observed fleet for which we
347 can have a relatively good estimate of its tag-reporting rate. Estimating the reporting rate is a
348 requirement for the use of tagging data. It is crucial to understand the difference in reporting
349 rates between fleets to estimate correcting factors for better-estimated crucial parameters for
350 stock assessments such as natural or fishing mortality, species movement and stock mixing
351 rates.

352 The observed fleet in this study was the European purse seiner fleet composed of Spanish and
353 French vessels, for which the reporting rate was estimated at 84.72% from tag seeding data
354 (**Table 4**). Based on this estimate, we were able to estimate the tag-reporting rate of 11 other
355 surface fleets operating, at least partially, in the same spatio-temporal strata than the European
356 purse seiner fleet. The Spanish baitboats from Canary Island or purse seiners from Curaçao
357 and Senegal exhibited larger reporting rates than the Ghanaian fleet or Portuguese baitboats
358 (from Madeira and Azores). The differences observed (more than 25%) between European
359 purse seiners and the same purse seiners registered under the flags of Cape Verde and three
360 Latino- American countries (i.e., Panama, El Salvador and Guatemala) are surprising as all
361 these purse seiners belong to Spanish tuna companies. There is no clear explanation for this
362 difference, but we suspect it may be due to the different landing locations of these fleets.
363 Indeed purse seiners registered under these flags may have a larger proportion of landings in
364 Mindelo (Cape Verde), as well as in Tema/Takoradi (Ghana), than the European fleet (Spain
365 and France) mostly landing in Abidjan (Cote d'Ivoire). This could suggest an additional effect
366 of the landing place to the reporting rate, as evidenced by Hampton (1997) in the Pacific
367 ocean. Such results underline the need to investigate the potential variables that could
368 describe the heterogeneity of reporting rates and, consequently, the possibility of considering
369 them in the analysis. For example, following the estimates made in this document, it would be
370 essential to initiate other analyses to know which variables in the strata construction or other
371 parameters, such as the tag type and the landing location, are the most important in describing
372 reporting rate heterogeneity. However, we could not carry out such analyses because we did
373 not have adequate data, such as tag seeding data covering many of the studied fleets and
374 catches data by landing location. It is relevant to notice that more than 90% of the tags used
375 during the AOTTP and all the tags used during the seeding experiments were conventional
376 tags. It would be interesting for future tagging programs to collect more adequate data to
377 perform these analyses.

378 Notice that in this study, the model includes the tag reporting rate of the observed fleet as an
379 estimator and not as a distribution. That is why the concerned fleet's result variance is not
380 always larger than the observed fleet variance. Future work could develop an integrated
381 approach to model the reporting rate such that the variance of the observed fleet is maintained
382 for all other fleets. Otherwise, as Brooks and Deroba (2015) showed, the variance of the
383 observed fleet estimator is not carried forward to subsequent estimators (i.e., the other fleets).

384 It must be stressed that the tag-reporting rate estimated from the tag seeding data was made
385 under the strong assumption that it remained homogeneous for this fleet over the entire study
386 period and spatial extent. Indeed, all the analyses carried out in this study were based on
387 several assumptions: (1) tags are distributed homogeneously over the spatial and temporal
388 scale of comparisons among fleets (i.e., at the resolution of the estimated mark rates " m "); (2)
389 reporting rates remain constant over time among species and are the same in areas beyond
390 spatio-temporal comparisons; (3) catches are accurately reported (with consequence on the
391 estimates as showed by Carruthers et al., 2015). Moreover, our method assumes that the
392 tagged fish are mixed throughout the release and fishery areas. This means that the fish
393 released from a relatively small region mix rapidly over a much broader region of interest, so
394 tagged and untagged fish are equally likely to be captured by commercial fisheries. Thus, the
395 results obtained are meaningful only under these assumptions and cannot be interpreted or
396 validated outside of them. However, we are aware that several studies have shown that tag-
397 reporting rates vary over time. Hampton (1997) showed a temporal dependence of the
398 reporting rate in a tagging program, and Hillary (2008) found that the reporting rate could
399 change from year to year with the example of the Indian Ocean EU purse seiner fleet whose
400 reporting rate changed from 2004 to 2007. However, there were insufficient tag seeding
401 experiments data throughout the duration of the AOTTP to expand the analyses.

402 Another crucial phase in the modelling is the strata construction. Hearn et al. (1999) identified
403 potential biases in aggregating return rates and catches without considering size classes. We
404 would have liked to address this issue, but the difficulty of having size data available and
405 appropriate for this study did not allow us to look at this aspect. However, we compensated
406 for this by including the school type variable in the construction of the strata. Today, it is
407 evident that fishing under dFADs (and other aggregating structures: oil platforms, anchored
408 FADs, school associated with the tagging vessel, etc.) is different from fishing free schools.
409 Besides, large yellowfin dominate free schools when dFAD schools mainly comprise skipjack
410 and juveniles of yellowfin and bigeye. However, the school type variables related to catch
411 data and tag recovery position is not free of bias. Indeed, the catch and fishing data are, in
412 most cases, reported by national scientists or estimated by the ICCAT secretariat.
413 Consequently, these data may contain uncertainties (e.g., misreporting, inadequate sampling,
414 etc.) and present challenges to resolve. A challenge in the construction of the strata concerns
415 the spatio-temporal distribution of the data. Previous studies using this method have proposed
416 several structures and compared the difference in results to evaluate the impact of the spatio-
417 temporal structure on the estimates of the tag-reporting rate. We selected five strata with a
418 monthly 1x1 squares degree to a semi-annual (January - June and July - December) 20x20
419 squares degree. Unfortunately, the capture-recapture data contained errors in many key
420 covariables of our study, school type, recapture positions (latitude and longitude), and dates
421 (month and year), which reduced the available data for analysis. In some cases, we proposed
422 methods to correct these (such as comparing species at release to species at recapture) and
423 removed them from the data used whenever possible. All of this pre-processing resulted in
424 only 72.19% of the original recapture data.

425 Finally, tag reporting rate estimates obtained from the AOTTP data are considerably higher
426 than those observed in the Indian Ocean (Carruthers et al., 2015). Indeed, an average of the
427 estimated tag-reporting rates (of the 11 other fleets) weighted by the recaptures yields 52
428 return tag out of 100 recaptured tags. Again, this value is considerably higher than the 15 tag
429 returns out of 100 recaptured tags found in the Indian Ocean by Carruthers et al. (2015).
430 Notice that these rates are not directly comparable because the fleets considered by Carruthers
431 et al. (2015) were more heterogeneous than those in this study. Indeed, their work included
432 longlines and artisanal fishing gears whose reporting rates are low. Nevertheless, a simple

433 comparison of tag seeding results shows that the RTTP and IOTTP observed fleet's tag
434 reporting rate was larger than those of the AOTTP estimated in this study.
435 Knowing fleet reporting rates is essential to using tagging data in fisheries research.
436 Therefore, it is fundamental to correct the tagging database to account for uncertainties in the
437 tag reporting rate and other factors before introducing tagging information into stock
438 assessment models. Berger et al. (2014) suggested a number of correction procedures for this
439 purpose. The quality or reliability of input data used to estimate the tag reporting rate, i.e.
440 seeding experience, release recovery data, and catch data affect our ability to monitor and
441 interpret estimation of reporting rates. A reasonable estimation of tag reporting rates begins
442 with collecting reliable data. The relatively low number of seeding experiments, the
443 unbalanced nature of the dataset coverage by observer fleet through time, and some missing
444 information on the recovery data during AOTTP are some limits of this study. However, its
445 results remained crucial for using AOTTP tagging data in future stock assessments.

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460 **Declaration of competing interest**

461 The authors declare that they have no known competing financial interests or personal
462 relationships that could have appeared to influence the work reported in this paper.

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465 **CRedit authorship contribution statement**

466 **S. AKIA:** Conceptualization, Methodology, Software, Validation, Visualization,
467 Investigation, Writing - original draft.

468 **M. Amade:** Conceptualization, Supervision, Writing - review & editing, Supervision.

469 **D. Gaertner:** Conceptualization, Validation, Writing - review & editing, Supervision,
470 Funding acquisition, Project administration.

471

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