5th meeting TFRB, 19 April 2024

Turtle Dove Adaptive Harvest Management mechanism

March 2024 Technical update (western flyway)[1]

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[1] *Document prepared in the frame of the service contract with the European Commission "Supporting the recovery of bird species of Annex II of the Birds Directive in non-secure conservation status" (09.0201/2022/886665/SER/D.3) in preparation for the December 2023 meeting of the Task Force on the Recovery of Birds (01/12/2023).*

1- WHAT IS NEW IN THE 2024 UPDATE: MAIN RESULTS AND CONCLUSIONS

The spring 2024 technical update on the Turtle Dove AHM mechanism provides new population data from the Pan-European Common Bird Monitoring Scheme (PECBMS), this time covering up to the breeding seasons of 2022 and 2023. Thus, we present quantitative information on the population estimates corresponding to the first two breeding seasons with the temporary hunting ban in place in the western flyway. The updated data show that the turtle dove breeding population size in the western flyway declined continuously between 2007 and 2021 and, in the spring of 2021, it was at its lowest level of the entire time series. However, following the temporary hunting ban in 2021 and 2022, the trend was reverted, and the population started to increase. The population size in 2023 was estimated to be the highest since 2011 (12 years). In line with the recent increase in population size, the 10-year trend, measured by the PECBMS multiplicative slope, improved from “moderate decline” to “stable”. The concurrence of both factors indicates that the 2-year hunting ban has had a noticeable effect at population level.

Another section provides updated data on key demographic parameters (reproduction and survival) from ongoing studies in Spain. These data indicate, on the one hand, that overall productivity seems to have decreased in 2022 and 2023, in concomitance with adverse weather conditions, whereas there is some evidence that survival may have improved at least in some areas at a time when the hunting bans were in place. These results support that the increase in population observed in the PECBMS data set is likely the result of increased survival following the temporary hunting ban.

Finally, we also used Population Dynamics P Systems (PDP) modelling tools to predict population trajectories over the next 30 years under different harvest management scenarios. Interestingly, several different options estimated similar trajectories in the moderate growth spectrum, showing that it may be possible to consider alternative management choices of reduced hunting in the future.

2- FLYWAY-SCALE POPULATION DATA (PECBMS)

The PECBMS turtle dove dataset, updated in 2024, refers to the breeding seasons of 1998 to 2023. Therefore, for the first time they include estimates of abundance for two breeding seasons (2022 and 2023) following the establishment of a temporary hunting ban in the hunting seasons of 2021 and 2022. Annex I presents information about exact data included and details on the methodology used to calculate the flyway indicators.

Data shows that, after a prolonged decline since 2007, the Turtle Dove population in the western flyway reached its lowest estimated size in the spring of 2021, at 1.56 million breeding pairs. However, that trend changed in the two breeding seasons following the hunting ban, with an increase of 400,000 bp to a new size of 1.96 mbp in 2023, the highest total for the last 12 years (Fig. 1). For comparison, the same trend was not observed in in the central-eastern flyway population, which declined continuously over the period 2000-2023 – from 1.04 mbp in 2003 to 0.56 in 2023, the lowest estimate of the time series; this represents a total loss of 0.48 mbp.

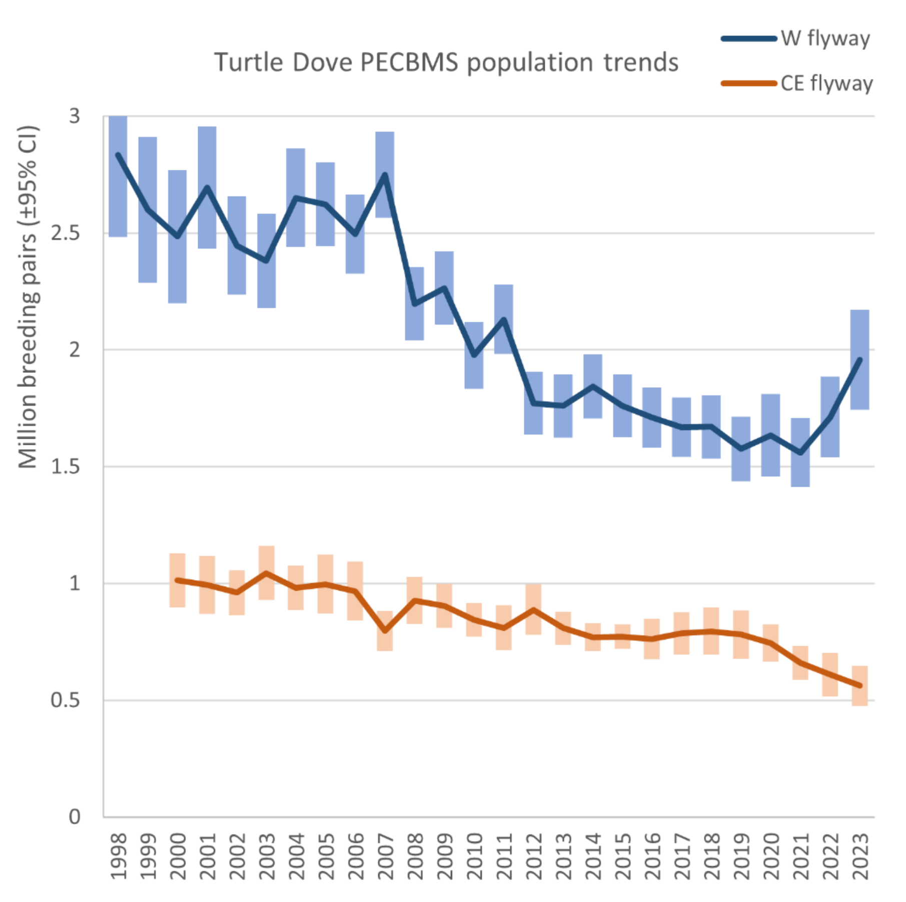

Figure 1. *Estimates of turtle dove breeding population size along the European part of the western flyway 1998-2023 and central-eastern flyway 2000-2023. Estimates of numbers of breeding pairs in each flyway were calculated by combining information on annual variations in national bird count data during surveys and information on population sizes reported by national authorities in the latest Art. 12 process. Error bars indicate 95% confidence intervals. Data: PECBMS (February 2024).*

Similarly, the 10-year multiplicative slope for the western flyway increased after two years of temporary hunting moratorium to 0.999 ±0.011 95%CI (2014-2023) from a pre-ban estimate of 0.983 ±0.010 95%CI (2012-2021). This meant that the western flyway 10-year trend improved from moderate decline to stable. In the central-eastern flyway, by contrast, the 10-year slope decreased in 2014-2023 (0.968 ±0.014 95%CI) with respect to 2012-2021 (0.988 ±0.013 95%CI), with the trend worsening from stable to moderate decline ($p<0.01$) (Fig. 2).

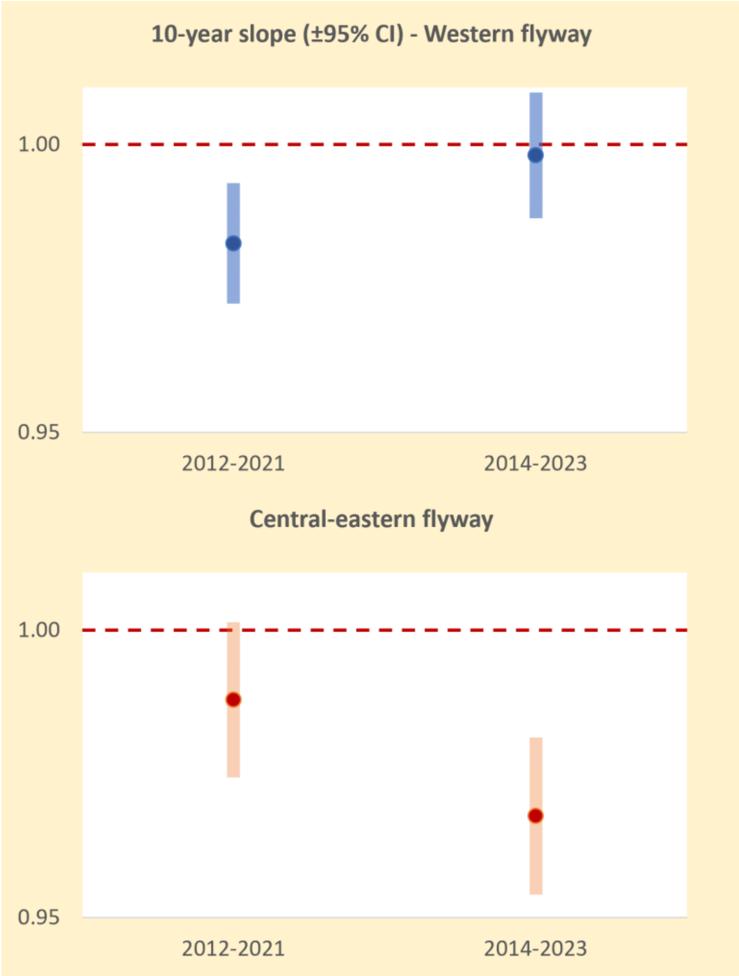

Figure 2*. 10-year multiplicative slopes for both flyways corresponding to the periods 2012-2021 and 2014-2023 with their 95% confidence intervals. The red dotted line marks population stability (λ= 1). As explained in the text, in the western flyway, the 10-year slope has improved from moderate decline (confidence interval lower than 1 but higher than 0.95) to stable (confidence interval crosses 1). In the central-eastern flyway, the opposite situation occurs, with the 10-year slope worsened from stable to moderate decline. Data: PECBMS (February 2024).*

The PECBMS data show that the population responded quickly to the hunting ban by reverting the trend and starting to augment. This is in line with the predictions of the population models of Bacon *et al*. (2023)[2] and de Vries et al. (2022)[3] that improving the survival of adults and juveniles, the vital rates to which population growth is most sensitive, would bring immediate effects at population level. The population has shown capacity to recover almost immediately and, even if this process may at some point be slowed down by density-dependence, it demonstrates that by prioritizing action to address unsustainable hunting it is possible to buy time to undertake more lasting interventions on habitat.

[2] *Bacon, L., Guillemain, M., Arroyo, B. et al. Predominant role of survival on the population dynamics of a threatened species: evidence from prospective analyses and implication for hunting regulation. J Ornithol* ***164****, 275–285 (2023). https://doi.org/10.1007/s10336-022-02038-4*

[3] *de Vries, E.H.J., Foppen, R.P.B., van der Jeugd, H. and Jongejans, E. (2022), Searching for the causes of decline in the Dutch population of European Turtle Doves (Streptopelia turtur). Ibis, 164: 552-573. https://doi.org/10.1111/ibi.13031*

The observed increase is likely to extend into 2024, given that the ban was maintained in the autumn of 2023.

3- UPDATED DEMOGRAPHIC DATA FROM SPAIN

Ongoing studies in Spain carried out by IREC and the Centre de Ciència i Tecnologia Forestal de Catalunya (CTFC) in four sites in two regions (Castilla la Mancha and Catalunya) include marking turtle doves with GPS tags to help with the location of nests. This has allowed estimating productivity (number of fledglings produced per breeding female over a whole season) and breeding success per clutch (the proportion of located clutches that have led to at least one fledging). As observed in Fig. 3, the latter parameter has been particularly poor in the last two years (whereas no significant differences have been found among sites or regions), probably linked to adverse weather conditions – 2022 and 2023 were particularly hot and dry years in the whole Iberian Peninsula.

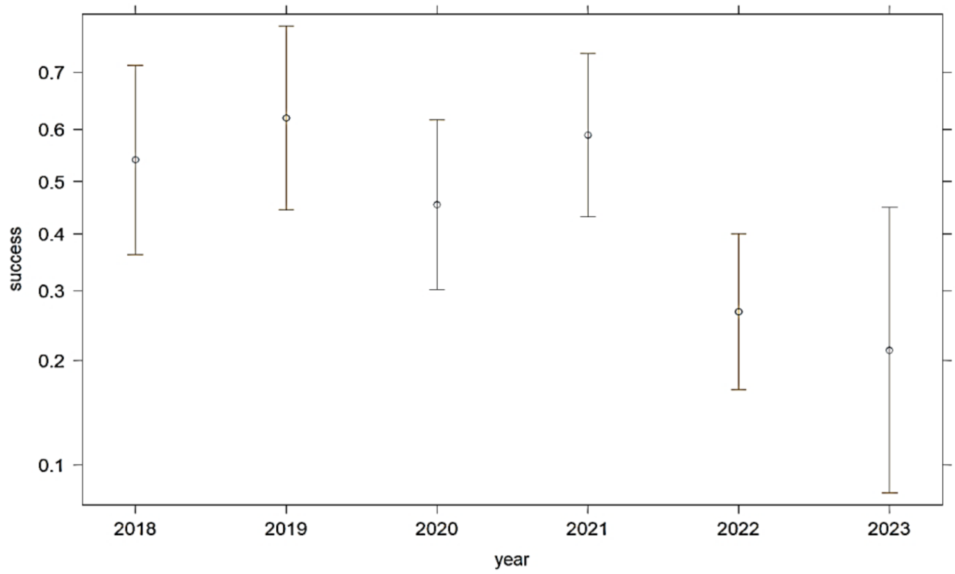

Figure 3. *Average breeding success (proportion of clutches leading to at least one fledgling) across study years.*

The reduction in breeding success was not compensated by an increase in the number of breeding attempts. Thus, the number of clutches per season did not vary significantly among years (Chi^2= 0.35 P = 0.62), remaining at an average of 2.05. As a consequence, productivity almost halved in the last two years, from ca. 2 fledglings/female/season to only slightly more than 1.

Therefore, the increased abundance observed in recent years from PECBMS data, is very unlikely the result of increased productivity, at least in Spain, which hosts a large fraction of the breeding population in the western flyway.

The ongoing capture-mark-recapture (CMR) programmes in Spain[4] have allowed estimating survival probability in at least two study sites, one in Castilla la Mancha

[4] *partly supported by the Spanish Ministry of Agriculture, Fisheries and Food, MAPA*

(Quintos de Mora SPA) and one in the Balearic Islands (in and around S´Albufera des Grau SPA, Menorca[5]). Table 1 includes the available data for those two programmes. Marked individuals carry a transponder attached to a plastic ring, which allows increasing recaptures through automatic reading in flat antennas (Table 1).

Table 1 *Summary data of turtle doves ringed and recaptured in Menorca and Quintos de Mora from 2019 to 2023. The columns "Capture year" and "N marked" indicate the year of first capture and the number of individuals captured for the first time (when they were marked). Other columns show the number of individuals recaptured each year and total individuals recaptured throughout the years.*

Study area	Capture year	N marked	Year of recapture				Total recaptured individuals
			2020	2021	2022	2023	
Menorca	2021	41			12	2	14
	2022	101				39	39
Quintos de Mora	2019	60	25	2	0	0	27
	2020	83		40	2	0	42
	2021	87			43	5	48
	2022	95				44	44

We adjusted Cormack-Jully-Seber (CJS) models with e-Surge for each study area. In the case of Quintos de Mora, we also included in the models to be tested a variable "period", considering pre-moratorium (from 2019 to 2021) and post-moratorium (from 2021 to 2023).

Results (Fig. 4) show an adult survival of (mean ± SE) 0.595 ± 0.042 for Quintos de Mora in the post-moratorium period, slightly higher than the survival rate of 0.559 ± 0.046 found for the same area for the pre-moratorium period. The estimate of adult survival for Menorca in the post-moratorium period was 0.624 ± 0.111, a value higher than that described for France in the pre-moratorium period[6]. Survival estimates for juveniles were also obtained, although the confidence interval for those was much larger due to the much smaller sample size for that age group (Table 1). Overall, these outcomes support that the increased population trend detected by PECBMS is very likely the result of increased survival resulting from the temporary hunting moratorium.

[5] *implemented by the Societat Ornitològica de Menorca (SOM) with the support of Consell Insular de Menorca and Govern Illes Balears*

[6] *Bacon, L., Guillemain, M., Arroyo, B., Carboneras, C., Fay, R, Sauser, C. & Lormée, H. 2023. Predominant hold of survival on the population dynamics of a threatened migratory game species: implications for hunting regulations. J. for Ornithology164: 275–285*

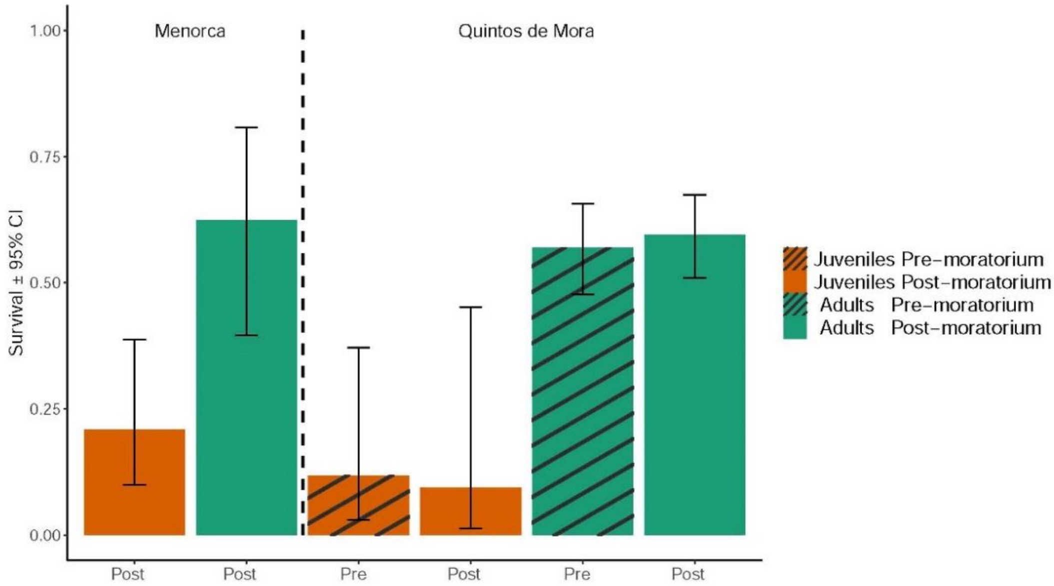

Figure 4. *Estimated survival probabilities of adult and juvenile turtle doves, pre-moratorium (from 2019 to 2021) and post-moratorium (from 2021 to 2023) in Quintos de Mora (Castilla la Mancha, Spain), and post-moratorium (from 2020 to 2023) in Menorca (Balearic Islands, Spain) for juveniles (in orange colours) and adults (in green colours).*

Analyses of the CMR updated information from France are currently underway to provide further confirmation of these data.

4- TURTLE DOVE PREDICTED POPULATION TRAJECTORIES FOR THE WESTERN FLYWAY UNDER DIFFERENT HUNTING SCENARIOS ESTIMATED THROUGH PDP MODELS

We used the Population Dynamics P Systems (PDP) model developed for turtle doves to assess the population consequences of different hunting scenarios, as a tool for facilitating discussions in the event of hunting being re-opened in the future. Specifically, we compared the population trajectories when implementing different hunting rates each year, as well as when implementing situations with intermittent hunting (i.e. hunting being allowed only certain years).

4.1 Methods

We implemented the PDP model using the demographic parameters (adult survival, juvenile survival and productivity) estimated by the Integrated Population Model developed by Bacon et al (2023)[7]. Additionally, our PDP model also assumed that hunting mortality is partly compensatory[8], and that a higher proportion of juveniles is killed by hunting than of adults[9].

We considered various possible hunting scenarios, as follows:

1. Scenario "0": no hunting in any of the years;
2. Scenario "2": 2% of the population available at hunting time harvested each year;
3. Scenario "4": 4% harvest rate each year;
4. Scenario "7": 7% harvest rate each year;
5. Scenario "13": 13% harvest rate each year;
6. Scenario "0007": this scenario represents a situation where a sequence of three years with 0% hunting is followed by one year with 7% harvest rate, and this sequence is repeated subsequently;
7. Scenario "000077": a sequence of four years with 0% hunting followed by two consecutive years with 7% harvest rate, and this sequence is repeated subsequently.

We tested those scenarios based on different premises: 4% harvest rate is roughly the harvest rate estimated by Bacon et al. (2023) to deliver population growth λ = 1 (i.e., leading to stability). 2%, half of the previous figure, is theoretically a harvest rate potentially leading to population growth and suggested by some stakeholders as a potential scenario to assess. 7% was roughly the harvest rate reported for 2020 (see Table S1), the last year when hunting was authorized in the western flyway prior to the moratorium, and when Spain implemented a more restrictive hunting policy compared to previous years, authorising turtle dove hunting only one or, in certain regions, two consecutive weekends, coupled with a daily quota of 5 turtle doves per hunter. Finally, 13% is roughly the hunting rate for 2019, the year prior to the moratorium. We also proposed two intermittent hunting scenarios ("0007" and "000077"), including a combination of years with no hunting ("0") and others with the harvest rate implemented in 2020 ("7")).

We considered 2023 as a starting point for the projection of trajectories and ran 100 simulations per cycle.

4.2 Results

Our results (Figure 5) show that, as predicted previously[10], maintaining the harvest rate of 2019 would lead to population decline, whereas maintaining a 0% hunting would lead to strong population increase. Scenarios with harvest rate lower than 4% (such as Scenario 2) would also

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[7] *Bacon, L., Guillemain, M., Arroyo, B., Carboneras, C., Fay, R, Sauser, C. & Lormée, H. 2023. Predominant hold of survival on the population dynamics of a threatened migratory game species: implications for hunting regulations. J. for Ornithology164: 275–285*

[8] *Péron, G. (2013), Compensation and additivity of anthropogenic mortality: life-history effects and review of methods.* J Anim Ecol*, 82: 408-417. https://doi.org/10.1111/1365-2656.12014*

[9] *Moreno-Zarate, L., Peach, W Rocha, G., Bota, G., Sardà-Palomera, F., & Arroyo, B. 2023. Age ratio of hunted birds, crippling losses and factors affecting daily bags of European Turtle dove in Spain: Implications for sustainable harvest management of a declining migratory species. STOTEN 868: 161192*

[10] *Bacon, L., Guillemain, M., Arroyo, B., Carboneras, C., Fay, R, Sauser, C. & Lormée, H. 2023. Predominant hold of survival on the population dynamics of a threatened migratory game species: implications for hunting regulations. J. for Ornithology164: 275–285*

lead to population increase, although the final population size after 30 years would be lower than that predicted for Scenario 0. Scenarios of intermittent hunting with 7% harvest rate combined with others with no hunting produce a similar population response to a scenario with a flat 2% harvest rate each year.

The latter presents interesting points for discussion, in terms of integrating governance issues together with ecological predictions. One of the agreed criteria for re-opening hunting is having in place credible and reliable mechanisms to implement reduced quotas. Implementing harvest rates of 2% might prove challenging for hunting authorities, given that they would involve either spatial restrictions or having systems to quantify harvest in real time and legal mechanisms to immediately stop hunting after a certain threshold was reached. A 7% harvest rate might be potentially easier to manage through the mechanisms implemented in 2020 in Spain (reducing hunting days to a minimum and implementing daily quotas per hunter).

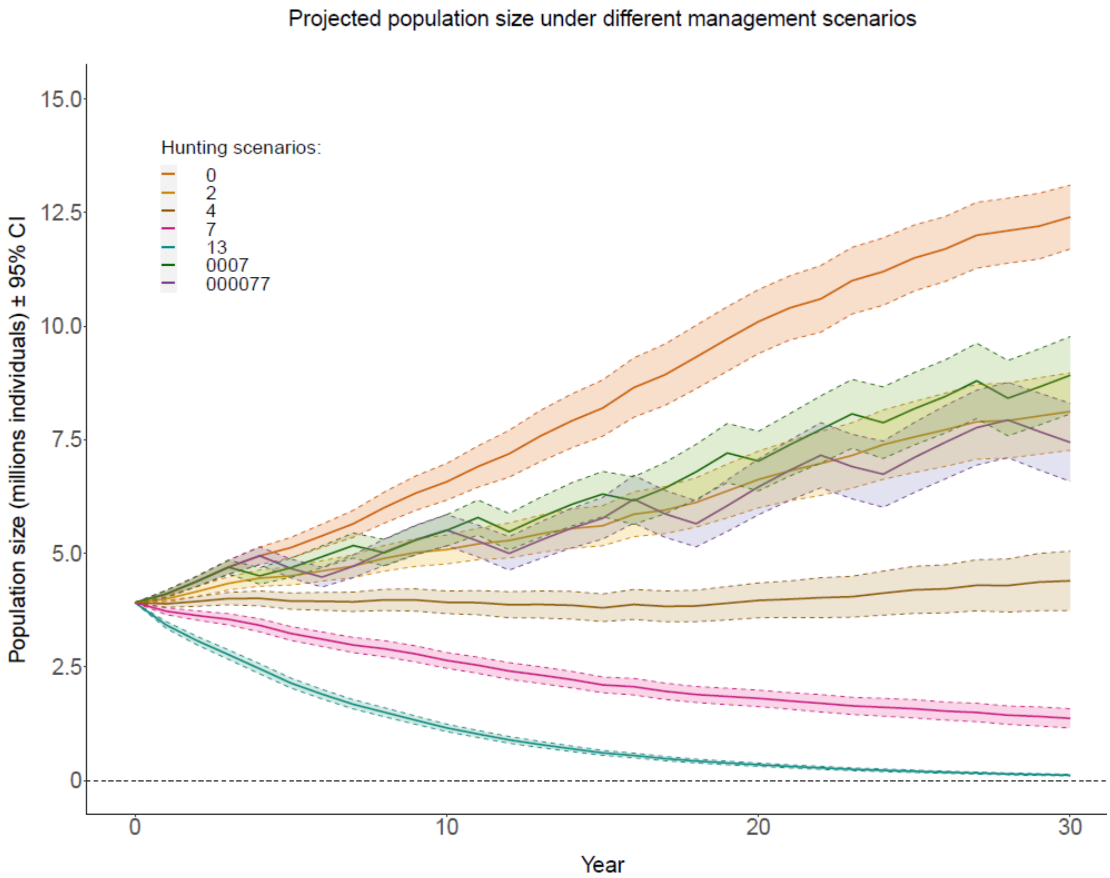

Figure 5. *Projected turtle dove population size in the western flyway estimated with the Population Dynamics P Systems method (PDP) for 30 years and different hunting scenarios. 95% Confidence Intervals are shown in dashed lines.*

5- ANNEX 1. PECBMS METHODOLOGY FOR ESTIMATING FLYWAY INDICES

Eva Šilarová and Jana Škorpilová (CZO)

5.1 Introduction

The PECBMS project office calculated indices and trends for both Turtle Dove flyways (western and central-eastern) from the PECBMS data. PECBMS national coordinators were requested to deliver data till year 2023 when possible. National coordinators put big effort to deliver as up-to-date data as possible, so we obtained data till year 2023 for most areas. Thus, out of 26 countries or regions, 19 delivered data till 2023 and 7 countries/regions delivered data till 2022. The allocation of countries to flyways was the same as in former years, the only change was that Cyprus was newly added to the Central-Eastern flyway. The final dataset was divided according to the flyways. Indices were calculated with the tool RSWAN, which is used for European index calculation. Its advantage is a stepwise completion of countries into regions and then to European level.

Permit for data provision was received from the national coordinators on 3.12.2020. All countries agreed to provide data.

5.2 Methods

5.2.1. Input distribution and preparation for rswan analyses

Two indices were calculated, one per flyway, according to the country distribution within flyways in the proposal (Table S1).

The final allocation of countries to flyways and year of latest data is as follows:

Central-Eastern flyway:

2023: BG, HR, CZ, EE, HU, IT-CE, LV, PL, RO, SK, SL

2022: AT, DE-CE, GR, LT

Western flyway:

2023: BE-WAL, FR, IT-W, PT, ES, CH, GB

2022: BE-FLA, DE-W, NL

Table S1. Distribution of countries per flyway, and last year of data available per country.

Country	Abbreviation	Flyway	Final year	Comment
Bulgaria	BG	central-european	2023	
Croatia	HR	central-european	2023	
Cyprus	CY	central-european	2023	Cyprus was a dded in the 2024 Report for the first time.***
Czech Republic	CZ	central-european	2023	
Estonia	EE	central-european	2023	
Hungary	HU	central-european	2023	
Italy_CE	IT-CE	central-european	2023	Italian data were specifically calculated for 2 parts according to the proposal. **
Latvia	LV	central-european	2023	
Poland	PL	central-european	2023	
Romania	RO	central-european	2023	
Slovakia	SK	central-european	2023	
Slovenia	SL	central-european	2023	
Austria	AT	central-european	2022	
Germany_East	DE-CE	central-european	2022	German data were divided according to the political division used in PECBMS, which corresponds with the proposal on Western and Central-Eastern flyways.*
Greece	GR	central-european	2022	
Lithuania	LT	central-european	2022	
Belgium-Wallonia	BE-WAL	western	2023	
France	FR	western	2023	
Italy _W	IT-W	western	2023	Italian data were specifically calculated for 2 parts according to the proposal. **
Portugal	PT	western	2023	
Spain	ES	western	2023	
Switzerland	CH	western	2023	
United Kingdom	GB	western	2023	
Belgium-Flanders	BE-FLA	western	2022	
Germany_W	GE-W	western	2022	German data were divided according to the political division used in PECBMS, which corresponds with the proposal on Western and Central-Eastern flyways.*
Netherlands	NL	western	2022	

** Germany delivers data to PECBMS with a 2-year delay. The calculation till 2022 is done only for the Turtle dove project.*

*** Italian team calculated national indices for both parts of the country on their own in the RTRIM-shell.*

**** Cyprus delivers data to PECBMS with monitoring period starting in 2006. Biogeographically, this country probably belongs to the Black Sea-Middle East flyway, but it would be the only country in our dataset representing that flyway. Therefore, the Task Force on the Recovery of Birds, acting as the AHM governing body, opted to treat Cyprus as belonging to the Central-Eastern flyway management unit.*

5.2.2. Flyway index calculation in RSWAN

The index for Central-Eastern flyway was calculated for the entire period 1982-2023, setting 1982 as the base year. For the Western flyway, the index was calculated for the entire period 1966-2023 (base year 1980). We use a tool called RSWAN, which is used as a standard tool for European index calculation in PECMBS.

5.2.3 Imputing of missing data during index calculation process

Each flyway index is calculated on the basis of a hierarchy of countries (for details see "PECBMS_computation_steps_2024.docx"). That hierarchy groups countries into regions with similar natural conditions, agriculture and history. This process allows calculating any missing values by using similar data and so to calculate indices in the most realistic way.

Imputing is used for all the missing years in the dataset. Therefore, a country which did not deliver data for last year is included in the supranational index calculations anyway. All the PECBMS countries which deliver high quality Turtle dove data are used for index and indicator calculations every year.

5.2.4 Country population sizes

The tool RSWAN, uses country population sizes for weighting of national data delivered by the countries/regions during the flyway index calculation.

Country population sizes from the European Red List of Birds (2021):

AT, BG, CH, CY, CZ, EE, ES, FR, GB, GR, HR, HU, LT, LV, NL, PL, PT, RO, SK, SL

Regional population sizes delivered by national coordinators:

BE-FLA, BE-WAL, DE-CE, DE-W

Italian population sizes calculated specifically for this project:

IT-CE, IT-W

Italian population sizes were delivered by the Italian coordinator. No available estimates at the regional level for flyways were available for Italy. Therefore, the Italian coordinator split the national estimates (150,000-300,000 BirdLife International 2017) in two according to a model assessing habitat suitability for the species: according to this model, 7.5% of the suitable habitat is located within the Western flyway and the remaining 92.5% within the Central-Eastern flyway.

Geometric mean for Italy divided into 2 parts was calculated this way:

212132,0343559640 = = square root of minimum_estimate * maximum_estimate

=> Geometrical mean for Central-Eastern part = 212132,0343559640 * 92.5% = 196222,1317792670

Geometrical mean for Western part = 212132,0343559640 * 7.5% = 15909,9025766973

5.3 Acknowledgements

The PECBMS data were provided by the following national coordinators: **Austria**: Benjamin Seaman, Norbert Teufelbauer (Monitoring der Brutvögel Österreichs), **Belgium**: Antoine Derouaux, Jean-Yves Paquet, Glenn Vermeersch (Common Breeding Birds Flanders & Common Breeding Birds Survey in Wallonia - Le suivi des oiseaux communs en Wallonie (SOCWAL)), **Bulgaria**: Iordan Hristov, Georgi Popgeorgiev (Мониторинг на обикновените видове птици - Common Bird Monitoring Scheme), **Croatia**: Ivan Budinski, Dubravko Dender, Vlatka Dumbović Mazal, Iva Mihalić, Mate Zec (Monitoring čestih vrsta ptica poljoprivrednih staništa u Hrvatskoj - Common Farmland Bird Monitoring in Croatia), **Cyprus**: Christina Ieronymidou, Stalo Leontiou (Πρόγραμμα Παρακολούθησης Κοινών Πουλιών – Common Birds Monitoring Scheme), **Czechia**: Jiří Reif, Zdeněk Vermouzek, Petr Voříšek (Jednotný program sčítání ptáků (JPSP) - Breeding Bird Census Programme), **Estonia**: Meelis Leivits (KAUR), Renno Nellis (EOÜ - point count project), **France**: Benoît Fontaine, Frédéric Jiguet, Romain Lorrillière, Lorraine Delthel (Suivi Temporel des Oiseaux Communs (STOC) - French Breeding Bird Survey (FBBS)), **Germany**: Malte Busch, Martin Flade, Bettina Gerlach, Johannes Schwarz, Sven Trautmann (German Common Breeding Bird Survey & German Common Bird Census), **Greece**: Aris Manolopoulos, Danae Portolou (Πρόγραμμα Παρακολούθησης των Κοινών Ειδών Πουλιών της Ελλάδας – Hellenic Common Bird Monitoring Scheme (HCBM)), **Hungary**: Zoltán Görögh, Károly Nagy, Tibor Szép (Mindennapi Madaraink Monitoringja (MMM) - Monitoring of our common birds), **Italy**: Mattia Brambilla, Gianpiero Calvi, Simonetta Cutini, Laura Silva (MITO2000 - Monitoraggio ITaliano Ornitologico), **Latvia**: Ainārs Auniņš, Oskars Keišs, Ieva Mārdega, Dagnis Vasilevskis (Latvijas ligzdojošo putnu uzskaites - Latvian Breeding Bird Monitoring scheme), **Lithuania**: Petras Kurlavičius, Renata Mackevičienė (Įprastų paukščių populiacijų gausos stebėsena (ĮPGS) – Lithuanian Common Bird Monitoring scheme), **Netherlands**: Arjan Boele, Joost van Bruggen, Adriaan Gmelig Meyling, Dorine Jansen, Chris van Turnhout, Jan-Willem Vergeer (BMP A – All breeding bird species project), **Poland**: Tomasz Chodkiewicz, Przemysław Chylarecki, Łukasz Wardecki (Monitoring Pospolitych Ptaków Lęgowych (MPPL) - Common Birds Survey), **Portugal**: Hany Alonso, Rúben Coelho, Cátia Gouveia, Guillaume Réthoré (Censo de Aves Comuns - Common Bird Census), **Romania**: Zoltán Benkő, Cristi Domșa, Ede Gábos, Zoltán D. Szabó, Judit Veres-Szászka (Monitorizarea Păsărilor Comune (MPC) - Common Bird Monitoring (CBM)), **Slovakia**: Jozef Ridzoň, Ján Topercer (Monitoring of breeding bird populations in Slovakia), **Slovenia**: Matej Gamser, Primož Kmecl (Slovenski monitoring pogostih ptic kmetijske krajine - Slovene monitoring of common farmland birds), **Spain**: Virginia Escandell, Emilio Escudero, Juan Carlos del Moral (Common Breeding Bird Monitoring Scheme (SACRE)), **Switzerland**: Christian Rogenmoser, Hans Schmid, Martin Spiess, Nicolas Strebel, Samuel Wechsler (Monitoring Häufige Brutvögel - Monitoring of common breeding birds), United Kingdom: James Heywood, Dario Massimino, David Noble (Breeding Bird Survey & Common Birds Census).

6- ANNEX 2. USING POPULATION DYNAMICS P SYSTEMS (PDP) TO PREDICT PAST TURTLE DOVE POPULATION CHANGES

6.1. Background and objectives

At the suggestion of FACE during the 3rd TFRB meeting (March 2023), we assessed how well the Population Dynamics P Systems (PDP) model could predict past changes in turtle dove population abundance, comparing the predictions of the model from an earlier date with the changes observed by the PECBMS monitoring. To do this, we considered the breeding population in 2007 (as estimated from PECBMS) as the starting point, and calculated the predicted population sizes from the PDP model from 2008 until 2023 as a function of the estimated harvest rate taking place those years based on reported and inferred data. We then compared the turtle dove breeding population size for the western flyway reported by PECBMS for 2008 to 2023 with the population numbers predicted by the PDP. This exercise is an ongoing work that will be part of a scientific paper being currently produced. Results thus have to be taken as preliminary.

6.2. Methods

We implemented the PDP model using the demographic parameters (adult survival, juvenile survival and productivity) estimated by the Integrated Population Model developed by Bacon et al (2023)[11]. The model assumed that hunting mortality is partly compensatory[12], and that a higher proportion of juveniles is killed by hunting than of adults[13]. Additionally, we adjusted in the model the harvest rate each year (as a difference from the mean observed in the period), based on the best available empirical data for each year, and inferred data when empirical data was lacking (see Table S2 for exact data used and details on calculation of the harvest rate).

Annual harvest rate was estimated as the ratio between hunting bag numbers and post-breeding population size, the latter estimated as the number of breeding pairs x 2 [adults], plus the number of breeding pairs x2.1 [juveniles], i.e., considering that all juveniles produced by breeding pairs were available for hunting.

For hunting bag size, we used annual estimates for Spain based on annual reports sent by each hunting estate, corrected by the proportion of hunting estates that had provided an annual report in each province and year. In the case of France, data were available only for 1998, 2013 and 2019. We used those data to infer the hunting bags for the missing years, based on predicted data from a General Linear Model with harvest as the response variable and year as explanatory variable in a quadratic relationship (Fig. S1). In the case of Portugal, we used hunting data from 2007 to 2015 available from ICNF (compiled and provided by CIBIO), based on information

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[11] *Bacon, L., Guillemain, M., Arroyo, B., Carboneras, C., Fay, R, Sauser, C. & Lormée, H. 2023. Predominant hold of survival on the population dynamics of a threatened migratory game species: implications for hunting regulations. J. for Ornithology164: 275–285*

[12] *Péron, G. (2013), Compensation and additivity of anthropogenic mortality: life-history effects and review of methods.* J Anim Ecol*, 82: 408-417. https://doi.org/10.1111/1365-2656.12014*

[13] *Moreno-Zarate, L., Peach, W Rocha, G., Bota, G., Sardà-Palomera, F., & Arroyo, B. 2023. Age ratio of hunted birds, crippling losses and factors affecting daily bags of European Turtle dove in Spain: Implications for sustainable harvest management of a declining migratory species. STOTEN 868: 161192*

provided by hunting estates and compiled per hunting district. For 2016-2018, we used hunting data from the Article 12 of the Birds Directive 2009/147/EC reporting system. Comparing data from Article 12 and ICNF for the years when both sources were available, it was possible to assess that Article 12 data were underestimated in relation to those reported by ICNF. We thus corrected hunting numbers for 2016-2018 from the Article 12 reports based on the percentage difference observed in previous years. Finally, we inferred hunting data for 2019 and 2020 in Portugal based on predicted data from a General Linear Model with harvest as response variable and year as explanatory variable (Figure S1). For Italy, data were only available for 2013 and 2019. For the period 2007-2012, we arbitrarily assumed the same hunting bag size as in 2013, and for the period between 2014 and 2018 we arbitrarily considered intermediate hunting bags between 2013 and 2019. To those data, we added crippling loses as 9.6% of the hunting bags[14]. And we considered zero-quota since 2021 for all Member States in the western flyway.

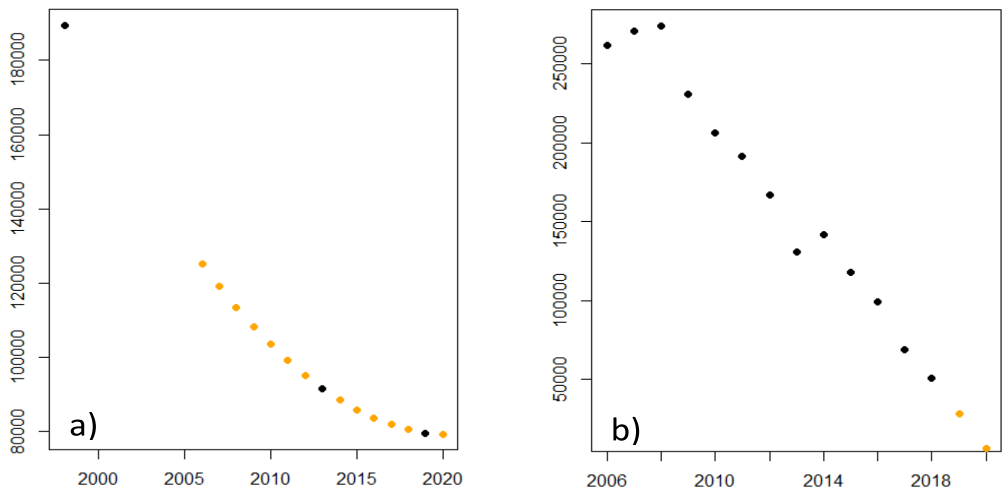

Figure S1. *Hunting bags inferred (in orange) for (a) France and (b) Portugal, according to a GLM with harvest as response variable and year as explanatory variable following a quadratic and a linear regression, respectively. Known hunting bags depicted in black.*

[14] *Moreno-Zarate, L., Peach, W Rocha, G., Bota, G., Sardà-Palomera, F., & Arroyo, B. 2023. Age ratio of hunted birds, crippling losses and factors affecting daily bags of European Turtle dove in Spain: Implications for sustainable harvest management of a declining migratory species. STOTEN 868: 161192*

Table S2. *Reported and estimated hunting bags of turtle dove for the western flyway (Spain, France, Portugal and northern Italy). In orange, hunting bags predicted from GLMs. In grey, arbitrary values allocated to northern Italy. Breeding pairs per year as reported by PECBMS. Harvest rate is the ratio of total hunting bag (including crippling losses) in relation to abundance at hunting time (breeding pairs*2 + breeding pairs*2.1).*

Year	Hunting bag Spain	Hunting bag France	Hunting bag Portugal	Hunting bag North Italy	Total hunting bag	Total hunting bag + crippling losses	Breeding pairs	Harvest rate
1998		189300						
2007	1063529	119158	270929	5000	1458616	1598351	2750728	0.143
2008	1094317	113510	273877	5000	1486704	1629130	2195831	0.182
2009	1040250	108291	230786	5000	1384326	1516945	2264213	0.165
2010	1054487	103501	206649	5000	1369637	1500848	1977266	0.186
2011	1009540	99139	191679	5000	1305359	1430412	2130097	0.165
2012	989418	95207	166918	5000	1256543	1376920	1771587	0.191
2013	922362	91704	131019	5000	1150084	1260262	1760826	0.176
2014	930033	88630	141860	3000	1163523	1274989	1842976	0.170
2015	929669	85985	117842	3000	1136495	1245372	1761413	0.174
2016	902067	83769	99143*	3000	1087979	1192207	1710600	0.171
2017	846476	81982	69016*	3000	1000474	1096319	1669043	0.161
2018	783569	80624	50931*	3000	918124	1006080	1670819	0.148
2019	668108	79695	28538	1450	777790	852302	1575624	0.133
2020	398909	11000	6318	1450	417677	457690	1633619	0.069
2021	0	0	0	0	0	0	1560190	0.000
2022	0	0	0	0	0	0	1712246	0.000
2023	0	0	0	0	0	0	1957405	0.000

**Values from Article 12 reports corrected according to differences between reported values in Article 12 and in ICNF for previous years.*

6.3 Results

The population size predicted by the PDP model followed fairly closely the population reported by PECBMS from 2008 to 2023 (Fig. S2), although the population stability detected by PECMBS from ca. 2013 was not observed, or only later and for a shorter period: the PDP predicted the turtle dove population size decline to slow down following changes in the harvest rate experienced between 2008 and 2020, with population size becoming relatively stable from 2017, and increasing after 2020.

Differences between both sets of data may result from differences in productivity: in the PDP model the values each year are randomly taken from the distribution of possible values, which may differ from the actual values experienced each given year. In any case, we consider that these results support that the demographic models developed for the western flyway are valid representations of their functioning (with the logical limitations that all demographic models include).

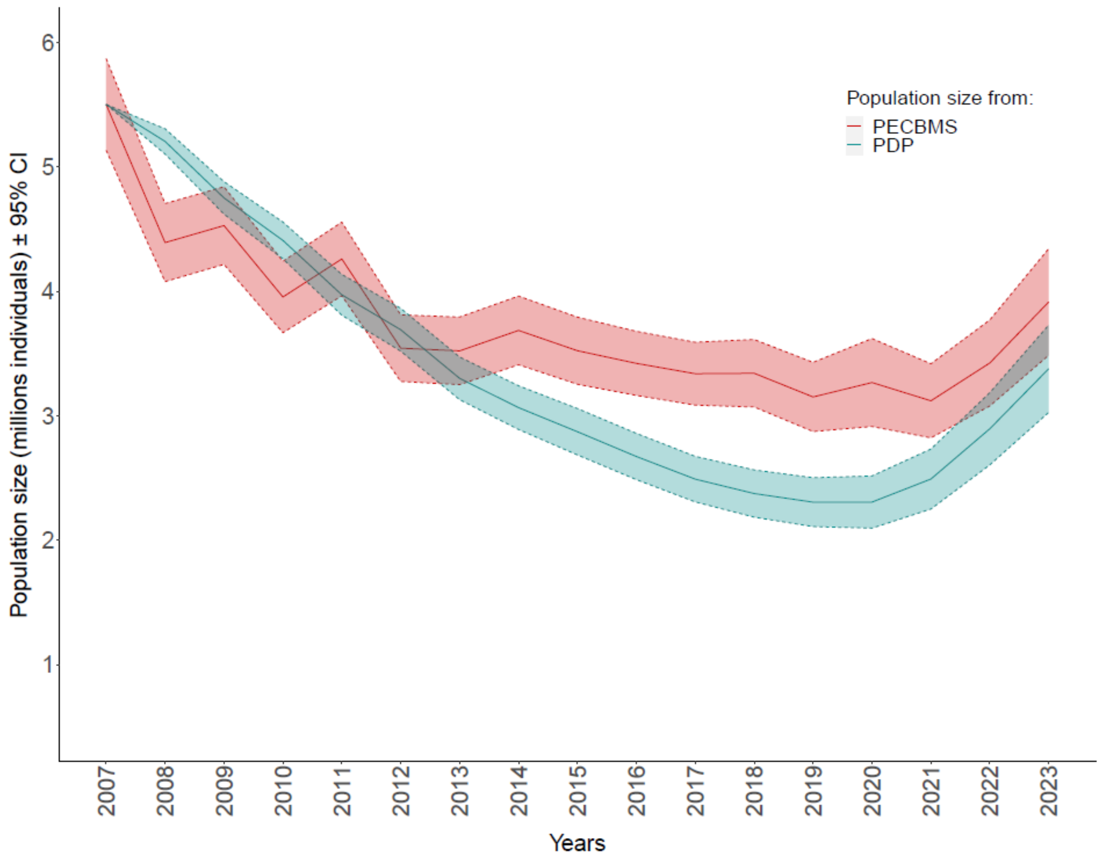

Figure S2. *Population size of turtle dove for the western flyway extracted from PECBMS (in orange colours) and estimated using the* Population Dynamics P Systems *method (PDP, in green colours) from 2007 to 2023. 95% Confidence Intervals are shown with dashed lines.*