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Research article

Ecological markers to monitor migratory bird populations: Integrating citizen science and transboundary management for conservation purposes

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ABSTRACT

Countries share responsibility for the management and conservation of migratory bird species. However, a limited understanding of population dynamics hampers the implementation of harvest and transboundary management. Age-ratios and population density can be useful indicators to assess population dynamics to improve management and conservation actions. Here, the dynamics of an Atlantic population of Common quail *Coturnix coturnix,* using 32,508 quail samples and 4814 hunter questionnaires over a 20-year period (1996–2016) served as a comparative study for examining age-ratio patterns related to different geographic zones, population density and weather parameters. Results show that age-ratios varied over zones and years, specifically age-ratio 1 (AR1), used as an index of late breeding attempts, varied from 0.1 to 0.21. Age-ratio 2 (AR2), a surrogate of central recruitment, varied from 0.16 to 0.66. Finally, age-ratio 3 (AR3), used as an indicator of the population's annual breeding success, varied from 3.69 to 6.68. Age-ratio is linked to internal and external factors (i.e. effect of rainfall, variations over time and density-dependent relationships) depicting how quail age groups make segregated migration in time and space. Quail age groups perform a complex pattern of migration because of entwined changes in abundance, migration routes and timing, influencing population connectivity and dynamics. Our findings highlight the relevance of citizen science and transboundary agreements to improve management and conservation measures of migrant species. Administrations and policy-makers in developed and developing countries must coordinate efforts to engage hunters in a participatory management systems to achieve sustainability.

1. Introduction

Wildlife resources are limited and commonly mismanaged. Yet the sustainable use of wildlife is mandatory for the conservation and maintenance of ecosystem services (Worm and Paine, 2016). Wildlife resource use continues to increase due to human population and economic growth (Xu et al., 2017a, 2017b; Yang et al., 2017). Global change impacts the behavioural ecology, breeding performance and movement patterns of migratory birds (Di Maggio et al., 2018; Haest et al., 2018). Because different ecological and socio-economic characteristics at winter grounds vs breeding areas can influence life history traits and demographic parameters, developed and developing countries must coordinate their management of migratory species (Ellison, 2014; Harrison et al., 2018). Coordination among countries is necessary for maintaining the favourable conservation status of these species (Kolpaschikov et al., 2015; Koschová et al., 2018). European wildlife conservation models assert that regulation plays a pivotal role in shaping management policy compatible with maintaining a satisfactory population level (European Union, 2010).

As information on terrestrial species harvests is limited, monitoring systems must be developed to sustain natural resource use (Ingram et al., 2015; Moa et al, 2017). The European management plan for quail *Coturnix coturnix* proposes the monitoring of exploitation and population trends (Perennou, 2009). Declines in large-scale biodiversity are ongoing (Uchida and Ushimaru, 2014), with the Common quail populations as an exception showing a positive population trend; unlike other migratory birds, which are undergoing widespread declines (Nadal et al., 2018a).

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Species characterized by more erratic or nomadic movements are difficult to manage and protect through current conservation planning approaches (Runge et al., 2014). Highly mobile and migratory species present a special challenge because they cross socio-political borders, exposing the species to many different threats including socio-political circumstances affecting population connectivity (Dallimer and Strange, 2015). On the other hand, quantification of the economic value provided by migratory species can aid in targeting management efforts and funding to locations yielding the greatest benefits to society and nature conservation (Mattsson et al., 2018).

Conservation management of quail populations must take into account both the ecological needs of the species and the social, cultural, economic, and political needs of people (Selier et al., 2016). Good natural resource management has four fundamental hallmarks: measurable objectives (hunting pressure on quail must be sustainable to maintain wild populations), evidence (reporting of quantitative information about population status), transparency (providing a hunting plan), and independent review (external appraisal) (Artelle et al., 2018). Because harvest data are either frequently lacking or are very crude estimates (O'Brien et al., 2017), management of migratory bird hunting must be improved with adaptive harvest management fostering learning and building capacity for auto-regulation among hunters.

Here, we take advantage of a long-term collaborative citizen science study (1996–2016) with hunters to collect biological samples for monitoring quail populations in Spain. Hunter participation is important in rural research to facilitate advancements in sustainable exploitation, increase environmental training opportunities, and sensitize hunters toward nature conservation (Dickinson et al., 2012; McKinley et al., 2017). Hunters contributed wing samples and filled out surveys allowing us to assess age-ratio index and density dynamics for interpreting population trends (Beissinger and Peery, 2007; Nadal et al., 2018b). The age-ratio index relationships along with other age-ratios index, density, weather parameters, and time, may explain different casual chains necessary to understand both population dynamics and contributions to ecological processes (Kramer et al., 2018; Layton-Matthews et al., 2018; Sherry, 2018) (Fig. 1). Quantification of age structure and demographic parameters as a proxy for the status and trends of wild populations is useful to improve management and conservation actions. Here, through hunter participation we aim to (1) describe age-ratio index of quail populations in different bio-geographic zones; (2) identify patterns of age-ratios over time, space and their relationship to other age-ratios, density and weather parameters; (3) assess the usefulness of known age-ratios to evaluate population trends in order to monitor, manage and conserve a transboundary species.

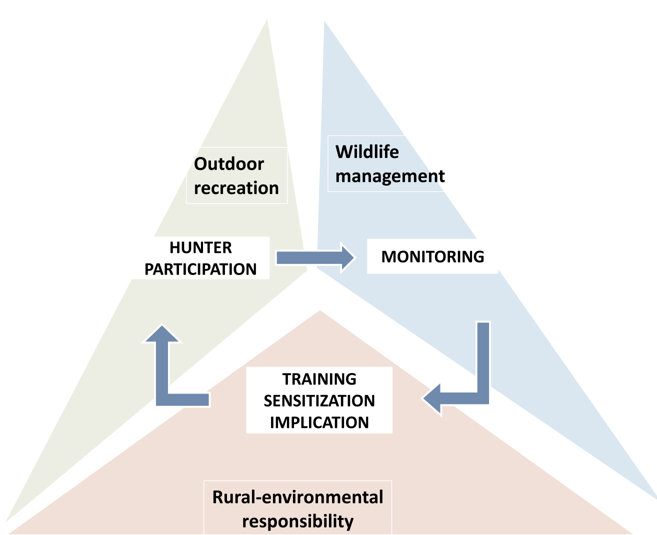

Fig. 1. The monitoring and sustainable hunting of quail involves three related phases.

2. Materials and methods

2.1. The study species

The Common quail is an Afro-Palearctic migrant bird, differing from other migratory birds in the stability of its populations. It is a sustainably harvested gamebird in Spain. To maintain the sustainability of the harvest, management tools for monitoring the wild population are needed. Quail have a short life expectancy, due to their migratory lifestyle, with few individuals living more than one year. In sedentary populations, life expectancy increases considerably but depends on predation and hunting pressure. The migratory quail's life history involves rapid development (1 month), with the achievement of sexual maturity at an early age (2 months), and a low average life expectancy (9 months) (Nadal et al., 2019). In view of the low life expectancy in migrant quail, we expect a high turnover rate in its population.

2.2. Study area

We studied the geographic zones of Spain based on images of cloudy zones (for more details see Nadal et al., 2018a). Consequently, we divided this territory into eight geographic units: the Canary Islands, South Iberian Peninsula, Balearic Islands, Ebro Valley, Duero Valley, North Plateau and the Northern Peninsula. From 1996 to 2016, we implemented a program of collaboration with the Spanish hunter federation (RFEC) involving hunters from these geographic zones to collect quail biological samples and fill out questionnaires (Burgess et al., 2017; Chapron et al., 2017). Voluntary participation in collecting biological samples and filling out surveys was proportional to quail abundance across geographic zones (Supplementary Information 1). We consider our results generalizable for common quail management across the area and countries inhabited by the species (Paul et al., 2014). Current and future management plans for quail must take into account the increase in anthropogenic activity and its impact on habitats and wild populations (Sherry, 2018; Sodhi et al., 2011). Higher economic growth requires greater use of natural resources, which in turn leads to more habitat degradation and wildlife declines (Stanton et al., 2018; Zakkak et al., 2015). Hence, higher income and more populated areas need coordinated, multi-country active management plans (Swagemakers et al., 2009; Walker et al., 2018). The responsibilities of each country should be proportional to their economic growth and human population (ORBYT, 2018; Fig. 2).

2.3. Data collection

We obtained rainfall and temperature data from AEMET (Spanish Meteorological Office), building a meteorological database for the eight geographic zones to obtain monthly averages for rainfall and temperature, and then calculated the rainfall and temperature from February to October. Quail hunting season opens in the middle of August and continues to mid-September. We collected 32,508 quail wings and 4814 hunter questionnaires from 1996 to 2016 across all geographic zones (Supplementary Information 1). DBC, FCCL, FEDENCA, RFEC (Spanish Hunting Federation) supported, disseminated and collected surveys and samples in this participatory study. We used printed envelopes with questionnaires to hold surveys. The Spanish Hunting Federation and its branch offices directly contacted hunters to request participation in the survey. Requests for involvement were also made through the hunting press, hunting radio and TV programs asking for the collaboration of hunters in the country and their participation in the survey. Surveys were distributed via the Spanish Hunting Federation and returned to the society. Survey respondents participated for one or more localities for several years, although few hunters participated for each data collection throughout the ten year duration of the study. Hunters participated in the survey alone or in conjunction with the hunting party. There are an estimated 110,000 quail hunters in Spain, 37,500 surveys were distributed and 4814 number of surveys were returned. Therefore the response rate was 12.84%.

2.4. Age-ratios and density

Quail have ten primary feathers, numbered from 1 (inside) to 10 (outside). The 8th, 9th and 10th primaries remain unchanged between the chick stage and first year plumage. Therefore, we used the wear-off in these feathers to classify a quail's age in months. We established six age classes, allowing three different age-ratios (Supplementary Information 2) index: age-ratio 1 (AR1), age-ratio 2 (AR2), and age-ratio 3 (AR3). These were measured from mid-August to mid-September (post-breeding migration). AR1 is an index of late breeding attempts, and is calculated by number of chicks less than one month old divided by the number of individuals of other groups. AR2 is an index of central and later breeding attempts, considering chicks and juveniles of less than three months old divided by the other groups. Finally, AR3 is an index of annual breeding, considering chicks, juveniles and juveniles of less than six months old (juvenile R) divided by the other groups (Nadal et al., 2018b).

$$AR1 = \frac{chick}{juvenile\ + juvenile\ R + adult1 + adult\ 2 + adult} \quad (1)$$

$$AR2 = \frac{chick + juvenile}{juvenile\ R + adult\ 1 + adult\ 2\ + adult} \quad (2)$$

$$AR3 = \frac{chick + juvenile + juvenile\ R}{adult\ 1 + adult\ 2\ + adult} \quad (3)$$

Density was calculated and standardized from each questionnaire using one quail hunting day. Questionnaires were filled out by individual hunters or hunter groups on a hunting day (Hochachka et al., 2012; Tulloch et al., 2013). Survey questions included the number of hunters in a hunting party, number of quail observed, hours spent hunting and number of bagged quail. However, for the purposes of this study, hunter participation data was not analyzed. We used two approximations to determine density. First, we calculated the hunting effort and second, the proportion of equality: quail bagged/quail observed = quail observed/quail in the area (Supplementary Information 3). We summarized the two approximations in a density equation as follows:

$$Density = \frac{number\ of\ quail\ seen^2}{hunting\ hours\ \times 1,5km \times (number\ of\ hunters + 1) \times 0.02\frac{ha}{km} \times\ number\ of\ bagged\ quail} \quad (4)$$

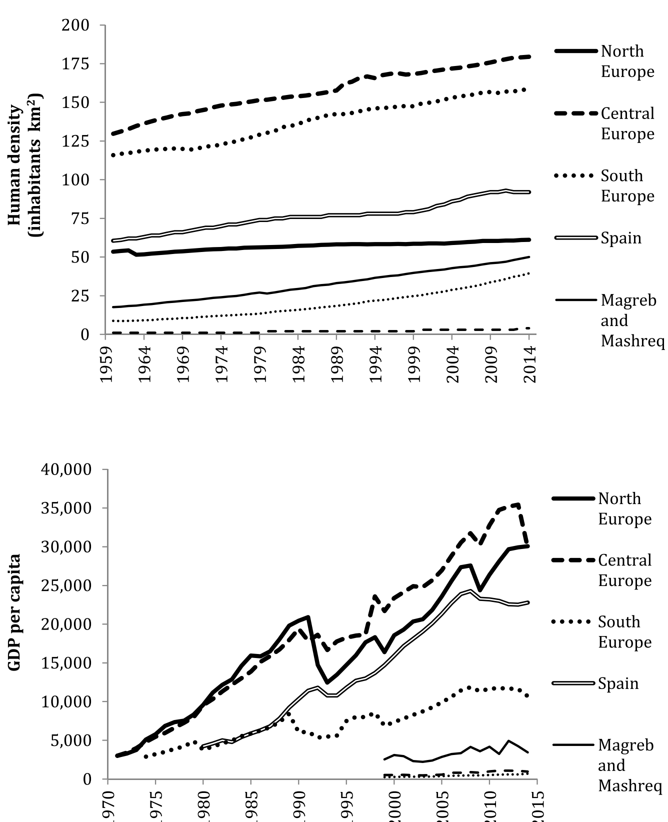

Fig. 2. Number of inhabitants and GDP (Gross Domestic Product) for the last few decades for countries with Common quail.

2.5. Data validation

Before the analyses, we validated and cleaned the data by reviewing all numeric information. When differences between the expected value and the reported value were detected, we contacted the hunter to validate or delete doubtful observations (Dickinson et al., 2010; Hochachka et al., 2012). We developed standardized rules for eliminating error from returned surveys, excluding data with erroneous information (i.e. a lack of coherence and rigor). For example, we removed the surveys with doubts and mistakes related to area of origin, date, reliability and fidelity of the observer, and/or contradictory or inconsistent values (Bonter and Cooper, 2012). We ruled out 32.82% of the surveys because they did not meet the requirements.

2.6. Statistical analyses

To contrast quail age structure among zones, we compared age-ratios with a Chi-square test on contingency table analysis. To detect changes in the quail age structure over time, we compared each age-ratio with an analysis of means for proportions of denominators by geographic zones. To show changes of quail age structure over space, we performed a logistic regression across zones. We explored with simple regression analysis the possible dependence of age-ratios for one year on the age-ratio of the previous year; checked the relationship between different age-ratios; contrasted the possible dependence of end-of-summer

Table 1
Quail age-ratios (AR1, AR2 and AR3) according to the different Spanish geographic zones during 1996–2016.

	AR1	AR2	AR3	N	Period
Canary Islands	0.03	0.16	6.37	199	2009–2011
South	0.01	0.24	3.96	2583	2002–2016
Balearic Islands	0.00	0.45	7.27	215	2003–2011
Ebro Valley	0.01	0.34	3.69	4228	1996–2016
Duero Valley	0.06	0.46	6.09	8488	2001–2016
North Plateau	0.09	0.66	6.68	15,173	1996–2016
North	0.21	0.64	4.36	1532	2002–2014

density on age-ratios and tested the possible dependence of density on age-ratios of the previous year, and vice versa. In addition, with simple regression we assessed the relationship of age ratios to rainfall and temperature in the period of February–July, and explored the association of age-ratios with time. Statistical analyses were carried out using JMP13 (SAS, 2016).

3. Results

In the late summer quail age structure varied significantly among geographic zones according to the three age-ratio indexes established (AR1: $\chi^2_6 = 783.5$, $P < 0.0001$, N = 32,391; AR2: $\chi^2_6 = 672.7$, $P < 0.0001$, N = 32,391; AR 3: $\chi^2_6 = 238.5$, $P < 0.0001$, N = 32,391, Table 1). Age-ratios also varied among years (AR1: $\chi^2_{19} = 614.5$, $P < 0.0001$, N = 32,391; AR2: $\chi^2_{19} = 3250$, $P < 0.0001$, N = 32,391; AR3: $\chi^2_{19} = 414.6$, $P < 0.0001$, N = 32,391). The logistic regression model in AR 1 showed significant differences among geographic zones over time ($\chi^2_4 = 40.87$, $P < 0.0001$, N = 80). With respect to AR2, there were no significant differences ($\chi^2_4 = 8.32$, $P > 0.08$, N = 80). Finally, AR3 showed significant differences for geographic zones over time ($\chi^2_4 = 28.36$, $P < 0.0001$, N = 80) (Supplementary Information 3). The analysis of means for proportions in AR1 in the North Plateau showed the most important variations (being 9 years of 20, different from the average). In contrast, we found the lowest variations in Duero Valley (5 years of 16) and no variation in Ebro Valley (Fig. 3, Supplementary Information 4). Concerning AR2, in all zones considered we found similar differences with regards to the mean. Only Duero Valley in 2008 differed from the other zones. Finally, AR3 showed distinct features in this analysis between geographic zones over time.

We found a moderate relationship between AR2 and AR1 ($R^2 = 0.42$, $P < 0.0001$, N = 80), and a weak relationship between AR3 and AR1 ($R^2 = 0.11$, $P < 0.002$, N = 80) and AR3 and AR2 ($R^2 = 0.20$, $P < 0.0001$, N = 80, Fig. 4). In contrast, we did not find any correlation between age-ratio of a year with age-ratio of the previous year. Density was not related to AR1 ($R^2 = 0.01$, $P > 0.27$, N = 41) or AR2 ($R^2 = 0.08$, $P > 0.07$, N = 41) but was related to AR 3 ($R^2 = 0.52$, $P < 0.0001$, N = 41, Fig. 3). No relationship between density in a year and age-ratio in the previous year for any of the three age-ratio indexes considered were found (AR1: $R^2 = 0.03$, $P > 0.32$, N = 33; AR2: $R^2 = 0.01$, $P > 0.50$, N = 33; AR3: $R^2 = 0.01$, $P > 0.67$, N = 33) and vice versa (AR1: $R^2 = 0.01$, $P > 0.60$, N = 33; AR2: $R^2 = 0.00$, $P > 0.94$, N = 33; AR3: $R^2 = 0.00$, $P > 0.82$, N = 33). We only found an association between AR1 and rainfall from February to October ($R^2 = 0.32$, $P < 0.0001$, N = 80, Fig. 4) but not with other weather variables. Over time, we only found a relationship between AR2 and the passing years ($R^2 = 0.19$, $P < 0.0001$, N = 80, Fig. 4).

4. Discussion

The three age-ratios show population status: late breeding attempts (AR1), central recruitment (AR2) and annual breeding success (AR3). The three age-ratios vary depending on the geographical zone and years. According to our results, age-ratio differences among geographic zones suggest distinct bouts of quail groups travelling across continents (Dhanjal-Adams et al., 2018). This is supported by the fact that quail groups may consist of different age classes consistent with age and sex patterns of migration (Hsiung et al., 2018). Our findings show that the three applied age-ratios (AR1, AR2 and AR3) are useful ecological indicators to substantiate decision-making processes, because these indexes are sensitive to population differences between biogeographic areas and demographic parameters. For example, in assessing last breeding attempts with AR1, we found that values were under 0.20 for the best zones and under 0.05 for the poorest zones, with the highest value in North Spain (Table 1) implying a high-quality habitat in August. Birds born in the area (chicks and juveniles) are indicated by AR2, and the annual productivity (chicks, juveniles, and juveniles R) is indicated by AR3. Age-ratios are influenced by quail routes (preferred migration pathways), aggregation (sites with quail concentrations) and dispersion (sites with low quail density) all of which may vary by zone (Lindén, 2018; Patchett et al., 2018).

Lower values of hallmark age ratio (see conclusions and Supplementary Information 5) signal poor late reproduction, poor reproduction in the area or poor breeding success along the migration route. Consequently we need to restrict harvest quotas to protect the population. Modern societies should be able to achieve conservation targets while providing opportunities for outdoor recreation (Pouwels et al., 2017). Along these lines, the participation of citizens in management and conservation programs is a tool widely used by administrations. In the case of game species, monitoring programs use hunter participation to improve social learning for sustainable management (Chang et al., 2017). Participatory monitoring provides a shared understanding and change in awareness and attitude related to sustainable harvests. However, citizen science is not a panacea, and further research is needed to better understand how hunter collaboration can build understanding and deliver positive outcomes (McKinley et al., 2017). By spreading scientific knowledge and engaging hunters in management formulations, participation can help identify solutions that lead to better environmental and social outcomes while avoiding unnecessary conflicts. Participation increases knowledge of responsible management, instills new values (perceptions) about wild quail and motivates protection of this migratory species (Jordan et al., 2010).

Our results suggest that the dependence of one age-ratio on another was weak. AR1 and AR2 in southern zones showed low values in contrast to northern zones, suggesting that quail density is better explained by AR3, because this index expresses annual productivity. On the contrary, density was not dependent on AR1 and AR2, because this parameter is

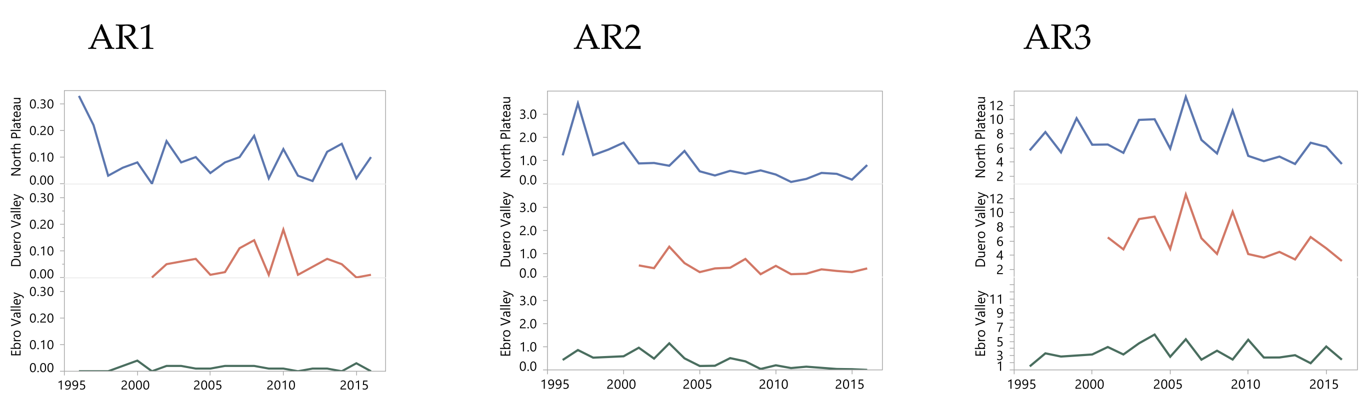

Fig. 3. Annual variation of quail age-ratios over time for the different Spanish geographic zones studied.

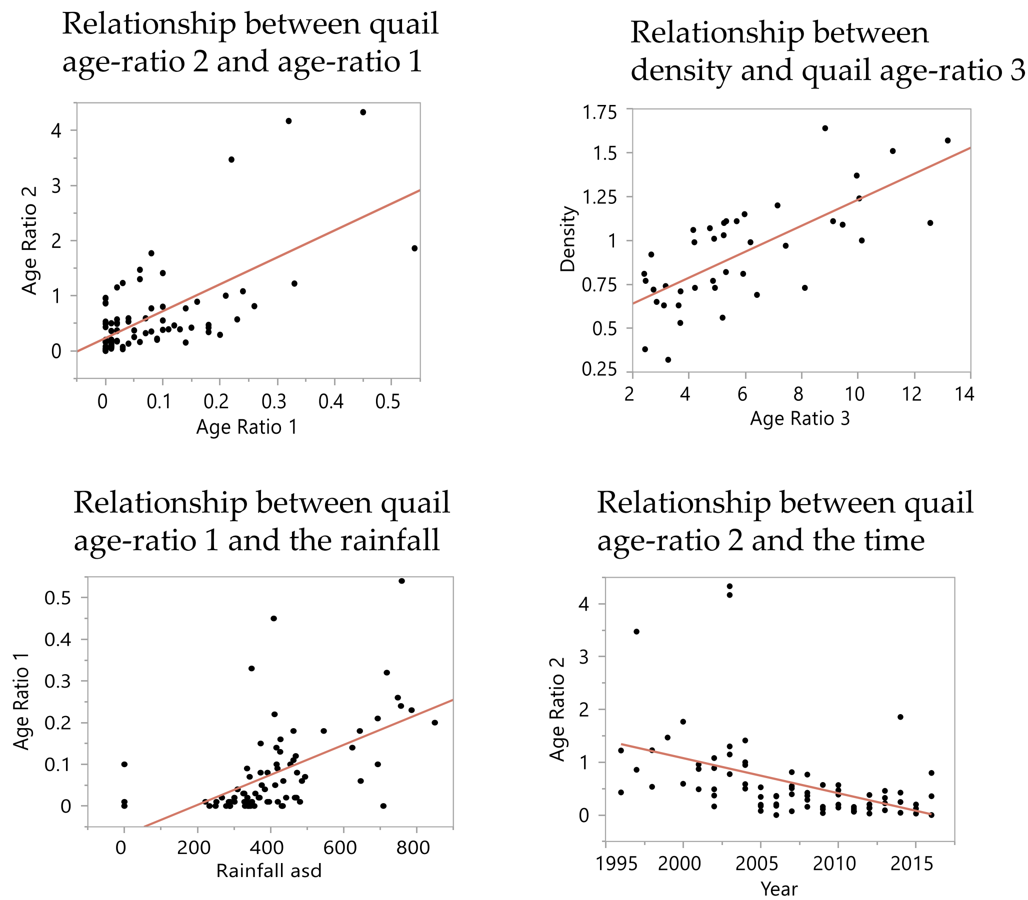

Fig. 4. Quail age-ratio relationships. Rainfall asd: average sum decilitre, obtained from February to October.

independent of last breeding attempts. Weather impacts net primary production, thereby affecting quail breeding success and predation (Ponti et al., 2018). AR2 decreased with the passage of years. This may be explained because in Spain, temperature increases in recent decades hastened quail arrival to breeding grounds (Cote et al., 2017; Kullberg et al., 2015). This agrees with the patterns observed in other migratory species showing reproductive failure (Socolar et al., 2017). In this sense, a progressive decrease in the breeding output for middle and later breeding attempts was observed in different Spanish geographic zones.

Currently, most migratory birds are declining due to global climate change (Patchett et al., 2018). However, quail populations remain stable/increasing, although quail are threatened by economic and human growth. Therefore, countries must work collaboratively to engage hunters and administrations in a participatory system of sustainable management. At the beginning of the 20th century, Egypt exported between 300,000 and 3 million quail every year to Europe - quail netted during spring migration (Eason et al., 2016; Guyomarc'h, 2003). Consequently, it seems necessary to encourage the development of wild quail management in an Afro-Palearctic context to address transboundary challenges and improve ecological connectivity, thereby limiting the mismanagement of wild populations due to different protection/management criteria, equipment and training in different countries (Bhat and Huffaker, 2007; Bischof et al., 2016). Afro-Palearctic countries have important asymmetries that create barriers and conflicts between countries, negatively affecting quail populations (Blanco et al., 2018; Roulin et al., 2017). Therefore, these political, social, economic, ecological, technical and scientific asymmetries must be addressed. In this sense, transboundary management addresses barriers and opportunities with costs and benefits in a complex set of interacting factors (Margalida et al., 2018; Swagemakers et al., 2009; Fig. 5).

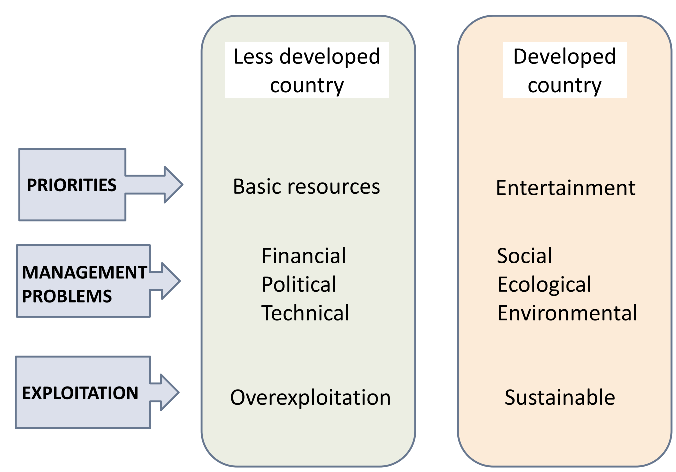

Fig. 5. Priorities, problems and exploitation of migratory bird in less developed and developed countries.

Our monitoring model provides a useful tool to design management plans at the transboundary population level. Afro-Palearctic countries should cooperate in order to manage transboundary quail populations. Cross-jurisdictional cooperative management of migratory species (Semmens et al., 2011) must consider that unstable countries do not protect biodiversity and habitat as well as nations with strong governance structures. Socio-political boundaries can impose substantial additional costs on the efficient and effective management of wildlife. Political borders dictate how biological diversity is monitored and managed (Bischof et al., 2016) and this can lead to over- and under-harvesting of wildlife. The management problems are political, social, economic, technical and scientific for less developed countries (healthy ecosystems) while ecological, environmental and social in developed countries (degraded ecosystems) (Tozer et al., 2018). Because quail harvesting is less controlled for less developed countries than in developed countries, it is necessary to balance this situation to enhance connectivity and improve population dynamics.

We must transform these asymmetries in cooperative synergies between less developed and developed countries (Sæther et al., 2016). The key to success resides in transfers of political, social, economic, ecological, technical and scientific issues in an adaptive way to less developed countries. Multilateral and bilateral meetings are necessary to form contractual agreements. Transferring payments through flexible and dynamic contractual mechanisms allows countries to negotiate adjustments in the schedule of side payments (Bhat and Huffaker, 2007) needed to encourage transboundary quail management. European management systems must be consolidated and open to African countries. Our findings support the idea that quail age-ratios as ecological indicators can be useful tools to manage and conserve wild populations. We must use this information to improve and correct management and conservation decisions.

5. Conclusions

Age-ratios are suitable indexes to assess population status and improve environmental management for sustainability. AR1 is related to rainfall in the zone and indicates aptitude for later breeding. AR2 indicates a decrease over time signalling, in our case, the effects of warming on breeding zones. AR3 is related to density and thus both density and AR3 are the best surrogates for population management. Based on our results, quail management benchmark values are as follows: AR1 (0.1–0.21); AR2 (0.16–0.66) and AR3 (3–6). From the adaptive management point of view, managers and policy-makers should consider how lower values indicate the need for decisions that prioritize the protections of these populations. Countries must share responsibilities in a dynamic way taking into account political, social, economic, ecological and education differences to promote adaptive harvest management. The European management system must reach Africa with essential transfers.

Author contributions section

Pennisi Lisa: writing. Ponz Carolina: design, analysis. Margalida Antoni: writing. Nadal Jesús: design, analysis, writing

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2019.109875.

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