Killing of birds by man with particular reference to illegal killing IKB

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1. General Introduction

1.1 Background and objectives, dataset

Quantifying intentional killing, especially when illegal, has recently been identified as a significant conservation issue. Illegal killing against protected species or when breaching the principles of sustainable harvesting for huntable species has recently stimulated efforts to quantify this phenomenon in areas like the Mediterranean (Brochet et al., 2016), Europe (Brochet et al., 2019), or the Middle East, Iran, and Iraq (Brochet et al., 2019). The Convention on Migratory Species CMS and the Berne Convention have activated different initiatives on the topic of Illegal killing, trapping and trade of wild birds (IKB). ISPRA (Istituto Superiore Protezione e Ricerca Ambientale, Bird Migration Research Branch, Italy), which is responsible for this module of the atlas, has direct experience on this specific issue, given the active role the Institute has had in the drafting and implementation of the Italian National Action Plan on illegal actions against wild birds. To date, Italy is the first country implementing such an AP.

Despite most European countries have aligned their national legislation to international environmental treaties, illegal activities continue to threaten birds in Europe. As an example migratory raptors, among other species, have (quantitatively) shown to be persecuted by illegal killing in the Mediterranean region (McCulloch *et al.,* 1992), Northern Scotland (Smart *et al.,* 2010) and Georgia (Van Maanen *et al.,* 2001). Therefore, the long historical coverage offered by the contents of the EURING Data Bank (EDB) represents a unique opportunity to improve existing knowledge on causes of intentional mortality by man, based on a geographical, historical, and seasonal basis, as well as with reference to the different methods adopted and taxonomic groups affected. Information on seasonal distribution of mortality intentionally caused by man is important to evaluate the relative demographic impact of taking on natural populations along their annual cycle. The range of species affected, the historical period and the geographic scale covered are unique features of the EDB contents and allow different analyses, including some targeting possible trends/changes in intentional taking by man for the same species and flyway along a time series of just over one century.

Firstly, we started with a general data exploration, with an overview of historical, geographical, and taxonomic patterns, which led to recognize a general declining trend in reporting intentional killing recoveries with time (section 7.2). We considered several reasons for this reduction and, as a possible explanation for the observed trend, tested the entry into force of the most relevant legal instrument for bird conservation along the whole flyway: the EU Wild Birds Directive (409/79EEC). In the different analyses performed we considered multiple spatial and temporal scales: at large scale we analyse how the intentional killing and taking of birds varied with the entry into force of the EU Wild Birds Directive, both for the original EU members and the more recently accessed ones (section 7.3). At a finer scale, we analysed the geographical distribution of "black-spots" (i.e., sites/areas of particularly intense deliberate killing of birds by man). Detecting these particularly risky areas, where the likelihood of deliberate killing of birds is high, can be beneficial in dealing with this worrying conservation issue (section 7.4). The black-spots identification was performed at different spatial resolution and scales, starting with the whole Eurasian-African flyway. This is one of the first attempts to date to point out critical areas in Africa based on ring recoveries, also to suggest conservation actions on the ground. The temporal scale of the phenomenon was considered from an historical and monthly basis, as well as dynamically. In section 7.5 we used the recovery data to estimate the starting and ending date of the deliberate killing. We run this analysis for two different time periods, before and after the entry into force of the EU Directive, to evaluate possible effects of related increasing

compliance. Finally, we exploited the unique features of the EDB to estimate the frequency of the "look-alike problem" (i.e., intentional killing of non-huntable species which are wrongly identified as legally huntable ones), which we defined based on mismatch between the species code reported when the bird was deliberately killed vs the one assigned by the EURING Scheme at ringing (section 7.6).

1.2 Data selection

The overall contents of the EDB have been selected by applying the following selection criteria:

Firstly, we retained records for which "use for atlas" was TRUE.

Then, based on values of the different fields of the EURING code (the alpha-numeric code internationally adopted to exchange detailed information on any recovery of a ringed bird among National Ringing Schemes within the EURING community https://euring.org/data-and-codes/euring-codes) we excluded records when:

- "*condition*" AND "*circumstances*" were 0 ("*unknown*"), given it is not known whether the bird was dead or alive at recovery;
- "*circumstances*" were coded as 29, 80-89, given these codes imply the bird was identified with methods different from the leg-ring, and no specific death circumstances were reported;
- "*condition*" code value was higher than 4, as we focus on dead birds;
- "*place code*" AND/OR "*scheme*" was unknown, as it is not known where the bird was found;
- "*date accuracy*" code value was higher than 5, to ensure the accuracy within +-2 weeks from the date of recovery;
- "*coordinates accuracy*" code value was higher than 6, to ensure location accuracy within 100km radius;
- a same bird recorded as dead more than once.

In this way, we got a dataset composed by the following cases of ringed birds reported as:

- 1,553,872 individuals
- 391 species
- 73 Families
- 23 Orders
- 147 countries
- 119 years, from 1900 to 2019

In the first phase we explored general aspects, starting with an overview perspective of historical, geographical, and taxonomic patterns. All the next sections begin with this subset of the EDB and every additional selection will be specified.

2. Results:

2.1 General overview: data distribution (taxonomy, historical period, geographical scope)

The following graphs offer an overview of the whole data set (recoveries within and outside Europe) relative to the distribution, along the historical period considered, of: Orders, Families, countries of recovery, conditions, and circumstances of recovery. The variables are ordered by frequency, not alphabetically.

The match between taxonomy and ringing scheme was not filtered, thus it might be possible to find taxa not distributed within Europe, given rings issued by European Ringing Schemes have been used for research projects in non-EU countries.

ORDERS:

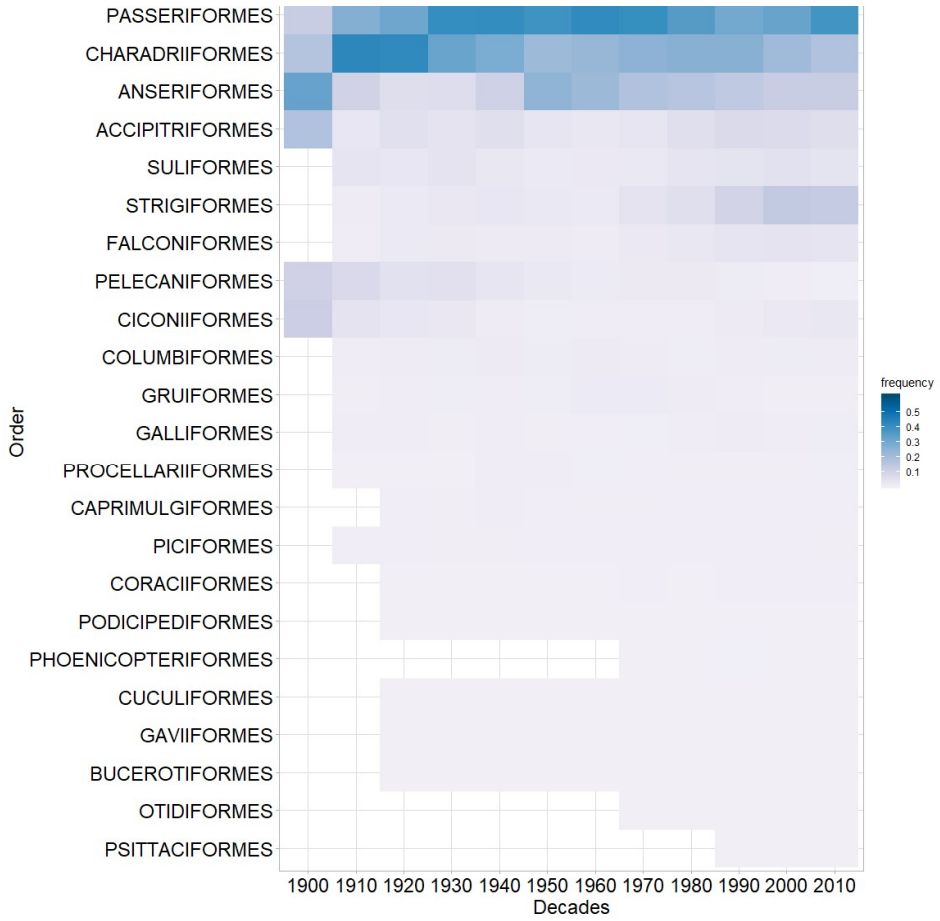


Figure 1: Chromatic graphic representation of the frequency of data at the level of Orders along the 12 decades in the dataset, dead birds only. Frequencies are reported per decade. Lightest shades of colour are frequencies <0.01 and white is missing data.

There are few Orders consistently more represented than others. This can be interpreted based on high numbers of species/Order (e.g., Passeriformes), high numbers of birds traditionally ringed/Order (e.g., Charadriiformes, Passeriformes), relevance of species within those legally huntable in Europe/Order (e.g., Anseriformes).

FAMILIES:

Figure 2: Chromatic graphic representation of the frequency of data at the level of Families along the 12 decades in the dataset, dead birds only. Note: frequencies are reported per decade. Lightest shades of colour are frequencies <0.01 and white is missing data.

Also, in the case of Families, some are consistently more represented than others. Similar considerations as those for Orders may apply.

COUNTRIES OF RECOVERY:

Figure 3: Chromatic graphic representation of the frequency of countries of recovery along the 12 decades in the dataset, dead birds only. Frequencies are reported per decade. Lightest shades of colour are frequencies <0.01 and white is missing data. Note: data abundance is relative to each decade, e.g., ~50% of the data from 1910 comes from the UK.

From this first synthesis of the dataset contents, and as expected, data are not homogeneously distributed in time. Furthermore, in subsequent analyses some least represented countries, Orders and Families, which only occasionally appear, have been excluded.

With the following graphs we describe how each Order, Family and Country contribute to the set of data referred to each decade. The categories are in reverse alphabetical order.

ORDERS:

Figure 4: Chromatic graphic representation of the frequency of data from each decade at the level of Orders. Lightest shades of colour are frequencies <0.1 and white is missing data. Please remind this representation is relative to each Order, so, for example, ~50% of data of the PHOENICOPTIFORMES are from the decade 1990.

FAMILIES:

Figure 5: Chromatic graphic representation of the frequency of each decade at the level of Families. Lightest shades of colour are frequencies <0.1 and white is missing data. Please remind this representation is relative to each Family, e.g.: ~50% of Phoenicopteridae data are from 1990.

COUNTRIES OF RECOVERY:

Figure 6: Chromatic graphic representation of the frequency of each decade across the countries of recovery. Note the countries represented are from the geographic area of Europe. Note: this representation is relative to each Country, e.g.: 100% of data from Afghanistan are from 1980. Lightest shades of colour are frequencies <0.1 and white is missing data.

This data exploration confirms that the volume of data becomes more consistent after the '60s and, for some countries, 100% of cases are concentrated in one or two decades only.

2.2 General overview: frequencies of conditions and circumstances of death

Condition type	N	Frequency
dead_noinfo	482280	0.310
freshly_dead	945183	0.608
not_freshly_dead	126409	0.081

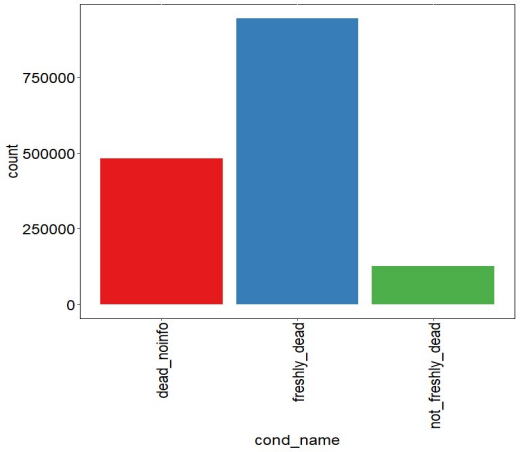


Figure 7: Histogram of the number of data per condition of recovery

TIME SERIES (decades) PER CONDITION

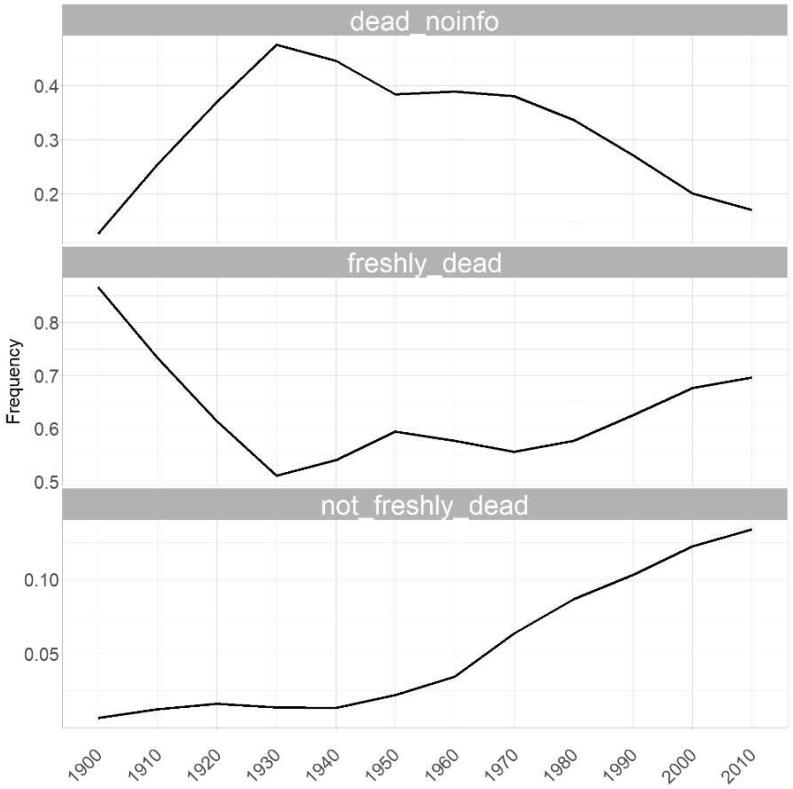


Figure 8: Graphic representation of the frequency of recovery condition per decade

Overall, 60% of cases refer to birds reported as freshly dead. The historical pattern for freshly dead birds shows a decline during the first few decades, followed by much smaller changes. On the other hand, the records of not freshly dead birds show an increasing trend. The data with no information decreased quite steadily after the '30ies. These trends might reflect an increasing effort in reporting all ringed birds found, even when not freshly dead.

We also looked at the frequencies of circumstances of recovery, considering only cases of dead birds where circumstances were known. The death causes in **bold** refer to intentional killing/trapping (i.e., intentional harvesting by man).

death_cause	N	Frequency
drowned	3884	0.004
found on ship	594	0.001
human_artifacts	51922	0.056
natural_issues_or_predated	172100	0.185
ringer	12946	0.014
road_casualty	228604	0.246
shot	**400729**	**0.431**
trapped_hunted_poisoned	**59626**	**0.064**

Table 1: circumstances of recovery of dead birds: number and frequency of cases

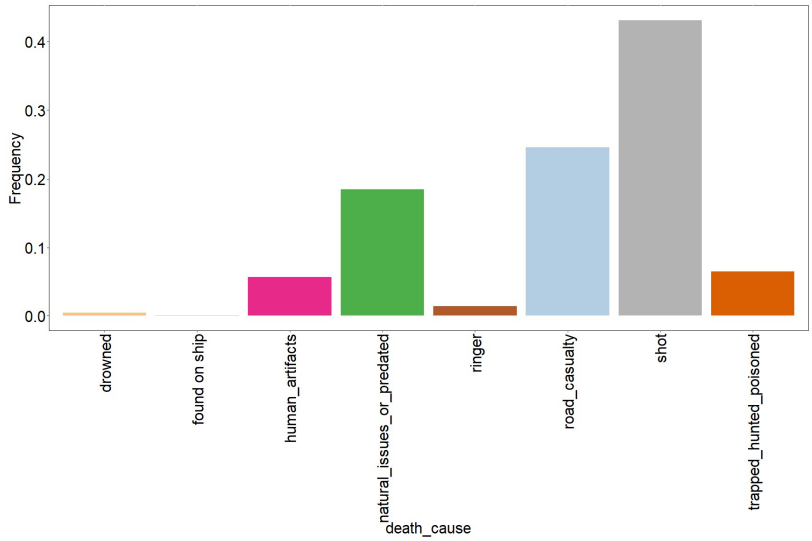


Figure 9: Histogram of the frequencies of data per circumstance of recovery (cause of death)

Overall, the most frequent circumstance of death is "shot" with over 40% of cases, which identifies intentional killing together with cases of birds being trapped, hunted, and poisoned. For circumstance of death not intentionally caused by man, the most common are road casualty (25%) and natural issue or predated (19%). The frequency of road casualties is indeed striking in terms of human-related losses.

TIME SERIES (decades) PER CIRCUMSTANCES (cause of death). Note: ordinate axis varies across graphs to better show patterns.

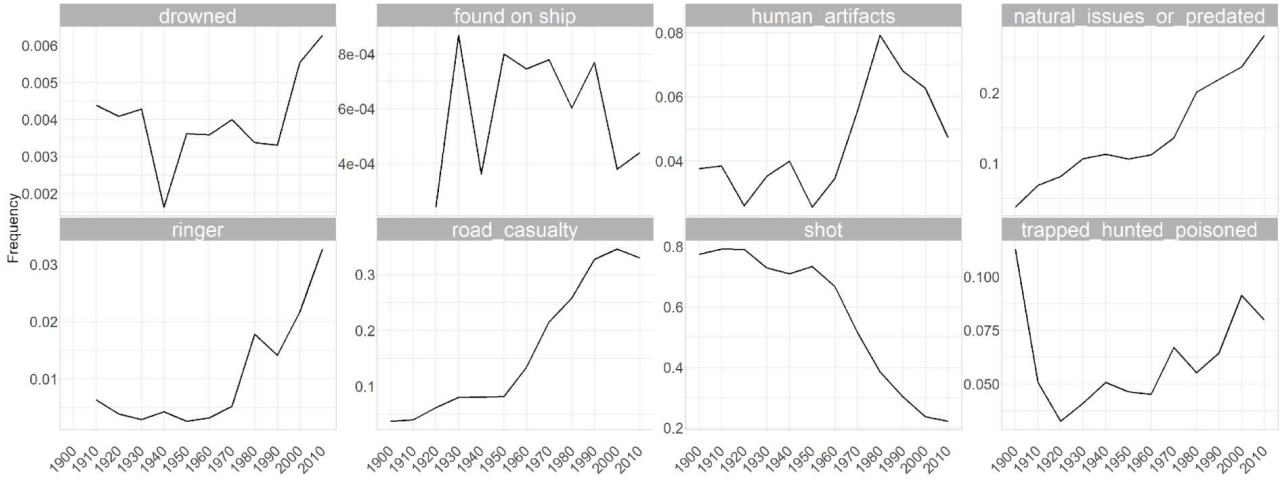


Figure 10: Graphic representation of the frequency of death circumstances along decades. The frequencies are relative to each decade. The frequencies relative to those found on ship "e-04" equals to 0.000, for example 4e-04=0.0004.

This time-series panel offers an overview of the historical variation of the frequency of death circumstances. Among interesting and striking historical patterns, the fast increase in road casualties, as a powerful indicator of increase in traffic with the ensuing impact on wildlife, and the sharply decreasing one of birds shot. For the latter, further analyses will focus on possible reasons for this steep and steady decrease during the last decades.

2.3 General overview: monthly distribution of recoveries of dead birds

The monthly distribution of recoveries of dead birds for each Order and Family contributes to evaluate the relative demographic impact of taking on natural populations along the annual cycle. The variables are in reverse alphabetical order.

ORDERS:

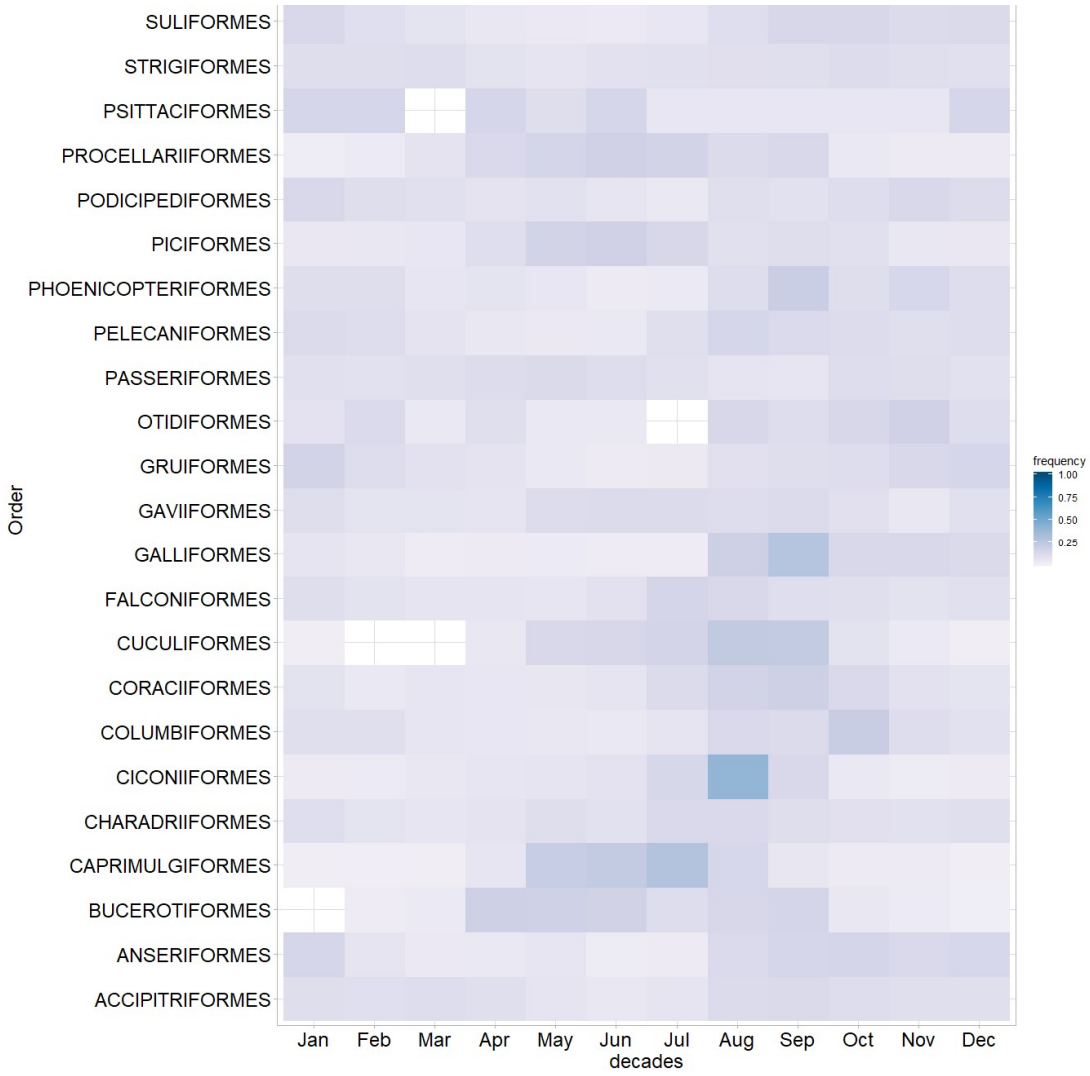


Figure 11: Chromatic graphic representation of the frequency of each month of the year at the level of Orders. Note: frequencies are relative to each Order. Lighter shades of colour are frequencies <0.1 and white is missing data.

It is interesting to note that there is a good coverage of data along the year for most taxonomic groups, which represents a good sampling for phenological analyses.

FAMILIES:

Figure 12: Chromatic graphic representation of the frequency of each month of recovery at the level of Families. Note: the frequencies are relative to each Family. Lighter shades of colour are frequencies <0.1 and white is missing data.

In general, there is a wide variability in seasonal patterns of recovery of dead birds, depending also on phenology and legal status.

TIME SERIES (months) PER CIRCUMSTANCES (cause of death). Note: ordinate axis varies across graphs to better show patterns.

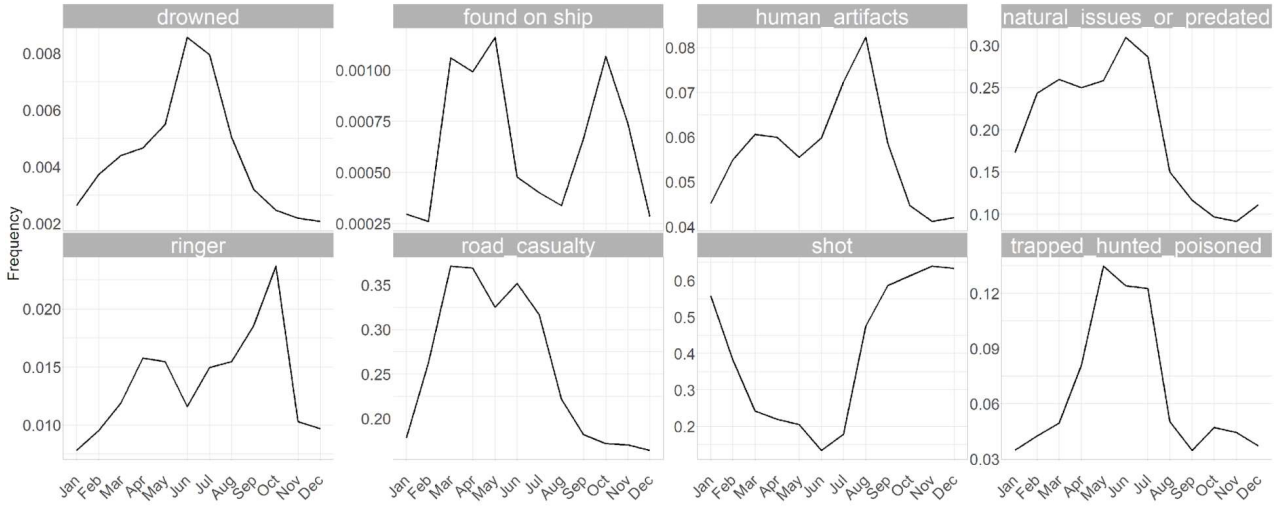


Figure 13: Graphic representation of the monthly frequency of death circumstances. Frequencies are relative to each month.

Deaths due to road casualties increase in spring and summer months, likely in relation to an increase in traffic during this period, as well as to the presence of breeding birds busy with intense movements during the nesting period and freshly fledged, inexperienced juveniles. Drowning events are mainly concentrated in the summer months, when water bodies are particularly attractive. Interesting is how the trapping and poisoning has quite an opposite pattern than shooting, which might also reflect the impact of methods different from shooting or different motivation in reporting legal hunting recoveries vs those deriving from activities peaking in intense phases of migration or breeding.

2.4 General overview: geographic distribution of intentional killing and taking of birds by man

In this section of the general data overview, we consider the geographical distribution of cases of intentional and not intentional killing in Europe and outside, through bar plots, a map and a map series to appreciate spatial and temporal changes.

INTENTIONAL or DELIBERATE KILLING is defined by EURING codes values 10, 11, 19 and 20, which identify a deliberate action of killing by man.

EURING CODE circumstances	Definition
10 Shot	Shot - for reasons other than codes 12 – 16 (i.e.: protection/safety)
11 Found shot	Found shot
19 Hunted	Words or phrases used to indicate the hunted bird has probably been shot
20 Intentionally taken	Hunted, trapped (including retraps by ringers), poisoned intentionally by man but not shot and not for reasons as for codes 21 - 29.

Table 2: definition of circumstances of recovery of dead birds

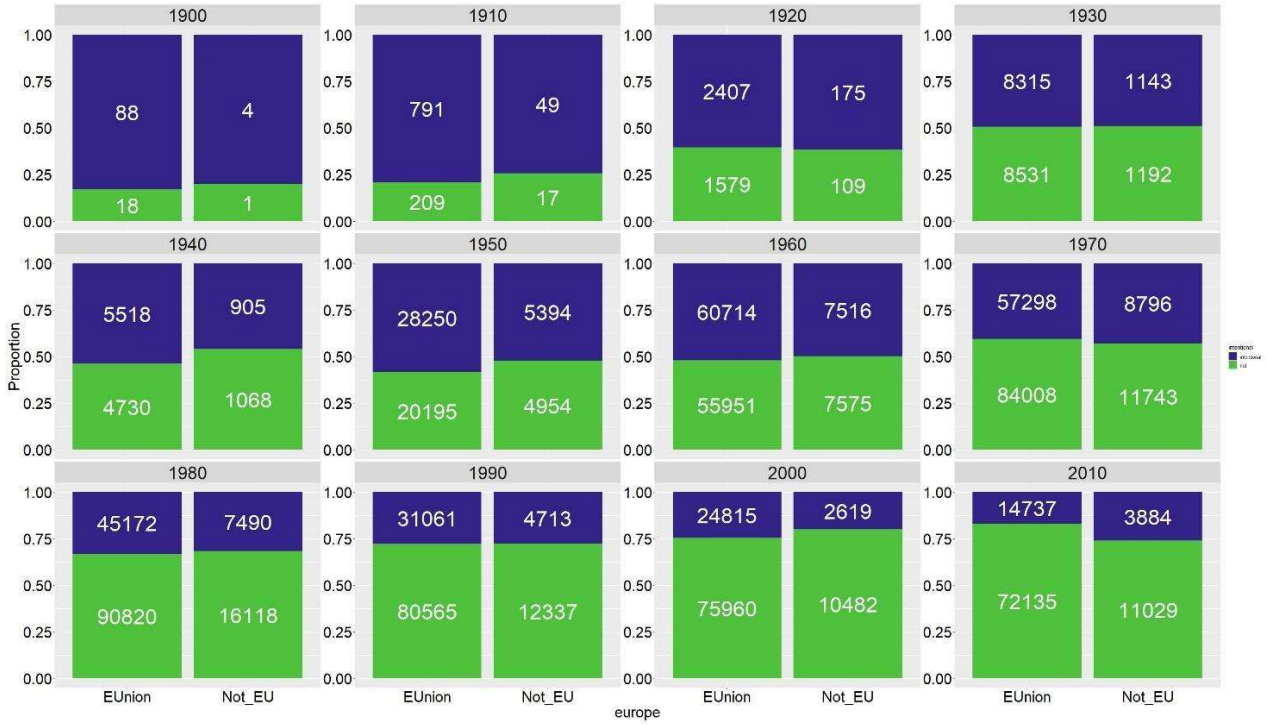


Figure 14: Bar plots per decade, comparing the proportion of intentional (dark blue) and not intentional (green) killing of birds in the European area ("EUnion", 28 countries including the UK) and Not European area ("Not_EU", 119 countries). White numbers represent sample size per each category.

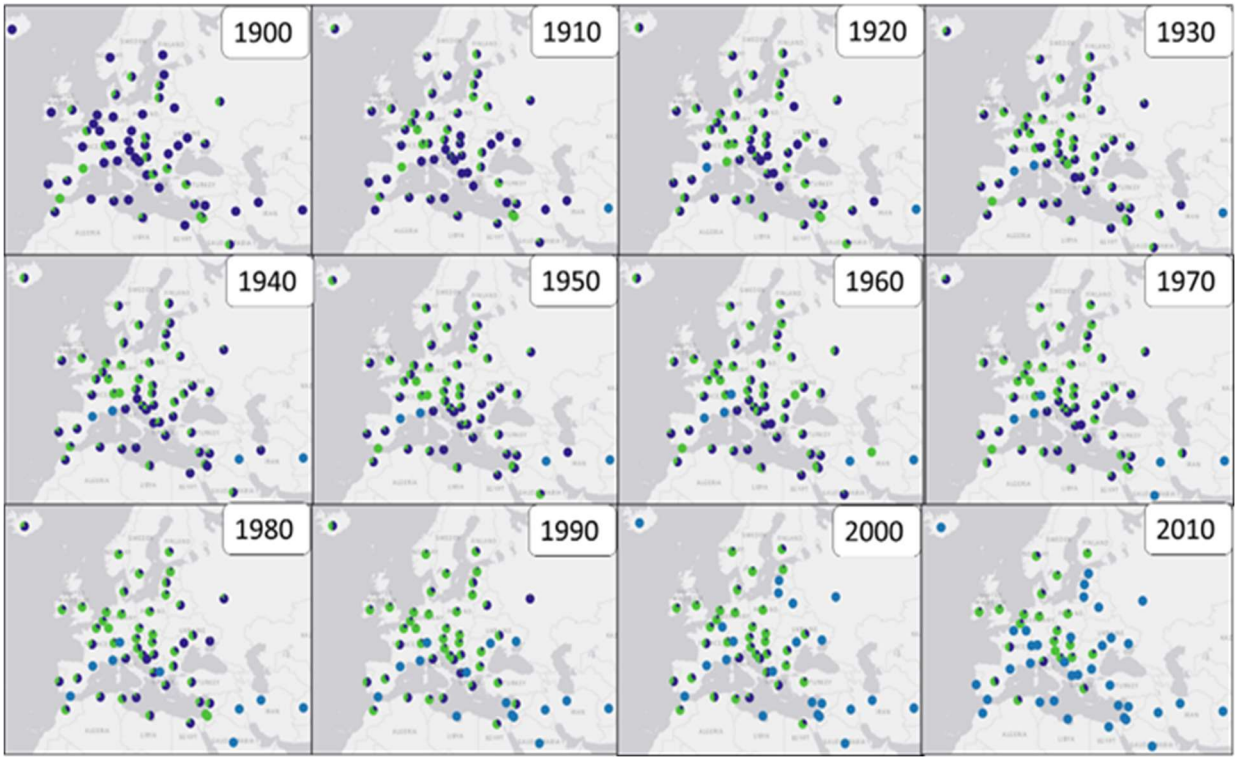


Figure 15: Map series of the European region to visualize the proportion of intentional killing per decade. Pie charts represent the proportion of the intentionally (dark blue) and not intentionally (green) killed birds per decade and

country of recapture. Light blue circles represent missing data.

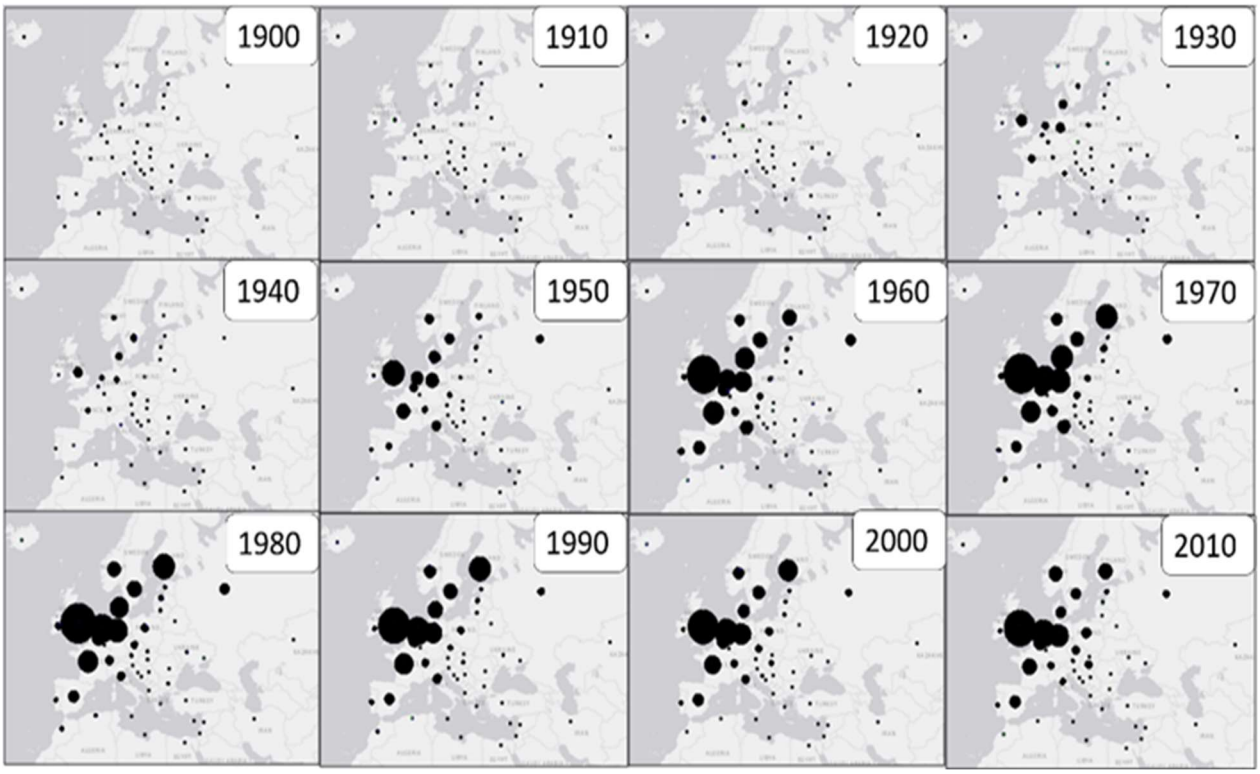


Figure 16: Map series of the European region to visualize, per each decade, the sample size of birds reported as dead (regardless of circumstances). Symbol size is proportional to the total amount of data available per decade.

Figure 17: Map of overall data. Per each country (centroids of coordinates/country) a pie-chart shows the frequency of intentionally (dark blue) and not intentionally (green) killed birds.

This data exploration highlights several aspects:

1- as indicated by previous analyses, most data originate from European Union countries;
2- within the EU, the proportion of intentional killing decreases significantly after 60s, while from the 80s across non-EU countries;
3- the number of recoveries largely varies also within EU countries, as a possible indication of variable ringing effort within different countries and/or within the areas of origin of birds moving across the different countries, as well as cultural differences possibly influencing reporting rate;
4- within the EU, the proportion of intentional killing as from recoveries of ringed birds changes along decades at different rates in different countries;
5- very interesting geographical differences are observed in the ratio between intentional/not intentional killing across African countries.

In the next section, different aspects in intentional killing reporting are commented and further investigated.

2.5 Historical trends in intentional killing reporting

Between 1960 and 2019 the intentional killing reporting declined from 52% to 17% in the EU (Figs. 14, 15). Exploring the causes of this decline is a pivotal as well as complex issue. Actually, ringing recoveries are the result of reports from citizens and do not originate from organized sampling programmes, therefore these data are affected by potential sources of bias. For example, the recoveries of birds taken by human activity (shot, trapped, road casualty, etc.) represents ~60% of the total "found dead" records (Fig. 9). Furthermore, ringed birds dying in remote areas, or where ringing practice is low, may have low reporting rates. Thus, socio-cultural factors influence the reporting probability, both positively (i.e., ~50% of the data from 1910 comes from the UK, Fig. 3) and negatively (e.g., when hunters may be reluctant to report a shot/trapped bird belonging to a protected species).

In the present section we focus on the European region, considering countries within and outside the European Union. We investigate the possible role of the first European environmental legislation, represented by the EU Wild Birds Directive (Directive 2009/147/EC), in the observed decline of reporting of deliberate killing of wild birds by man. The EU Wild Birds Directive (hereafter "the EU Directive") defines the minimum legal standards that all Member States must comply with, to protect and conserve wild birds and their habitats, in their territories and in the EU as a whole. It is the main legal instrument by which the Union delivers its obligations under the international conventions on bird conservation. It was issued in 1979 and entered into force in 1981, when 10 countries were part of the Economic European Union. The EU Directive considers all the over 500 species of wild birds living within the territory of the European Union, among which hunting species are identified, together with 194 to be protected all year round, the latter listed in Annex I. A further 81 species were later listed in Annex II of the Directive; 23 species in Annex IIA may be hunted across all European countries yet being protected during the sensitive periods of breeding (till the end of dependence of juveniles from adults) and from the onset of return migration towards the breeding areas. A total of 57 more species are listed in Annex IIB and may be hunted only in countries who apply for hunting these species. We had to exclude species listed in Annex IIB from our analyses, given it was impossible to obtain detailed list of what species were huntable and since when in each of the countries considered.

To assess the effectiveness of international environmental legislation as represented, in this case, by the EU Directive, we have given special attention to the period starting in 1981, when there were 10 members in the European Economic Community (as it was called then). Since then, the Birds Directive has formed a solid framework for bird conservation across the EU, and its geographical scope has enlarged together with the Union, to also include 10 new Members who joined in 2004, 2 in 2007 and Croatia in 2013. We consider EU countries including the UK, given the data analysed have been collected before Brexit. We present a historical description of recoveries in the EDB on the intentional killing of species listed in Annexes I and IIA of the EU Directive, as well as the whole list of EURING species reported within our geographical scope and considering the whole period of 119 years, covered by our study dataset. We also perform analyses on a monthly basis, to highlight the practical effects of the EU Directive in guiding the definition of

hunting seasons. The overall view of the effect of change before and after the EU Directive is finally presented geographically and per each country.

Geographical scope

The geographical scope of this section is the European territory of the 28 Member States of the European Union (EU28). However, some other country groups are defined:

- EU15: EU Member States before 1 May 2004
- AC13: countries that acceded to the EU after 1 May 2004
- non-EU28: countries beyond the EU28 borders

Figure 18: Geographical scope

Data description

Data referred to intentional and not intentional killing of birds by man which we have analysed, referred to species listed in the two Annexes, as well as not listed, are reported in the following table (sample size in brackets):

	Intentional	Not intentional	Total	N species
Annex_I	5.2% (20,855)	8.4% (93,280)	7.5% (114,135)	126
Annex_IIA	37.6% (150,886)	2.5% (28,371)	11.8% (179,257)	21
Others	57.2% (229,779)	89.1% (994,164)	80.7% (1,223,943)	198
Total	26.5% (401,520)	73.5% (1,115,815)	100% (1,517,335)	387

Table 3: data on intentional and not intentional killing analysed across categories of species

In general, birds listed in Annex IIA, which are legally huntable across the EU based on the Birds Directive, are those mostly reported as an effect of intentional killing, as well as representing 2.5% of the data referred also to not intentional death circumstances.

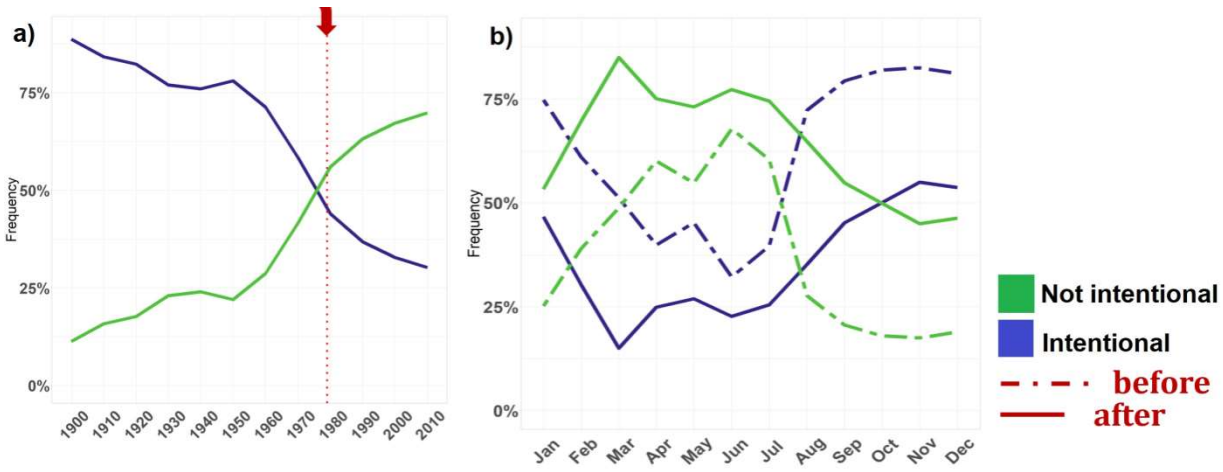


Figure 19: Overview of the historical (a) and seasonal (b) distribution of cases of intentional (blue) and not intentional (green) killing of birds as percentage of data per decade (a) and month (b). In a), the red dotted line and arrow highlight the entry into force of the EU Directive; in b), the period before the EU Directive is in dotted line, after 1981 in solid line. Data relative to all EU countries

At a broad scale, the intentional killing shows variations after the entry into force of the EU Wild Birds Directive. As shown in figure 19a, a decreasing trend of reports originating from intentional killing is registered along the decades, with the switch of trend matching the entry into force of the EU Directive. The seasonal distribution of mortality has stable patterns of intentional and not intentional killing before (Fig. 19b dotted lines) and after the Directive (Fig. 19b solid lines). The frequencies changed and switched in favour of not intentional killing except for hunting periods, where the intentional is still higher although much less than before the entry into force of the EU Directive.

2.6 Historical trends in intentional killing reporting per country and decade

In order to clarify the extent of the decline in reporting of intentional killing of birds by man, we firstly describe the general and intentional killing reporting per country as percentage of cases per decade. We represent this historical view for the whole sample of species and separately for species listed in Annex I and IIA, respectively. The total and deliberate killing reporting rate per decade and country is additionally distinguished per EU15 and AC13 countries respectively, highlighting the different periods of entry into force of the EU Directive. If the reporting trend is spread across most countries and after the entry into force of the EU Directive it shows a general decline, we can hypothesise this being an effect of compliance with the EU Directive, or/as well as a growing concern in reporting events of intentional killing, or an unknown mix of these different perspectives.

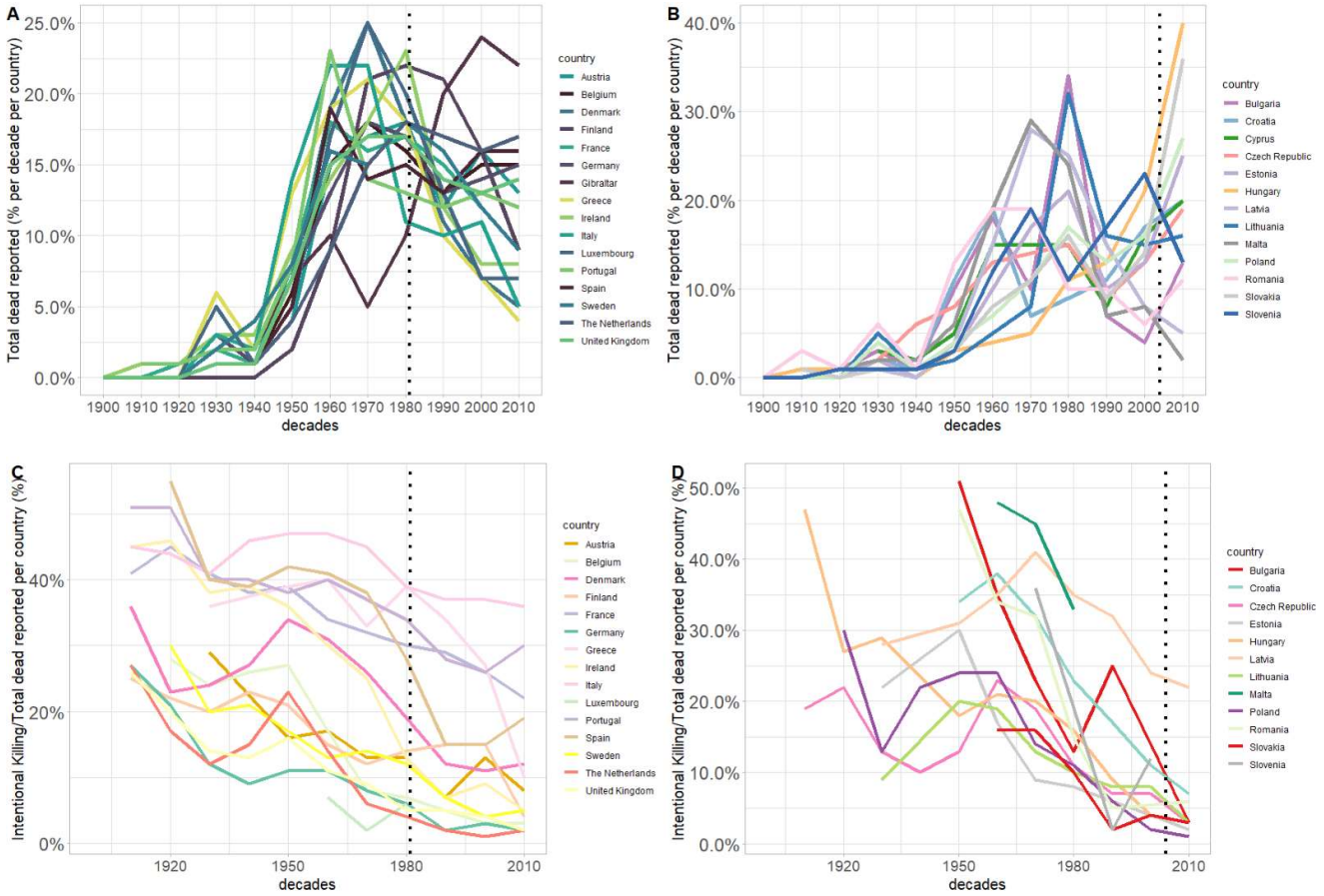


Figure 20: Total amount of birds reported as dead as percentage of cases per country of EU15 (A) and AC13 (B) per decade. Percentage of intentional killing on the total amount of birds reported as dead per country of EU15 (C) and AC13 (D). In order to better show patterns, the entries were filtered with total number of cases higher than 50 per each decade. All percentages are relative to each country and decade, based on the implementation of the EU Directive for EU15 countries since 1981 and for AC13 in 2004, as indicated by the vertical dotted lines.

Figures 20A and B show a somehow similar general historical pattern in reporting across all countries, reaching a peak between the 60s and the 70s and then (i.e., already before the entry into force of the Directive) declining with variable trajectories. The AC13 countries show a second increase close to joining the EU (decade 2000).

Figures 20C and D show the proportion of intentional killing with time, and it is interesting to note, especially among the EU15 countries, the presence of two groups: France, Portugal, Italy, Greece, and Spain (until the EU Directive) have not decreased the intentional killing as much as the other EU15 counties, considering all species together. The AC13 countries seem to be more homogenous after joining the EU, although their data suffer from a reduced sample size (see later).

Overall, the trends observed of total and intentional killing reporting decline seem to spread across the majority of the EU15 countries, especially after the entry into force of the EU Directive, suggesting the presence of an effect of this legislation within the single countries.

Considering only the species listed in the Annex I of the EU Directive, we expect a drastic drop on intentional killing reporting after its entry into force, because this list fully protects these species, making it illegal to kill them deliberately.

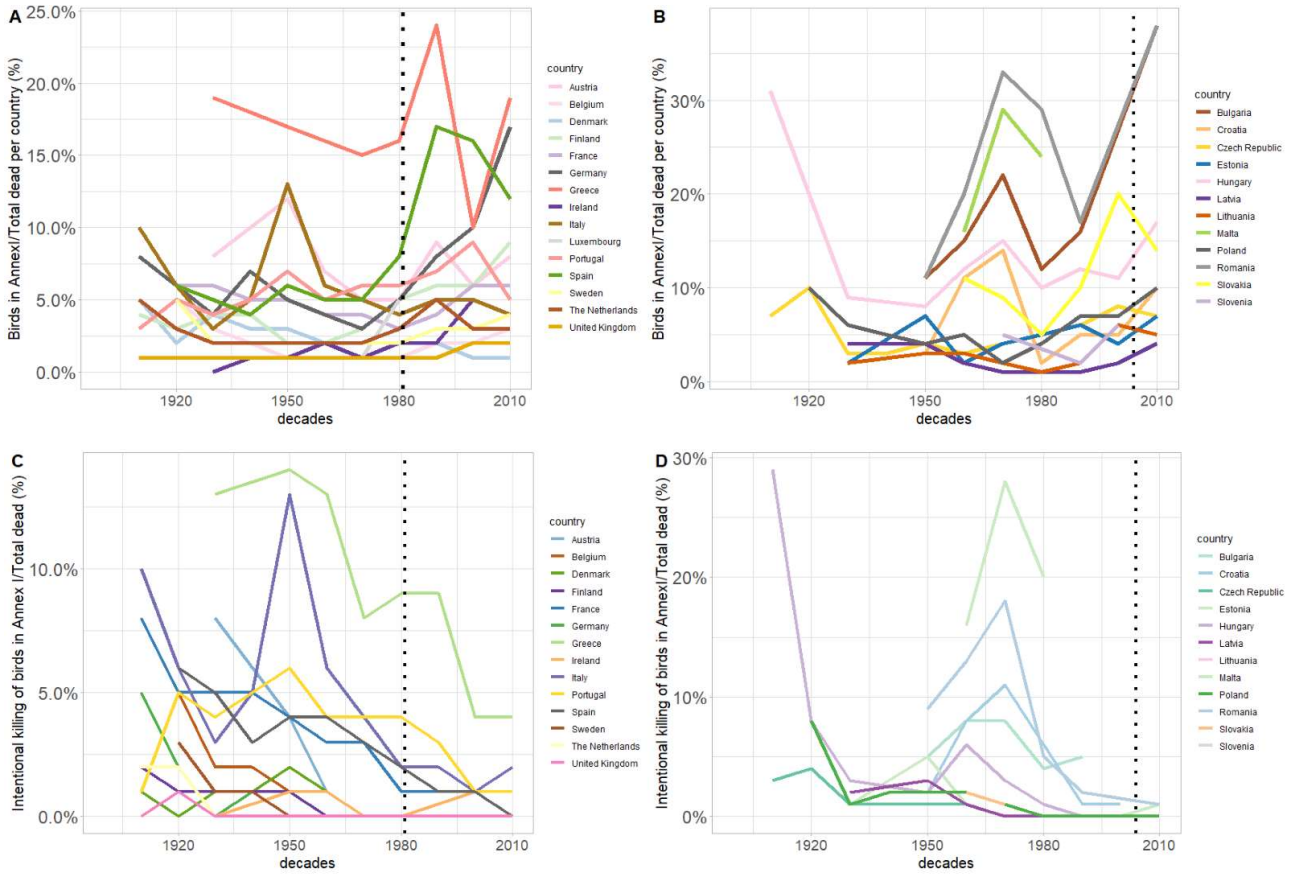


Figure 21 Annex I: Total amount of birds reported as dead belonging to species listed in Annex I as percentage over the total number of dead birds reported/country in EU15 (A) and AC13 (B). Percentage of intentional killing of birds listed in Annex I on the total amount of birds reported as dead/country in EU15 (C) and AC13 (D). In order to better show patterns, the entries were filtered with total number of cases higher than 50 per each decade. All percentages are relative to each country and decade, based on the implementation of the Directive for EU15 countries in 1981 and for AC13 in 2004, as indicated by the vertical dotted lines.

As shown in Figure 21 Annex I, the proportion of recoveries deriving from intentional killing is generally low, under 5% of the total of dead birds reported after the entry into force of the EU Directive in the EU15 countries, except for Greece, which maintained the highest reporting rate of intentionally killed birds and total amount of data referred to Annex I species.

Of the AC13 countries, the reporting of species listed in Annex I peaks in the 90s, although the intentional killing was relatively low, especially after the implementation of the EU Directive. Of the AC13 countries, Malta shows reports of over 50 dead birds only in the decades 60s-80s, out of which 15-40% were intentionally killed birds protected by the Annex I of the EU Directive.

Species listed in Annex IIA may be hunted throughout EU, following the principle of "wise use and ecologically balanced control of the species concerned". The EU Directive requires Member States to avoid hunting during the breeding period and till the end of dependence of juveniles from adults as well as, for migratory species, after the onset of return movements towards the breeding grounds.

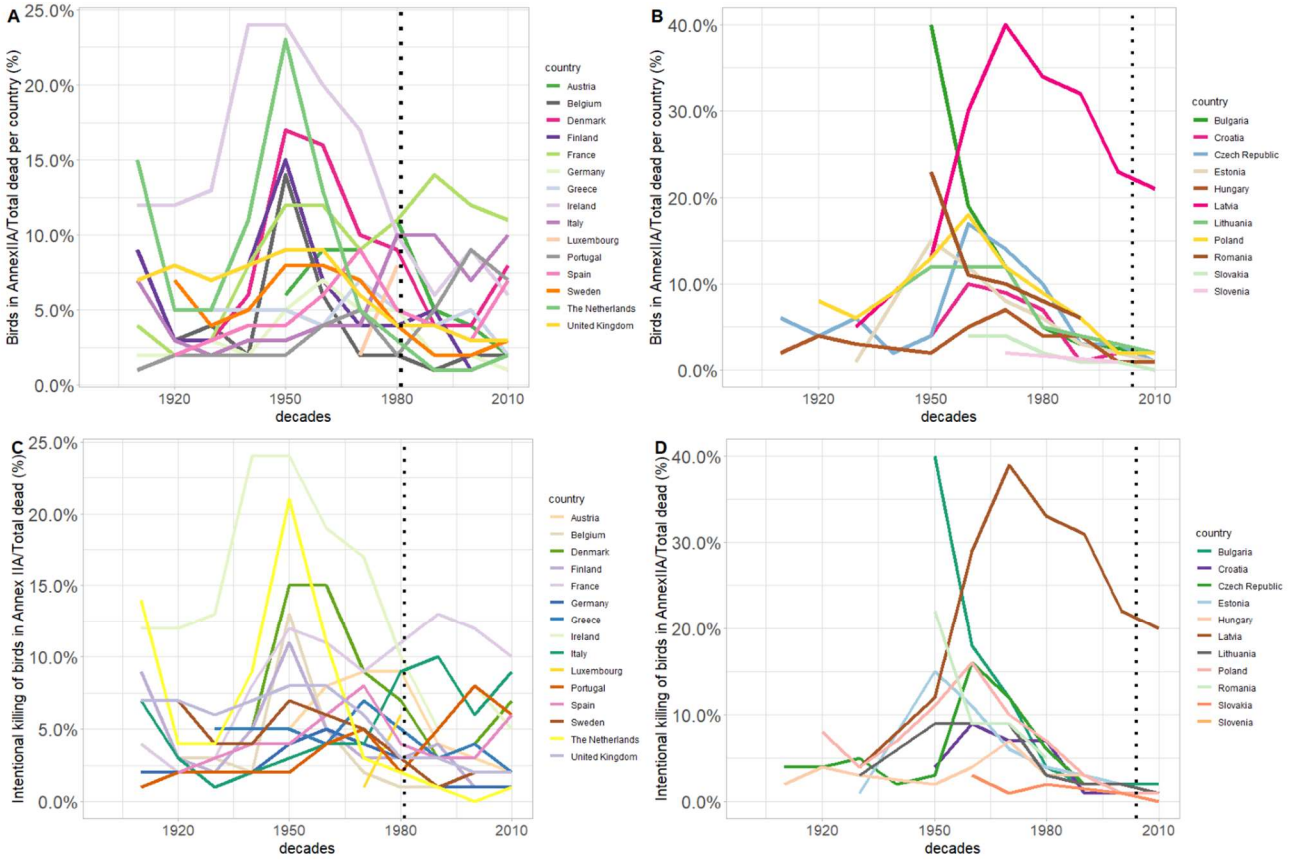


Figure 21 Annex IIA: Total amount of birds reported as dead listed in Annex IIA as percentage over total number of dead reported per countries of EU15 (A) and AC13 (B). Percentage of intentional killing of birds listed in Annex IIA on the total amount of birds reported as dead per countries of EU15 (C) and AC13 (D). The entries were filtered with total number of cases higher than 50 per each decade, to better show patterns. All percentages are relative to each country and decade, based on the implementation of the EU Directive for EU15 countries since 1981 and for AC13 in 2004, as indicated by the dotted lines.

Figure 21 Annex IIA shows a very similar pattern for the total and the intentional killing reporting along decades and for each country category. This means most of the reporting for these species primarily refers to intentionally killed birds. As a final stage of this historical perspective, we propose a figure that shows the proportion of cases of intentional vs not intentional killing per decade, respectively for all species (a), the ones listed in Annexes I (b) and IIA (c), separately for country category, pointing out the entry into force of the EU Directive.

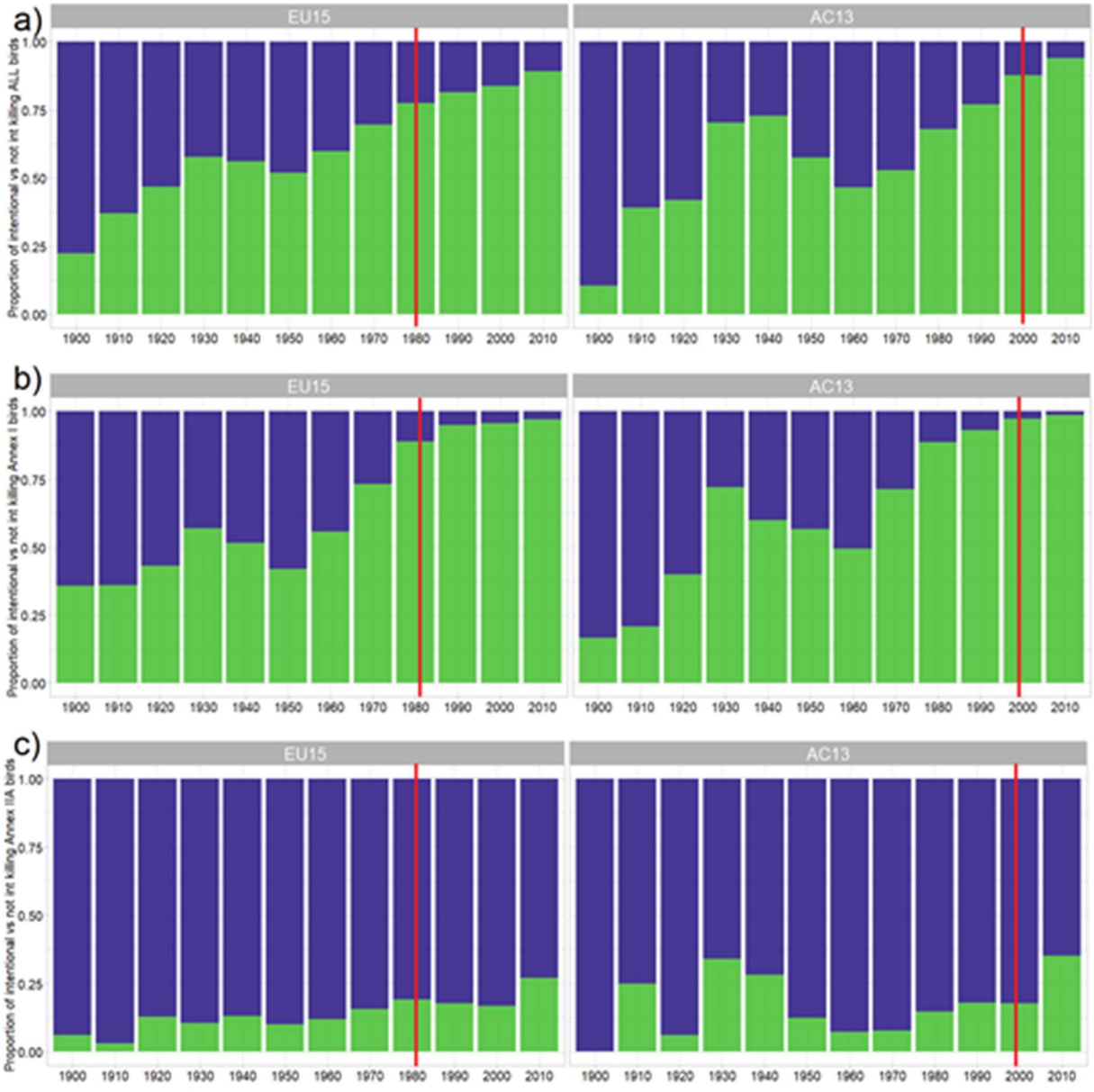


Figure 22: Proportion of intentional (blue) vs not intentional (green) killing of birds reported as dead per decade for EU15 and AC13 separately, considering: the whole dataset (a), species listed in Annex I (b), species listed in Annex IIA (c).

The trend described in figure 20 confirms a general historical decline in recoveries due to intentional killing, especially for species fully protected by the EU Directive through Annex I. For these same species, the decline in fact starts well before the entry into force of the Directive, both for EU15 and AC13 countries. A much less pronounced pattern is shown for huntable species (Annex IIA, figure 22c), which might suggest a role of the entry into force of the EU Directive in explaining the decline of reporting deliberate killing of protected species, given the absence of a similar clear trend in reporting of legally huntable ones.

2.7 Historical trends in intentional killing reporting events: monthly description of reporting across country categories

Monthly patterns of overall reporting cases vs those originating from deliberate killing before and after the entry into force of the EU Directive contribute to highlight the possible effects of the implementation of this important legislation regulating hunting across the EU. We therefore expect differences in monthly patterns of recoveries.

The following table summarizes the monthly percentage of birds reported as dead for species listed in annexes I and IIA of the Directive, as well as for all species in the general dataset analysed (sample size in brackets):

Month	Annex_I	Annex_IIA	Others	Total
Jan	4.7% (5342)	14.8% (26508)	8.5% (103925)	8.9% (135775)
Feb	4.1% (4641)	5.7% (10131)	7.8% (95959)	7.3% (110731)
Mar	5.4% (6161)	3.2% (5805)	8.2% (100463)	7.4% (112429)
Apr	6.3% (7216)	2.7% (4849)	8.9% (108406)	7.9% (120471)
May	7.6% (8697)	2.3% (4109)	10.0% (122229)	8.9% (135035)
Jun	14.0% (15936)	1.2% (2109)	9.3% (113522)	8.7% (131567)
Jul	14.0% (15989)	1.9% (3494)	9.7% (118432)	9.1% (137915)
Aug	16.3% (18586)	12.1% (21738)	8.6% (104940)	9.6% (145264)
Sep	10.8% (12332)	13.3% (23928)	7.1% (86884)	8.1% (123144)
Oct	7.2% (8210)	13.4% (24028)	8.2% (99791)	8.7% (132029)
Nov	5.0% (5749)	14.2% (25488)	7.0% (85202)	7.7% (116439)
Dec	4.6% (5276)	15.1% (27070)	6.9% (84190)	7.7% (116536)

Table 4: monthly percentage of birds reported as dead for species listed in annexes I and IIA of the Directive, as well as for all species (sample size in brackets)

The monthly pattern of recoveries of dead birds is different for the species listed in the different Annexes. Annex IIA species are protected from hunting during sensitive period of the birds' life cycle and, from this table, this period seems to span between March to July included. Nowadays the hunting periods are shorter across most of the EU, but we should consider that our study dataset spans a long period of time. June to September is the focal period for Annex I species. The cases of birds found dead belonging to other species seem to be more homogeneously distributed along the year.

The following figures look to all recoveries of dead birds in the EDB vs those reported as intentionally killed, to appreciate differences between before (grey) and after (yellow) the entry into force of the EU Directive.

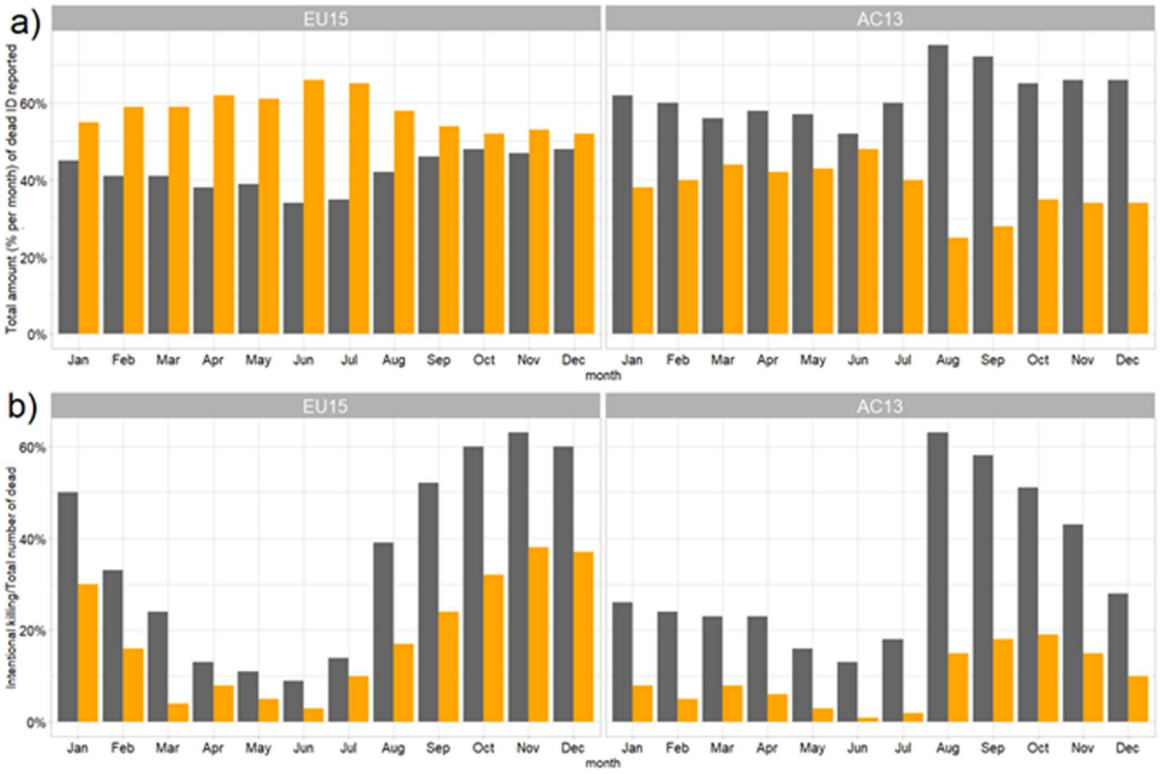


Figure 23: Percentage of the total number of birds reported as dead per month of the year (a) and percentage of intentional killing (b), calculated per country and per EU15 and AC13 separately. Grey – before, yellow – after entry into force of the Birds Directive

A general increase in the number of recoveries is observed after the entry into force of the EU Directive in EU15 countries, while an opposite pattern applies for AC13 countries (Fig. 23a). The contribution of cases due to intentional killing is generally lower after the entry into force of the EU Directive for both country categories (Figure 23b), suggesting a possible effect of the entry into force of the EU Directive.

Figure 23 Annex I: Percentage of birds listed in Annex I reported as dead per month of the year (a) and percentage of intentional killing of species in Annex I (b), calculated per country. Grey – before, yellow – after entry into force of the Birds Directive

The seasonal trend of Annex I species before and after the entry into force of the EU Directive seems generally stable, and no major changes have been registered, except for the number of cases, which increased after the EU Directive. A clear decline in the number of reports of intentionally killed birds belonging to Appenidix I species is observed in both categories of countries.

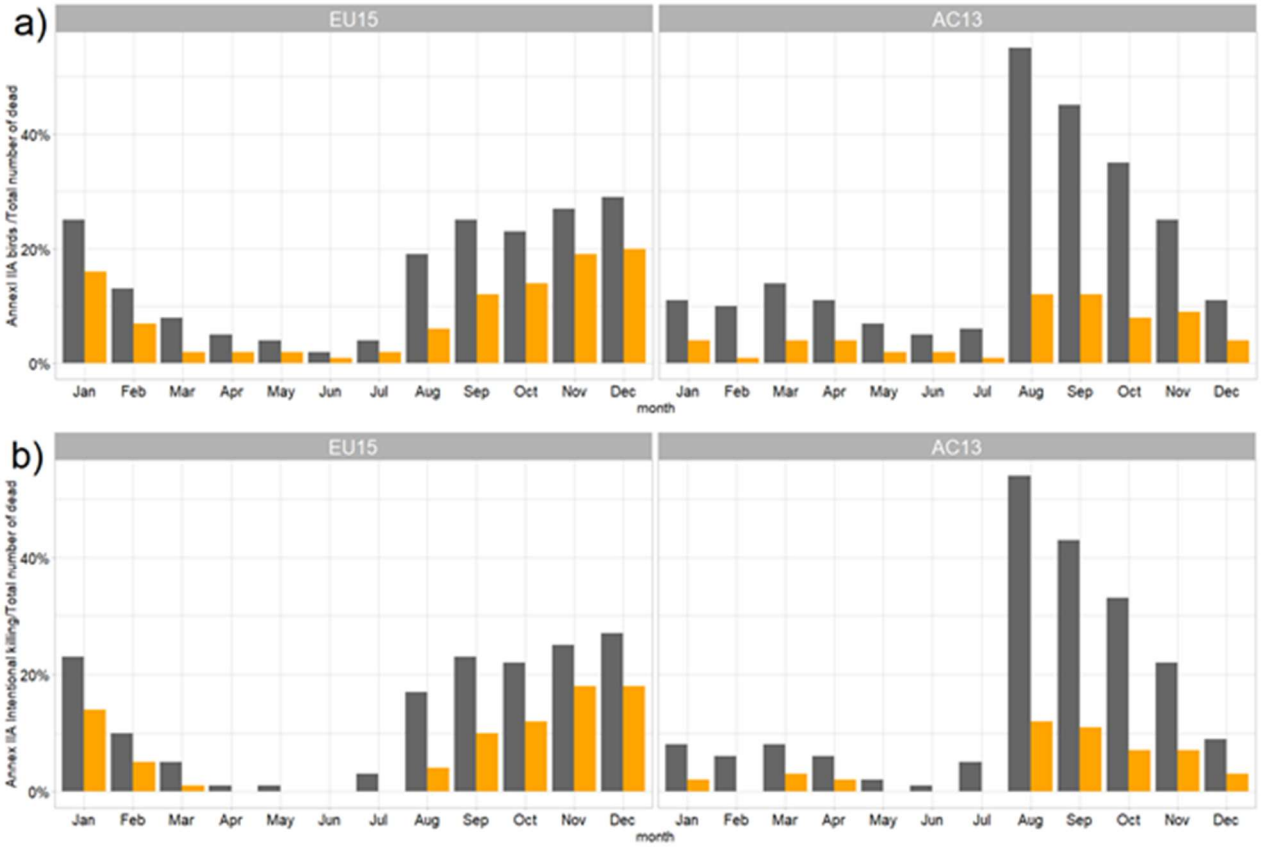


Figure 23 Annex IIA: Percentage of birds listed in Annex IIA reported as dead per month of the year (a) and percentage of intentional killing of species in Annex I (b), calculated per country. Grey – before, yellow – after entry into force of the Birds Directive

The monthly pattern of recoveries of dead birds belonging to species listed in Annex IIA is again very similar between total numbers of dead recoveries and those originating from intentional killing. A reporting decrease is registered both in EU15 and AC13 countries after the entry into force of the EU Directive yet maintaining fairly similar patterns than before.

The trend in AC13 countries drastically decreased after the entry into force of the EU Directive. The most sensitive period for birds in Annex IIA is November, December, and January in EU15, while August, September in AC13 countries.

Overall, the exploration of the seasonal pattern before and after the EU Directive reveals the effectiveness of the regulation according with the different Annexes. The trend per each country is presented in the Supplementary Material.

2.8 Historical trends in intentional killing reporting: death circumstances of intentionally killed birds

In this section we explore whether death circumstances have changed with the entry into force of the EU Directive, considering Annex I and Annex IIA species. A significant and specific decrease in intentional killing and taking ("shot" and "trapped/hunted/poisoned") for Annex I species would suggest a positive role of the EU Directive.

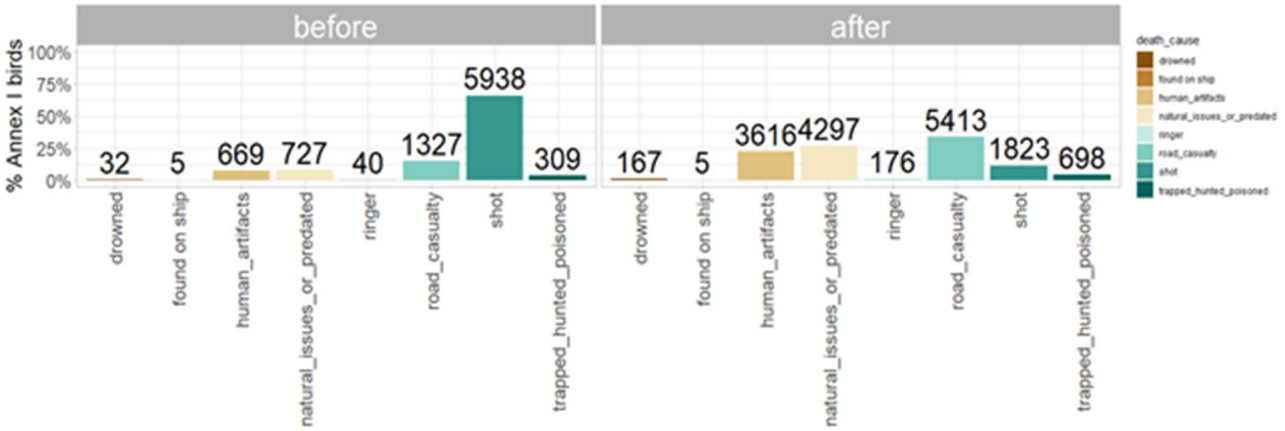


Figure 24 Annex I: Percentage of death causes of species reported in Annex I, before and after the EU Directive. Numbers over each bar are real values.

For species in Appendix I, the "shot" category drastically decreased, while death circumstances not intentionally caused by man (e.g., road casualty) increased after the EU Directive, as an indirect indicator also of progressive increase in traffic intensity.

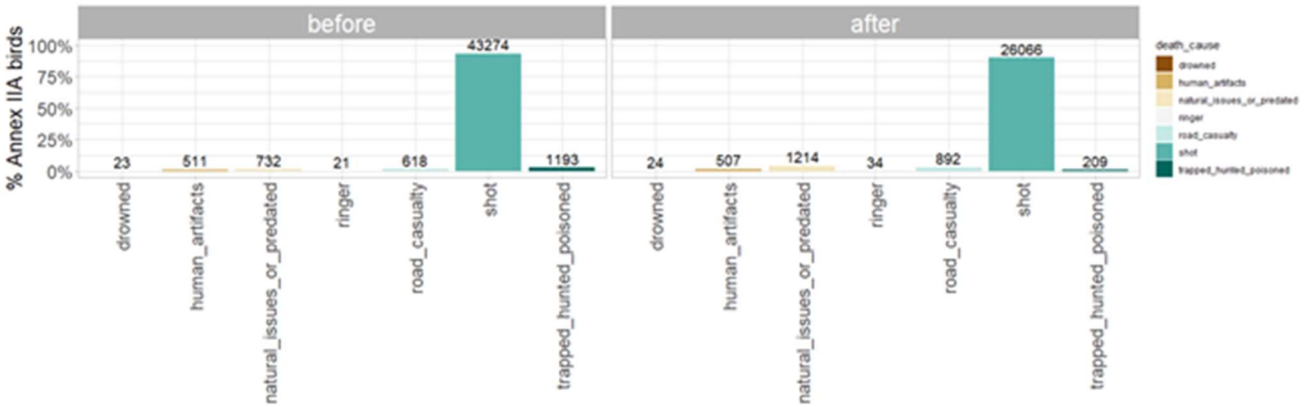


Figure 24 Annex IIA: Percentage of death causes of species reported in Annex IIA, before and after the EU Directive. Numbers over each bar are real values.

For species in Appendix IIA, the "shot" category remains by far the first cause of death before and after entry into force of the Directive. The relative increase for other categories after the entry into force of the Directive (e.g. traffic) is by no means comparable to the Annex I species, which could partly be explained also by the different numbers of taxa listed in the two annexes, respectively.

7.3.4 Historical trends in intentional killing reporting: map of change with the entry into force of the EU Directive

Another way to consider the possible effectiveness of the EU Directive is through visualising changes before and after the Directive within the geographical scope of our analyses (EU15, AC13 and not-EU28). The change is presented as the difference AFTER – BEFORE of the number of cases of intentional killing of birds' species listed in Annex I and Annex IIA (separately) over the total amount of dead recoveries (a difference between proportions). We called this measure of change "delta intentional" and is referred to the deliberate killing or trapping. The higher the delta intentional, the higher is the proportion of intentional killing after the entry into force of the EU Directive, hence the redder shade of colour for a given country. At the same time, we propose a word cloud with the EU28 countries in which the dimension of the name is proportional to the delta intentional, thus the bigger is the name the higher is the proportion of intentional killing after the entry into EU Directive and consequently the most inefficient the Directive was in that country. In the next section we will focus on spotting the locations with higher probability of deliberate killing more in detail, while in the Supplementary Material each EU28 country is analysed separately.

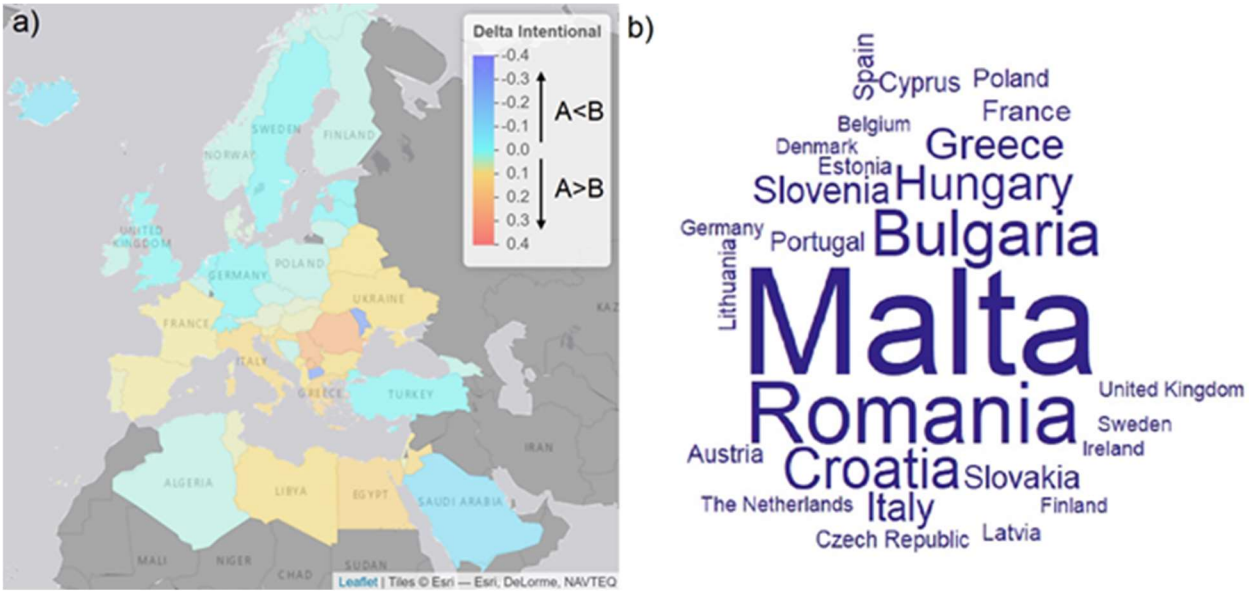


Figure 25 Annex I: a) Density map of the delta intentional of species in Annex I. b) Wordcloud of the delta intentional of species listed in the Annex I relative to the EU28 countries. The bigger the name the higher the proportion of intentional killing after the EU Directive.

For species always protected by the EU Directive, the effect is observed in several of the EU28 countries. Countries in central-northern Europe show a fairly low tendency towards lower frequencies, while a fairly low tendency towards higher frequencies is observed in countries of central-eastern Europe as well as around the Mediterranean, including Mediterranean European countries. This pattern is confirmed in the word-cloud.

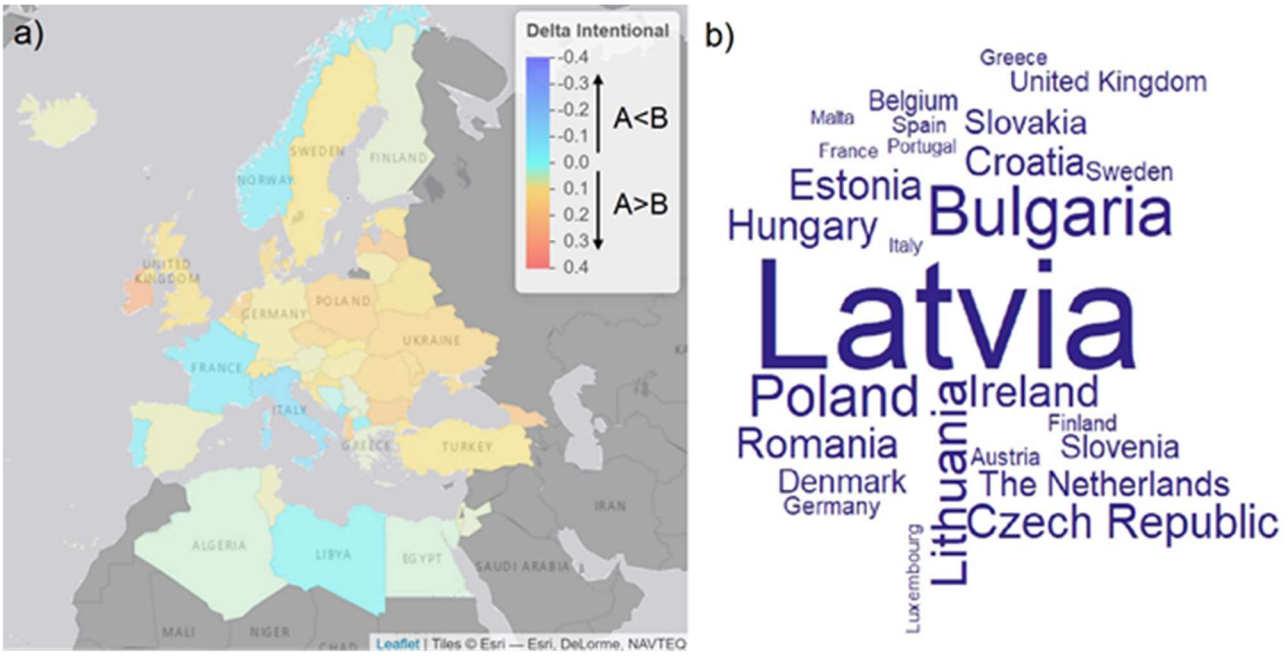


Figure 25 Annex IIA: a) Density map of the delta intentional of species in Annex I. b) Wordcloud of the delta intentional of species listed in the Annex I relative to the EU28 countries. The bigger the name the higher the proportion of intentional killing after the EU Directive.

For species whose hunting activity is regulated by the EU Directive, the effect seems to be less widespread, with several Northern and Eastern European countries showing an increase of deliberate killing of birds after the EU Directive and fewer countries showing a decrease, including around the Mediterranean.

Overall, through a historical, seasonal and geographical overview we showed that the decline of cases of intentional killing reports might be due to the effect of the EU Directive. Especially when focusing on species listed in the Annexes of the EU Directive it was possible to appreciate its effect with time on always protected species, but not on legally huntable ones (Fig. 22). The focus on seasonal patterns allowed to spot different temporal dynamics between country categories in reporting intentional killing birds listed in Annex IIA (Fig. 23 AnnexIIA). Finally, the focus on death causes of species in the different Annexes and the geographical variation in delta intentional suggest the role of the EU Directive in contributing to explain this decline in reporting. Surely before and after the entry into force of the EU Directive many historical and cultural changes took place across this huge geographical area, with the effect of an intricate mix of concern in reporting and compliance towards the Directive, likely including also cultural differences between countries.

2.9 "Black-spots" of intentional killing across the Eurasian - African flyway

2.9.1 Background

The Convention on Migratory Species CMS and the Berne Convention have activated different initiatives to tackle illegal killing, trapping and trade of wild birds (IKB). Recently, several studies estimated this phenomenon in areas like the Mediterranean (Brochet et al., 2016), Europe (Brochet, Van Den Bossche, et al., 2019), or the Middle East, Iran, and Iraq (Brochet, Jbour, et al., 2019). Trough qualitative data, these studies estimated 11-36 million birds to be killed/taken illegally each year in the Mediterranean region alone.

Detecting high-risk areas, where the likelihood of intentional killing of birds is relatively high, can be beneficial in dealing with these worrying numbers. Knowing where intentional killing is more likely to occur would provide an opportunity to concentrate conservation initiatives. Much of the effort and resources can be allocated to those high-risk areas, which can be the first step in the IKB management process. ISPRA is responsible for the IKB module as part of the Migration Atlas Project also as it has direct experience on this specific issue, given its formal role in the implementation of a National Action Plan on illegal actions against wild birds which the Italian Ministry for Ecological Transition has launched. Despite most European countries have aligned their national legislation to international legal instruments, illegal activities continue to threaten birds in Europe. As an example, migratory raptors, among other species, were (quantitatively) shown to be persecuted by illegal killing in the Mediterranean region (McCulloch *et al*., 1992), Northern Scotland (Smart *et al*., 2010) and Georgia (Van Maanen *et al*., 2001).

2.9.2 Objectives

Here we report the identification of high-risk areas, which are generically referred to as "black-spots" of deliberate killing of birds by man. The same analysis is repeated at three spatial scales and for species of Annex I (species protected all year around) and IIA (seasonally huntable species) of the EU Directive. The spatio-temporal scales and lists of species considered are:

- Species listed in Annex I: the whole migratory flyway before and after the entry into force of the EU Directive;
- Species listed in Annex I: the European region before and after the entry into force of the EU Directive;
- Species listed in Annex IIA: the whole migratory flyway before and after the entry into force of the EU Directive;
- Species listed in Annex IIA: the European region before and after the entry into force of the EU Directive during the longest possible hunting period;
- Species listed in the Annex IIA: the European region before and after the EU Directive during months which have most likely never seen hunting activities, at least in most European countries and given also the overall historical period covered (May-August).

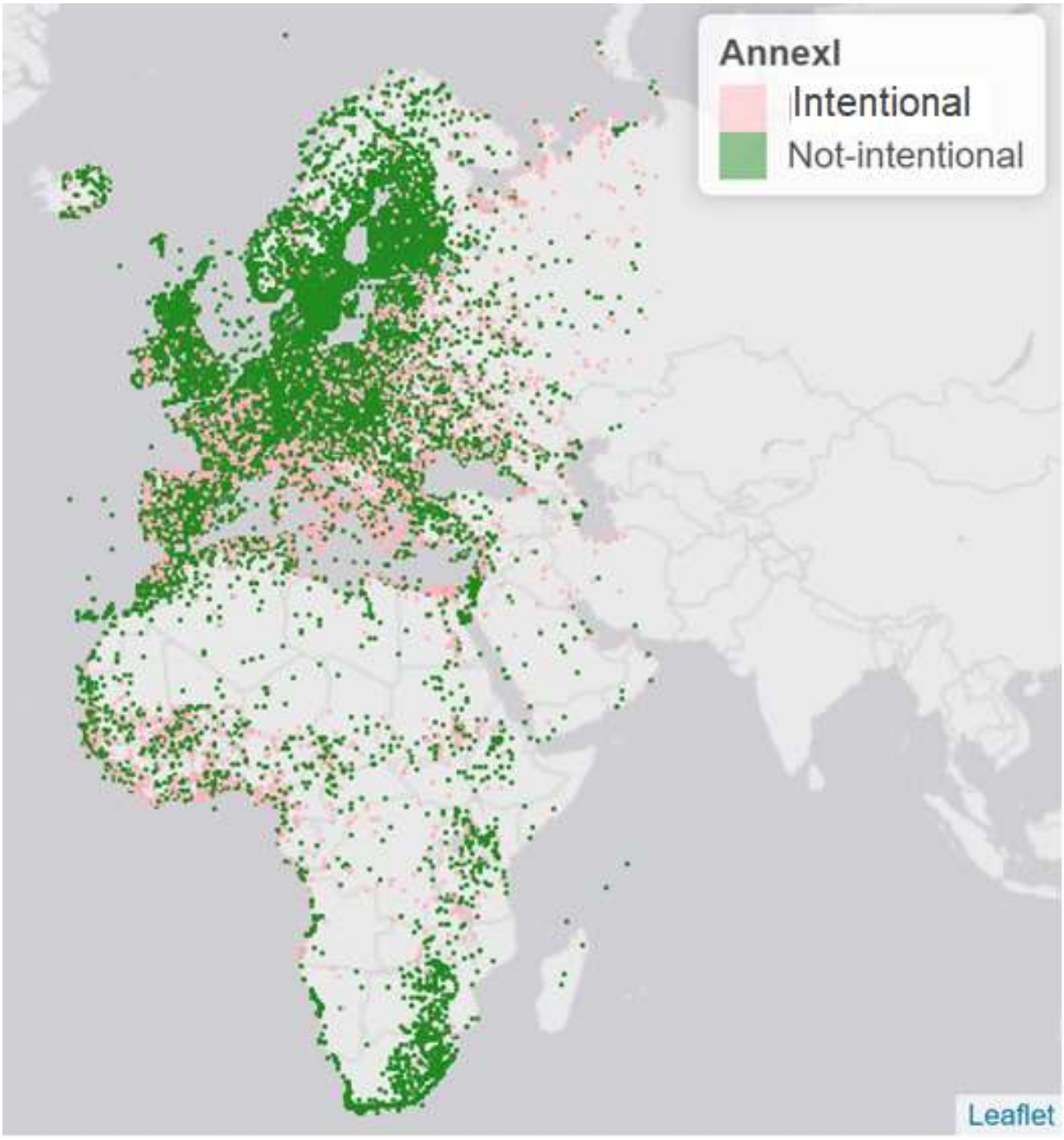


Figure 26: Map of all individuals reported as "found dead" (green) and as shot, poisoned, and trapped (pink) between 1900 and 2019

2.9.3 Method for "Black-spots" identification

The database used in this section is the EDB filtered as explained previously (*see* 1.2). All recovery locations relative to the species considered were filtered within the spatial limits covering each geographical area investigated. We counted how many "found dead" and "deliberately killed" recoveries fell into each cell of a spatial grid (e.g. SpatialPolygons, 2°x2° for the whole flyway, 1°x1° for the European region). The sums were spatially interpolated in the grid cells by using a univariate kriging procedure using the inverse distance weighting ("idw" function in "gstat" package in R) that allows a direct specification of the inverse distance

weighting power (Cressie, 1993). The power was chosen using values from 0.1 to 8 with increasing steps of 0.1. For each power value, the root mean square error (RMSE) was evaluated and the kriging was then run using the power value that minimized the RMSE.

Having interpolated the data, we proceeded with the identification of the black spots. The Kernel Density Estimation was chosen, which involves systematically running a kernel matrix (cell size 2×2 pixel for whole flyway, 1×1 pixel for European region) over the area of interest to visually spread the effects of points over adjacent space (Krisp et al., 2009). The major issue of the kernel density estimation is the choice of an arbitrary threshold for what is and is not a hot spot. Therefore, the Getis-Ord GI* statistics was chosen to make the threshold choice more objective (Getis & Ord, 1992; Ord & Getis, 1995). The amount of difference between an area and its neighbouring ones was converted to a z-score reflecting the number of standard deviations that the killing level in an area differs from neighbourhoods. Areas with high z-scores (indicating killing significantly above the mean) were identified as black spots, while areas with low z-scores were identified as cool spots.

Using the same interpolated data and the same neighbour's identification method ("nb2listw" function in "spdep" package in R), the Moran's I spatial autocorrelation value was calculated. The Moran's I is a value between -1 and 1 which identifies whether the dataset is clustered (values higher than 0), dispersed (values lower than 0) or random (values equal to 0). Therefore, we proceeded by testing the null hypothesis "the proportion of intentional killing is randomly spatially distributed" and choosing the "greater" alternative (i.e. clusters present). The Monte-Carlo permutation test for Moran's I statistic was chosen, 999 random permutations of the spatial weighting scheme, to establish the rank of the observed statistic in relation to the simulated values (Cliff & Ord, 1981).

To find the worst locations, the interpolated values were filtered keeping outlier values from the interquartile range above the third quartile. The procedure described above (Kernel density Estimation, Moran's I permutation test) was repeated with the only change of the Getis-Ord GI* statistics being run with a kernel matrix of 0.5×0.5 pixels.

The following maps on black-spots are each referred to the geographical area and period considered, hence they are not meant for direct comparisons between periods within pairs of maps. For example, the absence of an area in the map of worst locations before the entry into force of the Directive and its presence in the map after the Directive does not mean more intentional killing takes place in that area after the Directive but that, after the Directive, the area shows higher estimates of intentional killing than average values recorded in the surrounding areas considered. It is therefore not a quantitative measure in the strict sense, given the "colour" depends on the degree of distancing from an average which is calculated for the given area and period.

2.9.4 Annex I species across the flyway

The EDB hosts data of dead birds belonging to 126 species of the 194 listed in Annex I of the Birds Directive.

- 122,060 individuals were recovered as found-dead between 1900 and 2019 (green dots, Fig. 26)
- 23,722 (19.43%) individuals were recovered as deliberately killed between 1900 and 2019 (pink dots, Fig. 26)

EU Directive	Moran's I	p.value	pow.min	N deliberately killed	N found dead
Before	0.831	0.001	2.8	16185	41894
After	0.888	0.001	2.5	7537	80166

Table 5: Summary table of the procedure of data interpolation: period before or after the EU Directive, Moran's I statistic, the p-value of the Monte Carlo permutation test for the Moran's I, the minimum power used for the kriging, sample size of intentionally killed and found dead individuals.

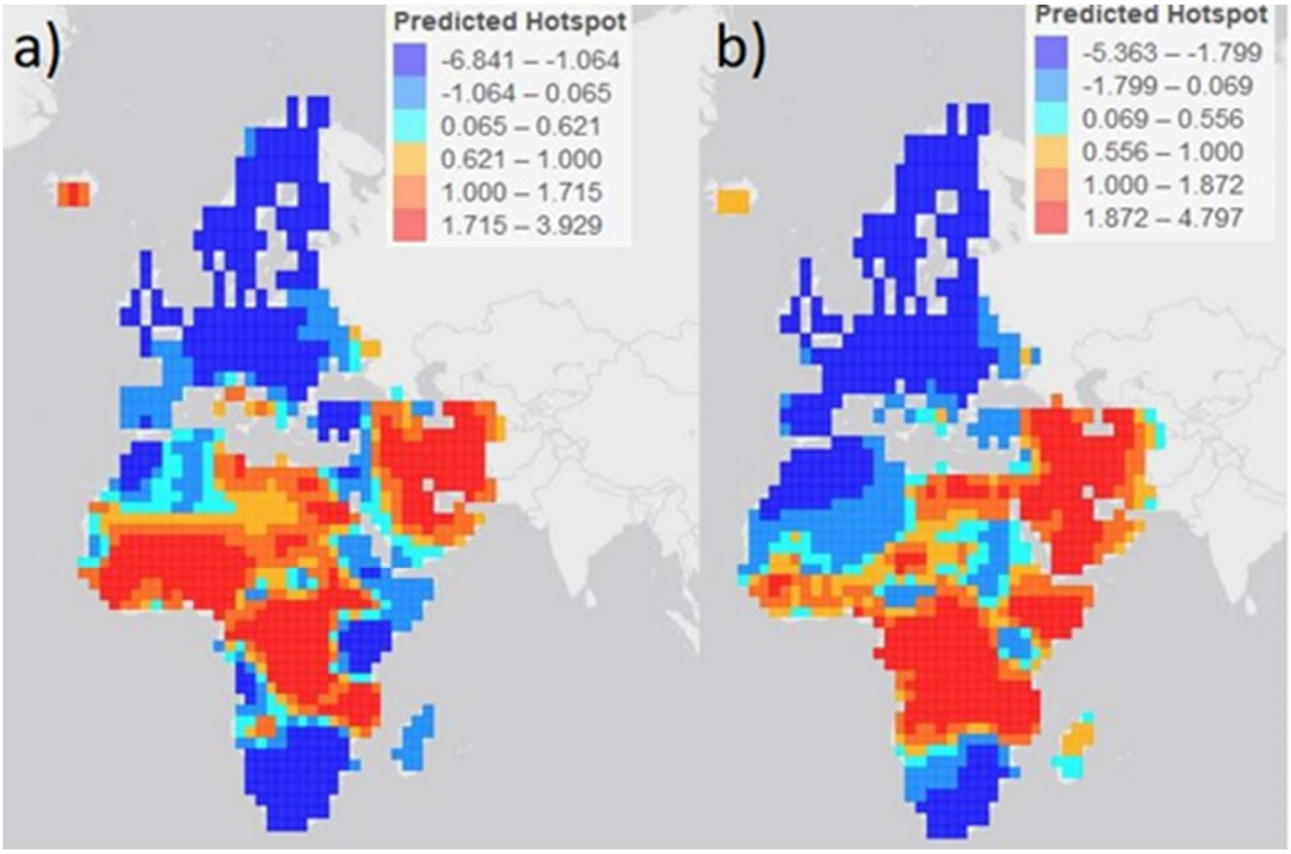


Figure 27: Visualization of the black (red) and cold (blue) spots of deliberate killing before (a) and after (b) the entry into force of the EU Directive, using Kernel Density Estimation with Getis-Ord GI*

Before the entry into force of the EU Directive, there was no international legislation regulating the harvesting of wild birds and the map obtained by spatial interpolation shows black-spots in cells spread between Mauritania and Mozambique (leaving out Somalia, Kenya and Tanzania) and the middle Eastern areas. Most of Europe resulted covered by cold-spots cells, meaning the deliberate killing proportion were lower than the neighbouring cells of the spatial grid. The Mediterranean region resulted covered by black-spots, especially in cells located in Egypt, Libya, Tunisia, Italy and Balkans (Fig. 27a). The proportion of deliberate killing was not randomly spatially distributed as the Monte-Carlo permutation test for Moran's I rejected the null hypothesis and accepted the “greater” alternative (Table 5). This means the dataset after interpolation still resulted clustered, hence validating the black/cold spots identified with the Kernel Density Estimation method.

Also the proportion of deliberate killing after the entry into force of the EU Directive was clustered (Table 5). The map obtained by the spatial interpolation of the data covering the period after the EU Directive (1981-2019) shows a drastic change from black to cold spots in the cells of the Mediterranean region, including cells in the Balkans, Italy and Tunisia (Fig. 275b). The black-spots locations in the cells covering the Middle East remained similar to the one before the entry into force of EU Directive. In the cells covering the African countries, instead, the black-spots location moved from Northern-Western cells (Mauritania, Niger, Mali, Nigeria) to Southern-Eastern cells, particularly in the area between Angola, Zambia, Mozambique, DRC, Ethiopia and Somalia.

2.9.5 Annex I species: European region

- 108,759 individuals were recovered as found-dead between 1900 and 2019
- 18,578 (17.1%) individuals were recovered as intentionally killed between 1900 and 2019

EU Directive	Moran's I	p.value	pow.min	N deliberately killed	N found dead
Before	0.826	0.001	2.8	13350	35304
After	0.871	0.001	2.5	5228	73455

Table 6: Summary table of the procedure of data interpolation: period before or after the EU Directive, Moran's I statistic, the p-value of the Monte Carlo permutation test for the Moran's I, the minimum power used for the kriging, sample size of intentionally killed and found dead individuals.

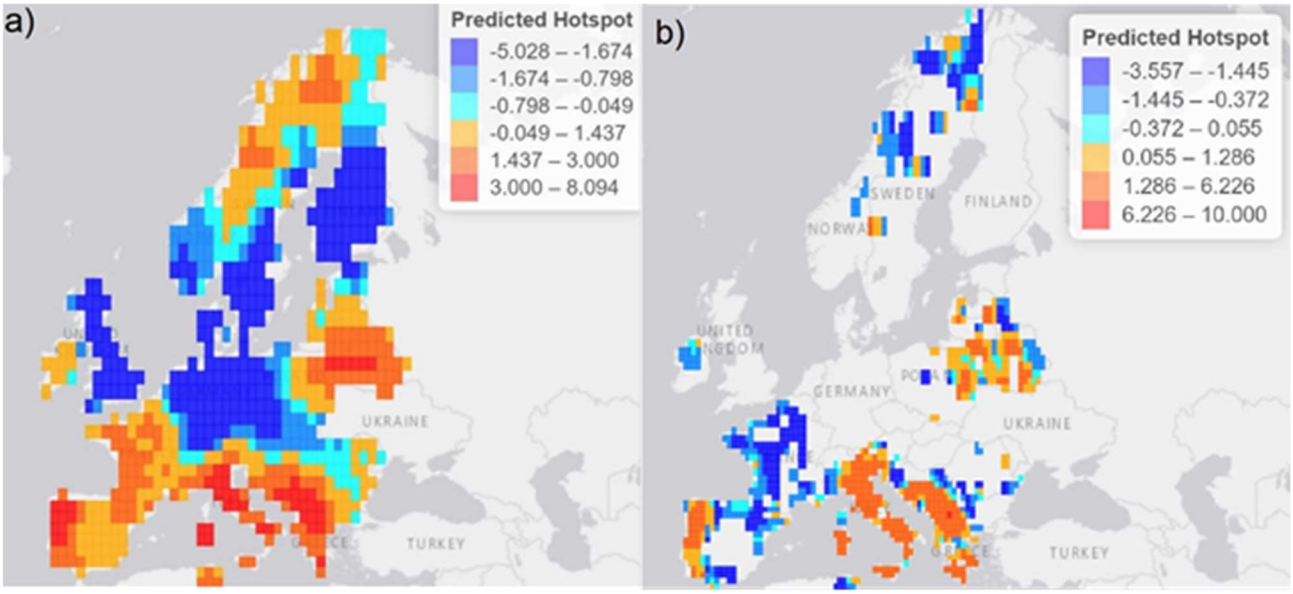


Figure 28: Visualization of the black and cold spots of deliberate killing before the entry into force of the EU Directive focusing on European region alone. (a) General view on spatial grid of 1x1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid.

When considering the European region alone, the data remained clustered both before and after the entry into force of the Directive (Table 6). Before 1981, black-spots were mostly concentrated in the Mediterranean area (Fig. 28a), specifically in cells covering Greece, the Balkans and Italy (Fig. 28b).

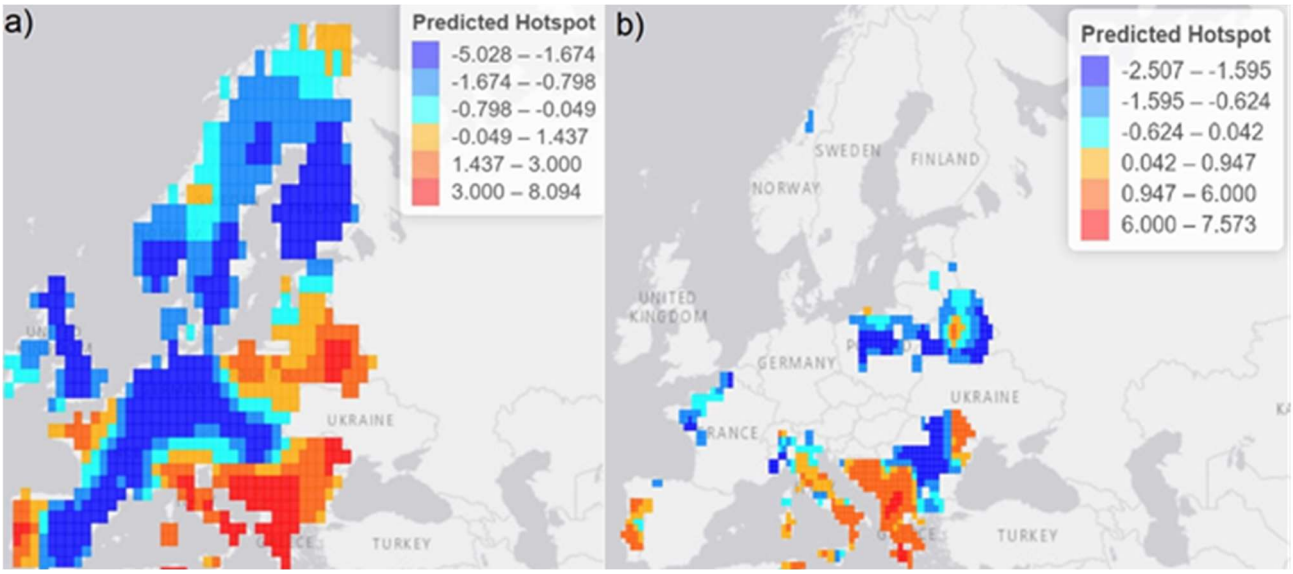


Figure 29: Visualization of the black and cold spots of deliberate killing after the entry into force of the EU Directive focusing on European region alone. (a) General view on spatial grid of 1 x 1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid.

After the entry into force of the EU Directive, the situation generally improved, especially in the Iberian Peninsula and in France (Fig. 29a). In Italy the presence of black-spots persisted locally, for example in northern regions as well as in the south (Fig. 29b). A wide black-spot remained in large areas of the Balkans and in Greece.

2.9.6 Annex IIA species: across the flyway

The EDB hosts data of dead birds belonging to 22 species of the 23 listed in Annex IIA.

- 199,590 individuals were recovered as found-dead between 1900 and 2019 (green dots, Fig. 30)
- 161,600 (80.97%) individuals were recovered as deliberately killed between 1900 and 2019 (pink dots, Fig. 30)

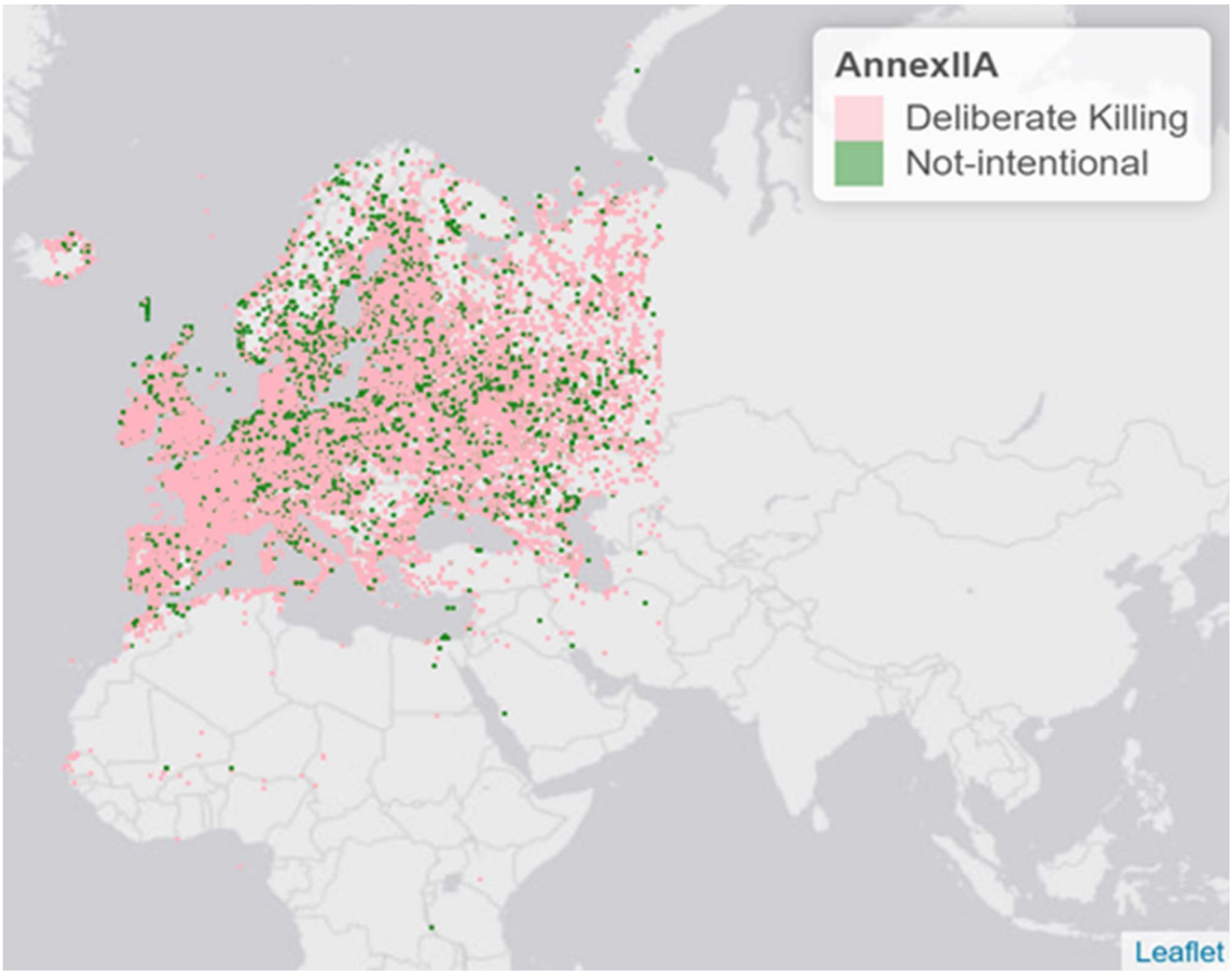


Figure 30: Map of all individuals reported as "found dead" (green) and as shot, poisoned, and trapped (pink) between 1900 and 2019, belonging to species listed in Annex IIA.

EU Directive	Moran's I	p.value	pow.min	N deliberately killed	N found dead
Before	0.662	0.001	1.9	122149	149960
After	0.689	0.001	2.4	39451	49630

Table 7: Summary table of the procedure of data interpolation: period before or after the EU Directive, Moran's I statistic, the p-value of the Monte Carlo permutation test for the Moran's I, the minimum power used for the kriging, sample size of intentionally killed and found dead individuals.

The map obtained by spatial interpolation shows black-spots in cells spread between Western Africa, Western Europe (and Italy), and the middle East. Most of central Europe resulted covered by cold-spots cells. The Mediterranean region resulted covered by black-spots, especially in cells located in Morocco, Algeria, Tunisia, Iberia Peninsula and Italy (Fig.29a).

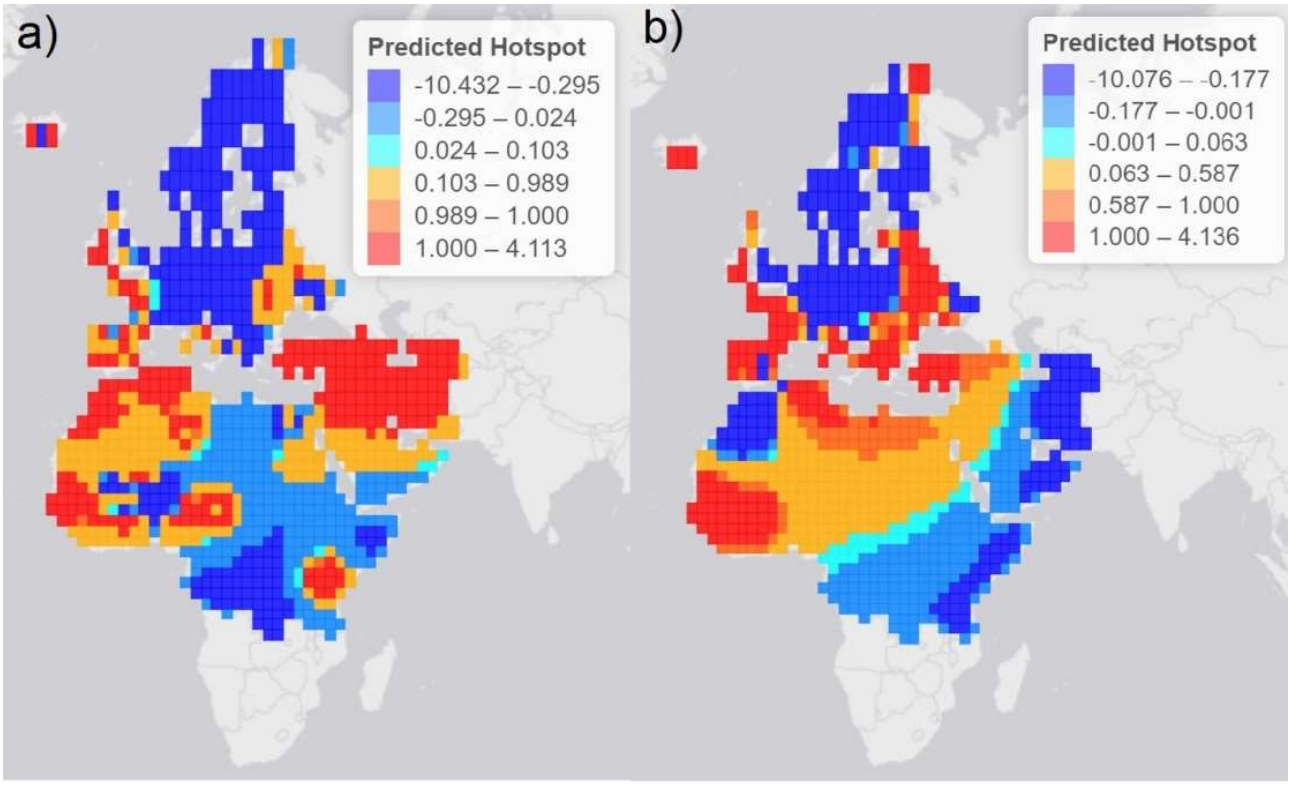


Figure 31: Visualization of the black (red) and cold (blue) spots of intentional killing before (a) and after (b) the entry into force of the EU Directive, using Kernel Density Estimation with Getis-Ord GI* .

The proportion of intentional killing was clustered in both periods considered (Table 7). The map obtained by the spatial interpolation of the data covering the period after the EU Directive (1981-2019) showed an intensification of the frequency of intentional killing in areas previously identified as black-spots (Fig. 31 b). The black-spots locations in the cells covering Northern African countries were more intense in Mauritania and along the Mediterranean, while the situation in the Middle East shows a partial improvement, remaining however critical between Turkey, Syria and Lebanon (Fig. 31b).

General note: please consider that the number of recoveries outside the European region is limited.

2.9.7 Annex IIA species: European region, hunting months

- 146,989 individuals listed in Annex II A were recovered as found dead between 1900 and 2019
- 125,618 (85.5%) individuals were recovered as deliberately killed between 1900 and 2019

EU Directive	Moran's I	p.value	pow.min	N deliberately killed	N found dead
Before	0.586	0.001	1.7	93912	108691
After	0.676	0.001	2.3	31706	38298

Table 8: Summary table of the procedure of data interpolation: period before or after the EU Directive, Moran's I statistic, the p-value of the Monte Carlo permutation test for the Moran's I, the minimum power used for the kriging, sample size of intentionally killed and found dead individuals.

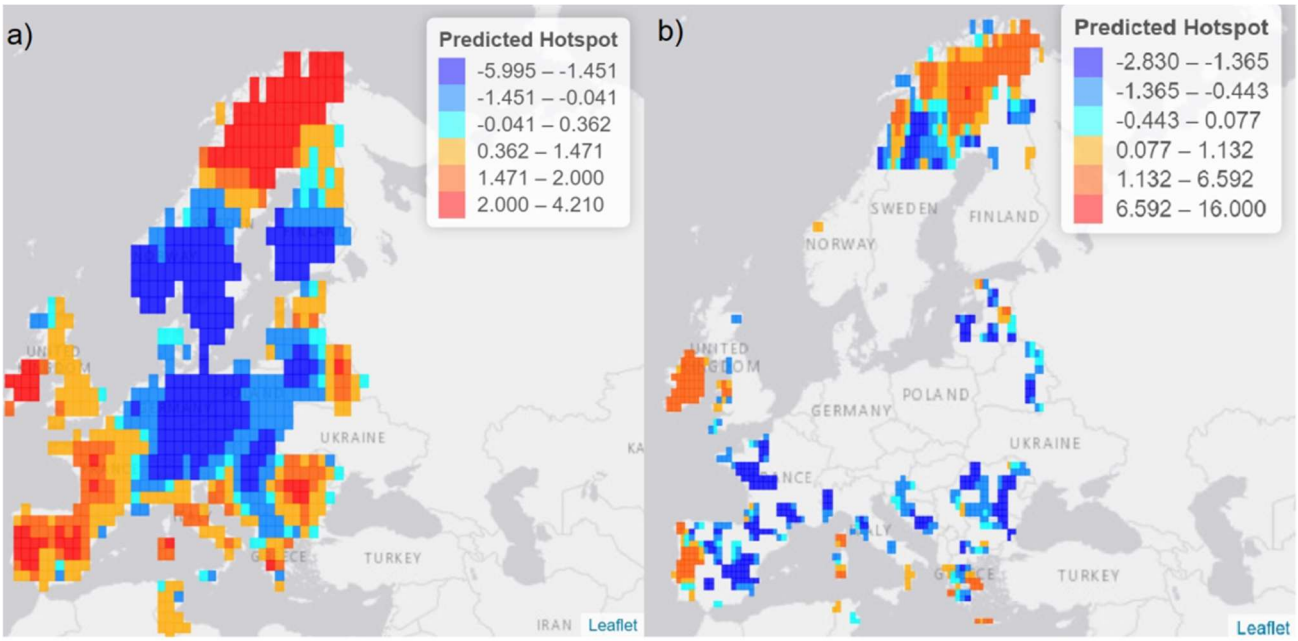


Figure 32: Visualization of the black and cold spots of deliberate killing BEFORE the entry into force of the EU Directive of species listed in the Annex II A during the hunting months and focusing on European region. (a) General view on spatial grid of 1x1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid.

The EDB data on the European region during months of possible open hunting resulted clustered both before and after the entry into force of the EU Directive (Table 8). Before 1981, high-frequency cells of intentional killing were widespread across the UK, Northern Sweden and Norway, Lithuania and Belarus, Romania and the Mediterranean area (the Iberia peninsula, France, Italy, the Balkans and Greece, Fig. 32a). Areas of particularly intense intentional killing were in Ireland, northern Sweden and Portugal, and more locally so in England (i.e.: Wales), Italy (i.e.: Sardinia, Stretto di Messina) and Greece (Fig. 32b).

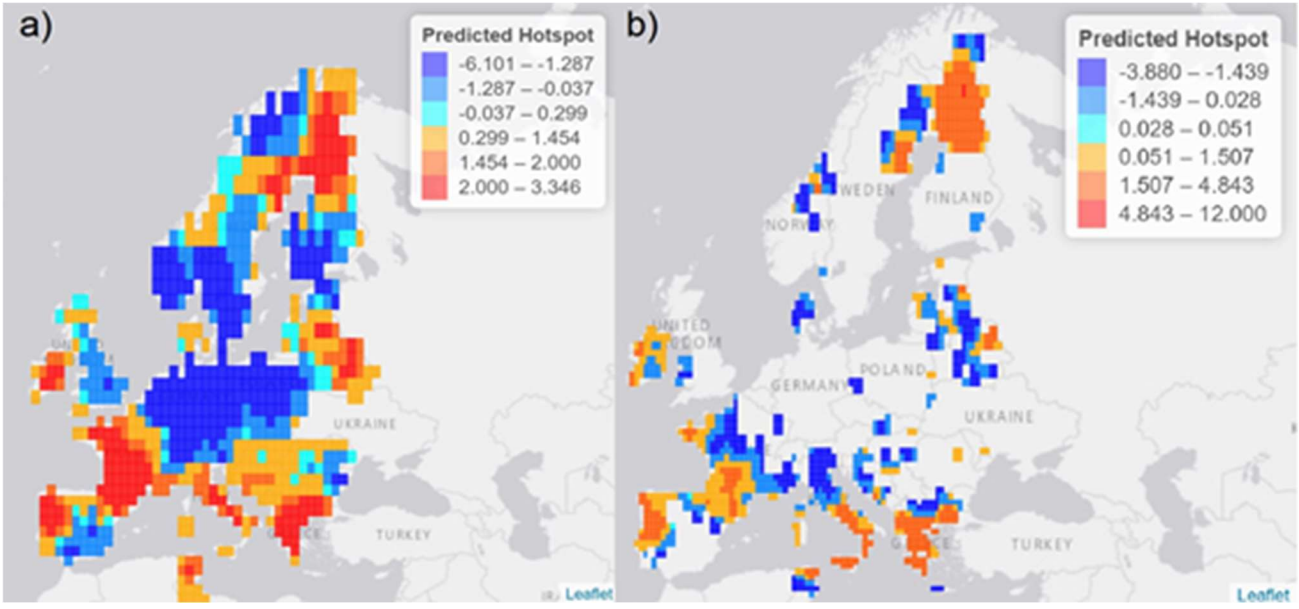


Figure 33: Visualization of the black and cold spots of deliberate killing AFTER the entry into force of the EU Directive of species listed in the Annex II A during the hunting months and focusing on European region. (a) General view on spatial grid of 1x1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid.

After the entry into force of the EU Directive, during the hunting months, the number of intentional killings decreased from 63.9% to 21.5% of the total number of birds "found-dead" listed in Annex IIA (N= 146,989). However, the frequency of intentional killing changed only in some locations like in England and Norway, that become cold-spots (Fig. 33a). The other black-spot areas identified before the EU Directive remained and in some cases became wider and intensively higher than neighbouring cells (i.e.: Portugal, Pyrenees, Italy, Greece and Albania, Finland, Fig. 33b).

2.9.8 Annex IIA species: European region, May-August

- 11,832 individuals listed in Annex IIA were recovered as found-dead between 1900 and 2019
- 4,878 (41.2%) individuals were recovered as deliberately killed between 1900 and 2019

EU Directive	Moran's I	p.value	pow.min	N deliberately killed	N found dead
Before	0.863	0.001	2.7	4220	8861
After	0.874	0.001	2.1	658	2971

Table 9: Summary table of the procedure of data interpolation: period before or after the EU Directive, Moran's I statistic, the p-value of the Monte Carlo permutation test for the Moran's I, the minimum power used for the kriging, sample size of intentionally killed and found dead individuals.

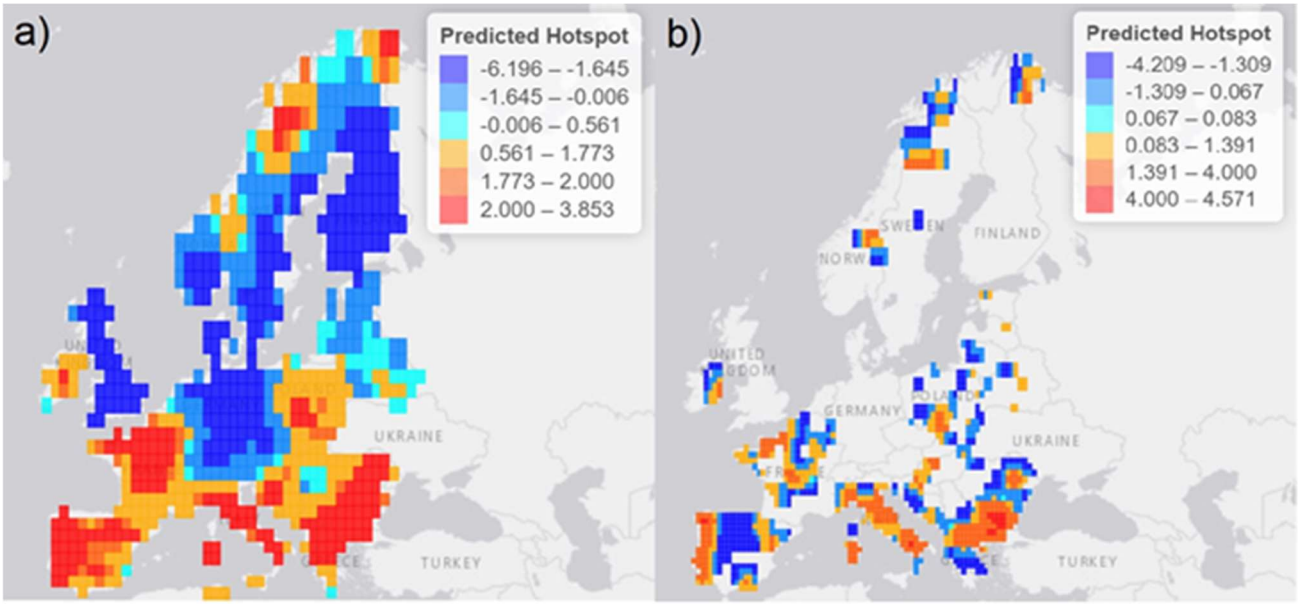


Figure 33: Visualization of the black and cold spots of deliberate killing BEFORE the entry into force of the EU Directive of species listed in the Annex IIA during the non-hunting months and focusing on European region. (a) General view on spatial grid of 1x1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid

During May, June, July and August, likely non-hunting months across the EU, data are clustered both before and after the entry into force of the EU Directive (Table 9). Before 1981 the black-spots were mostly concentrated in the Mediterranean area, specifically in cells covering Iberia, France, Italy, Croatia, Montenegro, Albania and Greece (Fig. 33a). Looking at the worst locations, the most widespread black-spots were confined in Portugal and Northern Spain, Italy and between Romania and Bulgaria. Several local black-spots are in Sweden, Norway, Ireland, France and Poland (Fig. 33b).

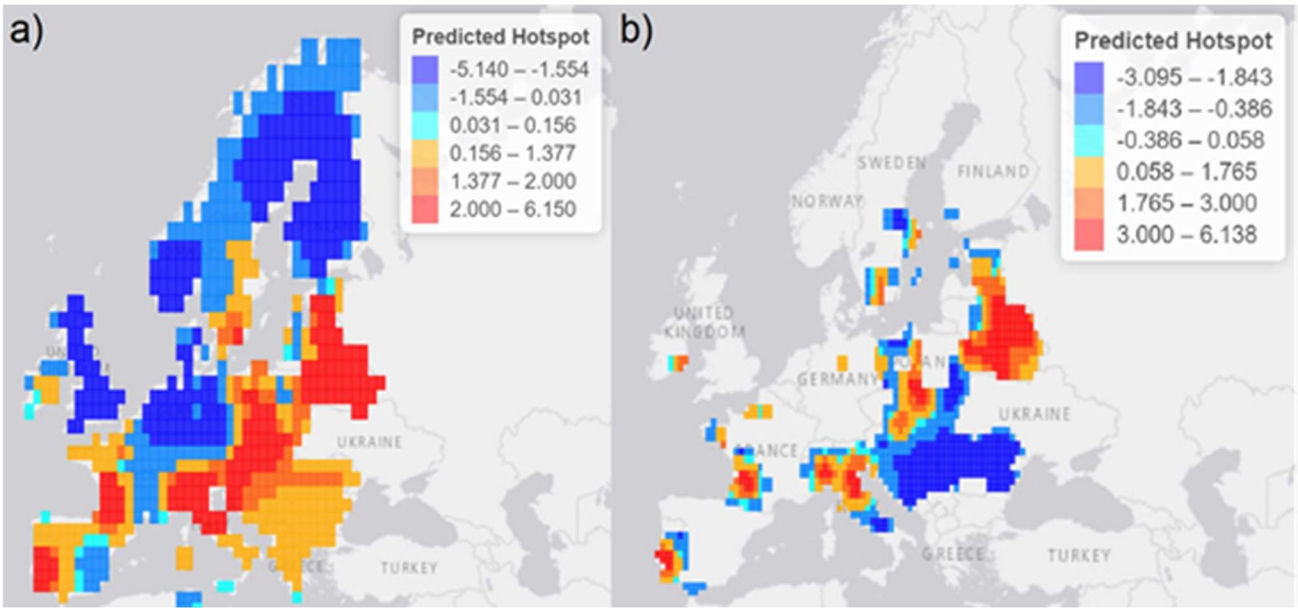


Figure 34: Visualization of the black and cold spots of deliberate killing AFTER the entry into force of the EU Directive of species listed in the Annex IIA during the non-hunting months and focusing on European region. (a) General view on spatial grid of 1x1 degree. (b) Local black-spot considering only the worst locations, visualizing them over a 0.5x0.5 pixel grid.

Between 1981 and 2019 during the EU not-hunting months, the number of deliberately killed birds dropped at 658 individuals across the European region. The black-spots in Eastern Europe were concentrated in wider areas: Belarus and between Poland, Czech Republic and Slovakia (Fig. 34a). In Western Europe the black-spots were more localised: "Alentejo" region in Portugal, "Aquitaine" region in France, Lombardia, Veneto and Emilia Romagna in Italy (Fig. 34b).

2.9.9 Final comments

Although the EDB, as all datasets, suffers of limitations and biases, it has been possible to highlight several areas where the frequency of intentional killing of birds by man is consistently higher than in neighbouring areas, also when considering different geographical and spatio-temporal scales.

After the EU Directive, persistent black-spots are in Italy, with some differences between lists of species: Central-Southern regions for the species listed in the Annex I and species listed in Annex IIA during the hunting months; Northern regions for species listed in the Annex IIA during not-hunting months. Another persistent black-spot is in Portugal, especially the Central and the Alentejo regions both for the species listed in Annex I and IIA during non-hunting months. Persistent black-spots for intentional killing of species listed in the Annex IIA more than for species in Annex I are in France, specifically the regions of Aquitaine and Britannie, and Ireland, Midlands and Southern regions. The area of the Balkans (Croatia, Bosnia and Herzegovina, Montenegro, Albania, Bulgaria) and Greece showed black-spots mainly for species listed in Annex I, after the EU directive.

2.10 "Look-alike" issue

This section focuses on intentional killing of morphologically similar species, generally defined as the "look-alike" issue. Species misidentification can negatively impact on the efficacy of sustainable harvesting

models (Zhou *et al*., 2016). This issue is well studied for wildlife trading and trapping (e.g.: Alfino & Roberts, 2019), much less so for intentionally harvested animals due to lack of data.

Here, we provide one of the first attempts to quantify the look-alike issue using the unique features of the EDB. We propose a temporal overview of the frequency of its occurrence, by quantifying the frequency of mismatches between the species code reported when the bird was deliberately killed vs the one originally assigned by the relevant EURING Scheme at ringing. Additionally, we show how the frequency of look-alike events in intentionally killed birds is distributed before and after the entry into force of the EU Directive as the environmental legislation regulating hunting periods and huntable species.

Estimating the frequency of mismatch in identification when non-huntable birds are wrongly reported as belonging to legally huntable species is pivotal to clarify the impact of this issue on conservation measures. This may also be useful to suggest improvements to limit the issue, such as targeted training which may help reducing frequency of misidentification and proper implementation of the look-alike principle when setting sustainable harvesting models.

When considering the EDB contents for this specific analysis, we selected cases of intentionally killed individuals, and identified three categories of cases:

MISMATCH: when the species identified and reported by the observer is different from the one coded by the Scheme at ringing;
UNKNOWN: when the species reported by the observer has not been identified, i.e. the species is coded as "unknown";
CORRECT: when there is no mismatch in species identification provided upon recovery and at ringing.

	N	percent
CORRECT	237,293	57.34%
MISMATCH	3,193	0.77%
UNKNOWN	173,315	41.88%

Although it is impossible to distinguish whether any "mismatch" is intentional or unintentional, this is the only criterion we can use to analyze when selecting data to be analysed. On the other hand, the extremely high frequency of "unknown" category cases, accounting for over 40% of data, jeopardizes more solid estimations.

The proportion of the three categories of cases varied along decades in EU15 and AC13 countries, as shown in Figure 35 (please note that each category is differently coloured: **Correct**, **Mismatch**, **Unknown**).

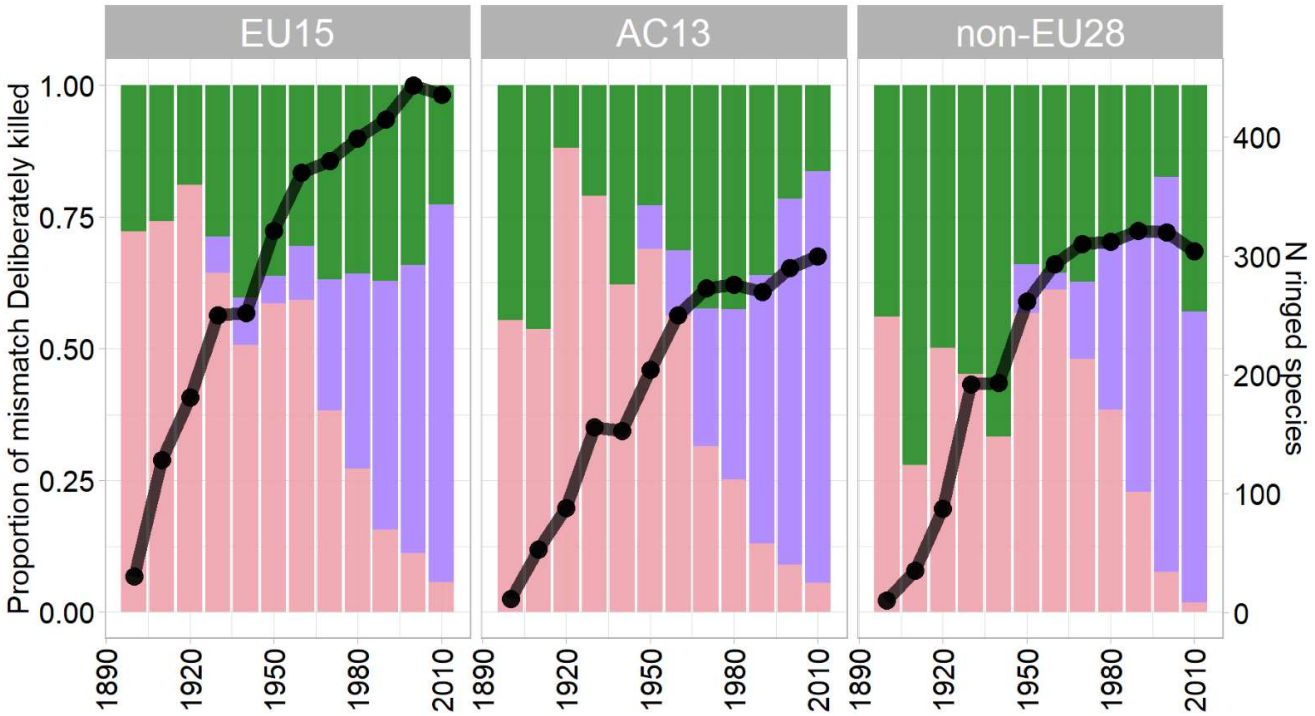


Figure 36: Proportion of Correct (green), Unknown (pink) and Mismatch (light purple) categories over the intentionally killed birds reported per decade in EU15, AC13 and non-EU28 countries separately. The right y-axis and the black line show the number of ringed species (not individuals) recorded per decade.

Within the intentionally killed recoveries, the proportion of the Unknown category saw a marked decline between the 1960s and 1970s, both in the EU15 and AC13 countries. At the same time, the Mismatch started to increase and, interestingly, this increase largely follows the one of the overall number of ringed species, the latter being an effect of increasing ringing activities and the progressively widespread use of trapping methods allowing to catch and ring fully grown birds (e.g., mist-nets) and not primarily chicks at the nest, as in the early days of ringing in Europe. The entry into force of the Birds Directive put a special emphasis on the extent of the most worrying cases, i.e. when the mismatch involves a protected species, as those listed in Annex I.

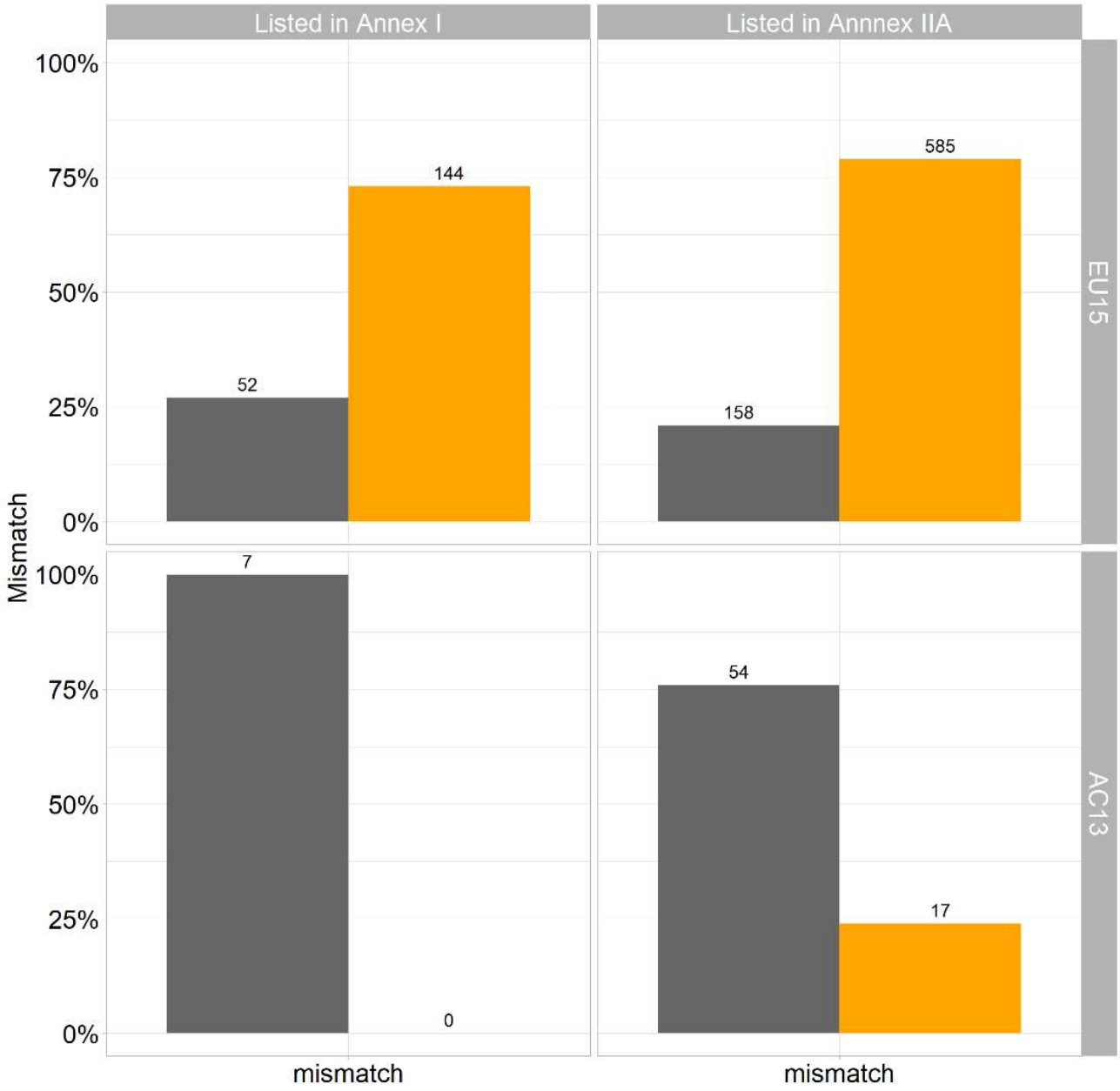


Figure 37: Frequencies of mismatches for deliberately killed birds before (grey) and after (yellow) the entry into force of the EU Directive, separately for the EU15 and the AC13 and species listed in Annex I and Annex IIA. Sample size visible over each column.

In the EU15 countries, the number of mismatches increased after the entry into force of the EU Directive. The relative frequencies for species listed in the different Annexes show very similar values in the larger sample referred to EU15 countries. This increase in mismatches with protected species can be an effect of the special attention the Bird Directive poses on the conservation concern deriving from look-alike events. We have looked more in detail to which species were wrongly reported when birds listed in Annexes I or IIA were intentionally killed, respectively, with special attention to the frequency of cases of protected species (Annex I) being mismatched with legally hunted ones.

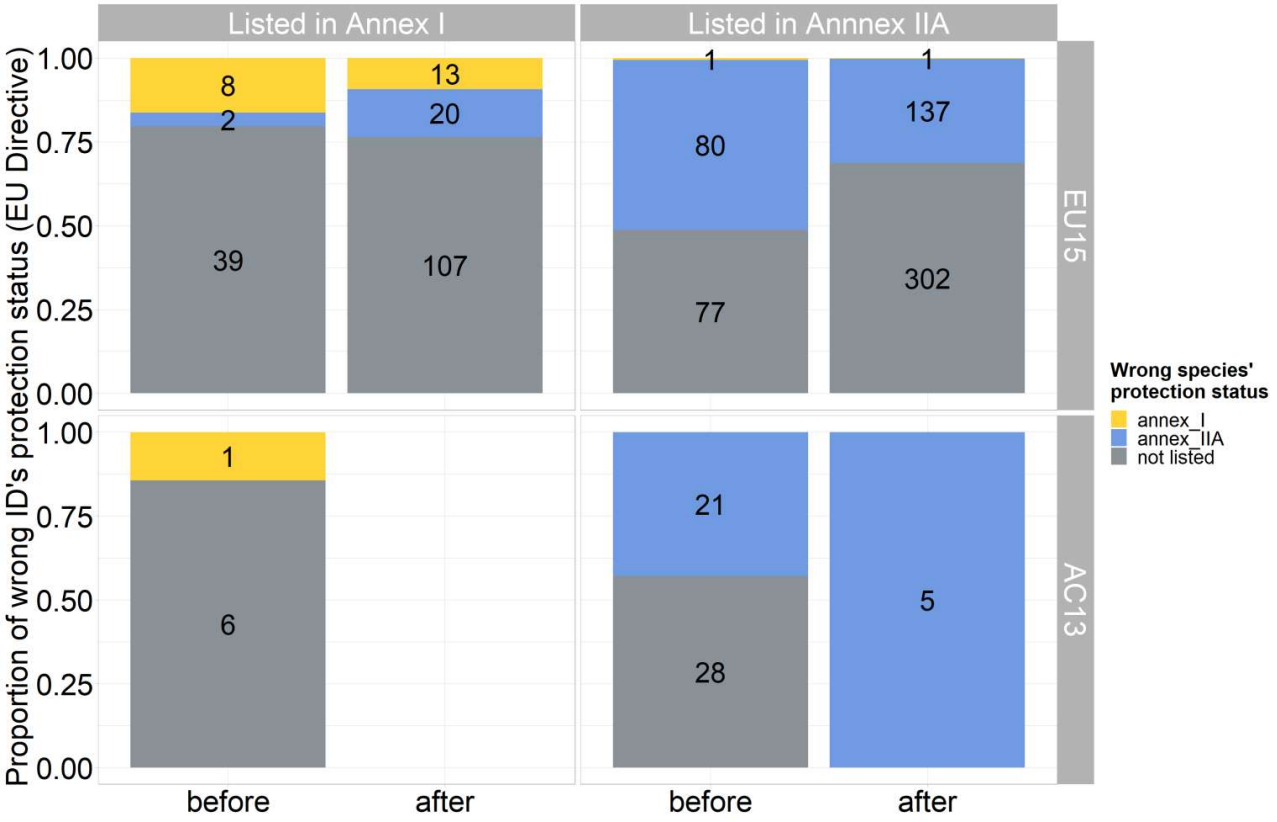


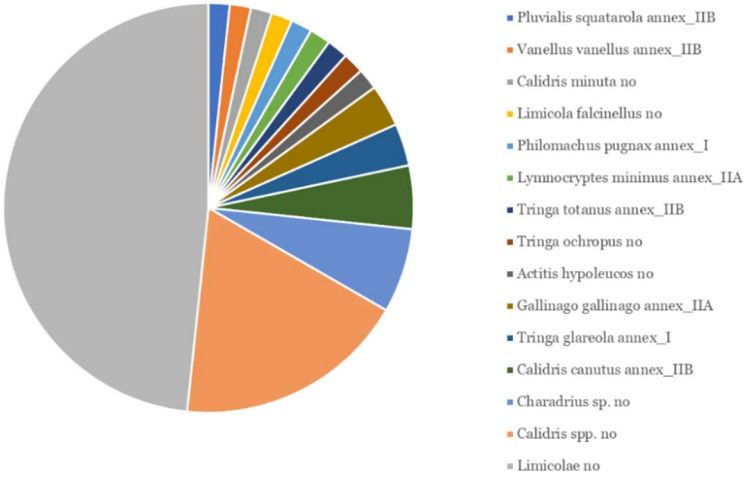
Figure 38: Proportion of legal status of wrongly identified intentionally killed species, separately for the EU15 and the AC13 and species listed in Annex I and Annex IIA. Sample size over each legal status category. E.g.: 8 cases in the EU15 countries before the entry into force of the EU Directive that a species listed in Annex I was wrongly identified with another species listed in Annex I (yellow); only 2 cases with species listed in Annex IIA (blue) and 39 cases with species not listed in the EU Directive (grey).

For the EU15 countries, in 93.12% of cases intentionally killed birds belonging to species listed in Annex I of the EU Directive were wrongly identified as legally huntable ones. In particular, with 83.67% of cases before, and 90.7% after the entry into force of the EU Directive. The AC13 countries seem to follow the same pattern of the EU15 ones, but any consideration is hindered by reduced sample size.

Although look-alike cases refer to less than 1% of the entire dataset, we believe it is still relevant to consider these data. Knowing which species are more frequently mismatched - and with which other species - contributes to reflect in improving the implementation of the look-alike principle to minimize the risk of unwilled harvest of protected species.

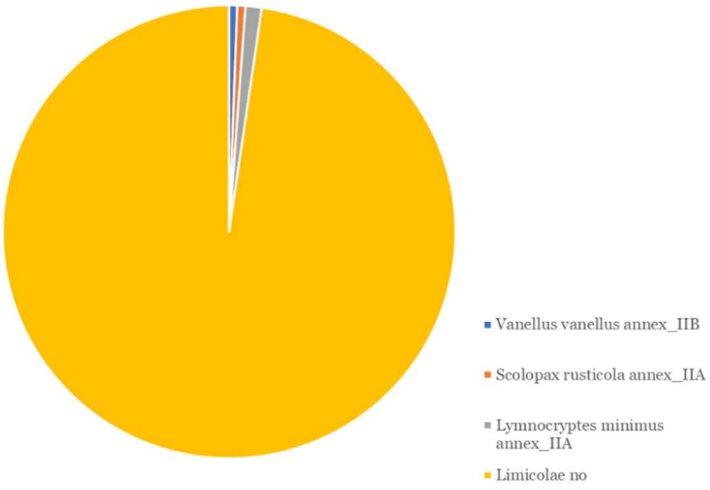
We counted as mismatch even the cases when the species code at dead recovery is a generic Family code (e.g. *Anas sp.*, *Turdus sp.*), as some species within the Family are protected. The following pages show examples of species with frequent look-alike cases, listed either in Annex I and IIA of the Birds Directive.

Calidris alpina (listed in Annex I)



- **Total deliberate killed= 3588**
- **Total mismatched= 60**
- **N wrong species=15**

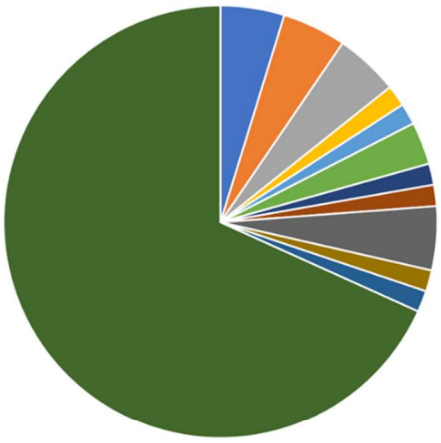
Gallinago gallinago (listed in AnnexIIA)



- **Total deliberate killed= 7154**
- **Total mismatched= 173**
- **N wrong species=4**

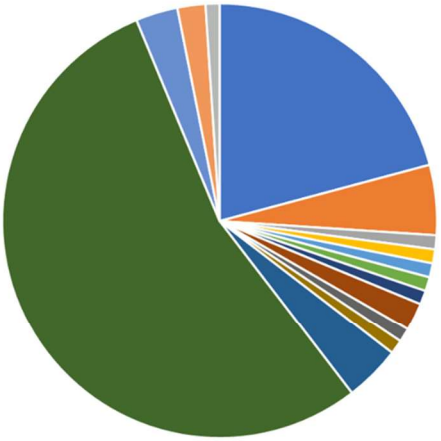
Anas platyrhynchos (listed in Annex IIA)

Total deliberate killed= 60017
Total mismatched= 136
N wrong species=12



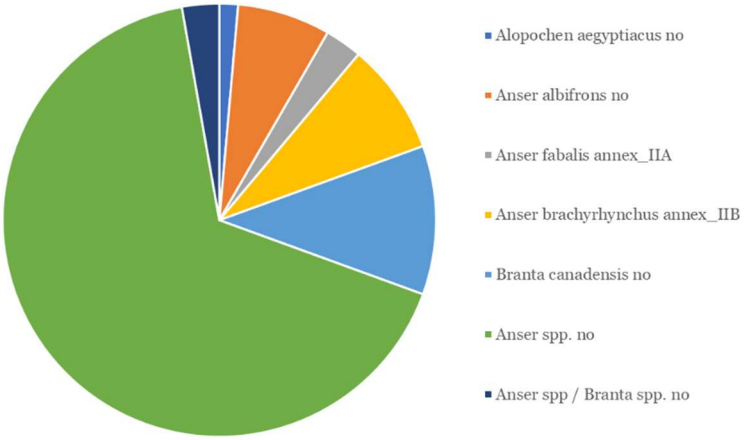
Anas crecca (listed in AnnexIIA)

Total deliberate killed= 26088
Total mismatched= 103
N wrong species=15



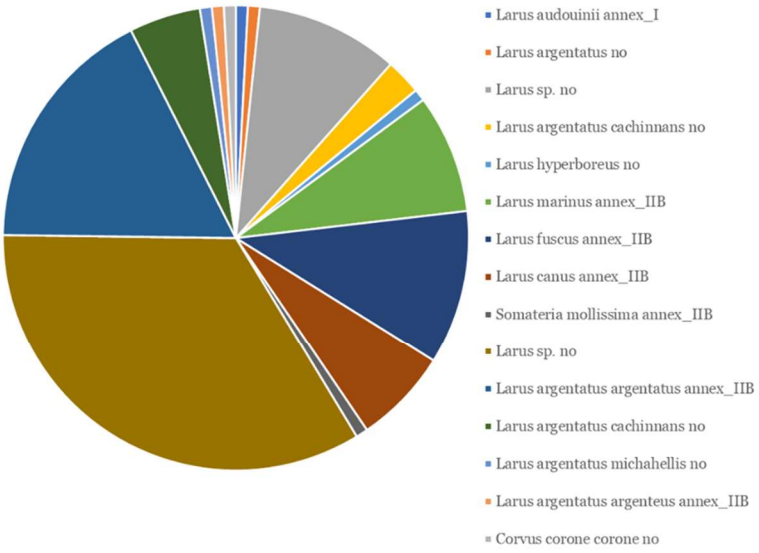
Anser anser (listed in AnnexIIA)

Total deliberate killed= 7923
Total mismatched= 95
N wrong species=7

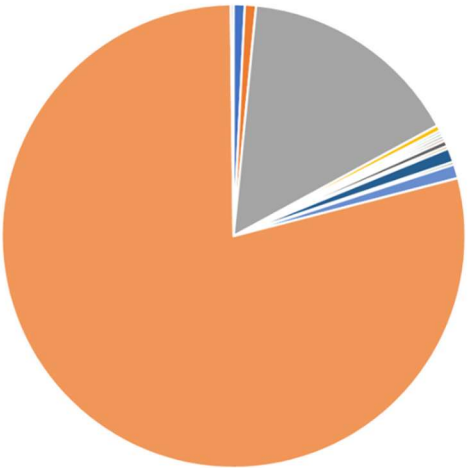


Larus argentatus (not listed)

- **Total deliberate killed= 24362**
- **Total mismatched= 105**
- **N wrong species=11**



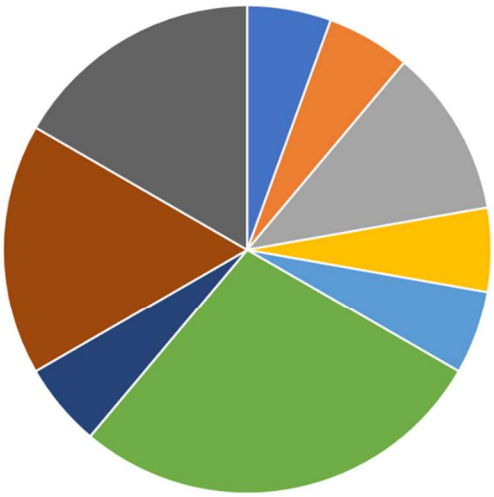
Turdus philomelos (listed in AnnexIIB)



- Sturnus unicolor no
- Turdus torquatus no
- Turdus iliacus annex_IIB
- Turdus viscivorus annex_IIB
- Coccothraustes coccothraustes no
- Coturnix coturnix annex_IIB
- Alauda arvensis annex_IIB
- Fringilla montifringilla no
- Turdus pilaris annex_IIB
- Scolopax rusticola annex_IIA
- Sturnus vulgaris annex_IIB
- Vanellus vanellus annex_IIB
- Turdus merula annex_IIB
- Turdus sp. no
- Turdus philomelos philomelos no

- **Total deliberate killed= 14788**
- **Total mismatched= 532**
- **N wrong species=15**

Sturnus vulgaris (listed in AnnexIIB)

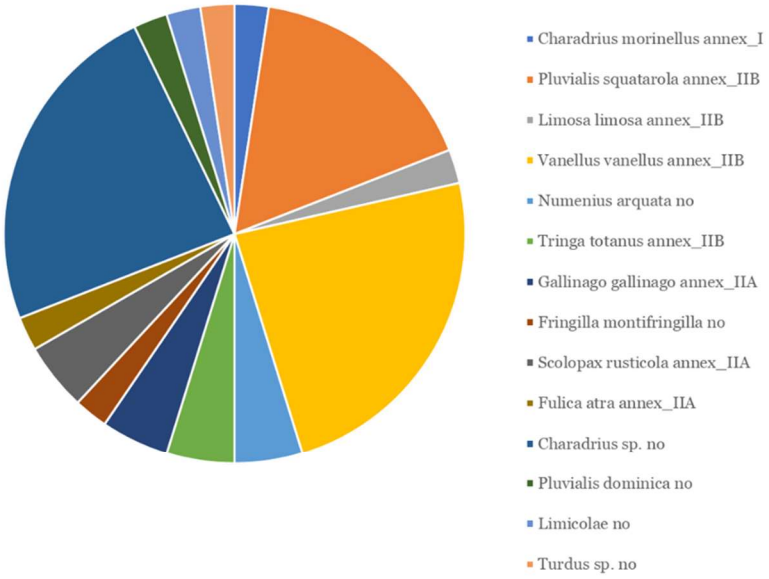


- Sturnus unicolor no
- Pluvialis apricaria annex_I
- Turdus iliacus annex_IIB
- Gallinago gallinago annex_IIA
- Turdus pilaris annex_IIB
- Turdus merula annex_IIB
- Turdus philomelos annex_IIB
- Turdus sp. no
- Sturnus sp. no

Total deliberate killed= 13958
Total mismatched= 18
N wrong species=9

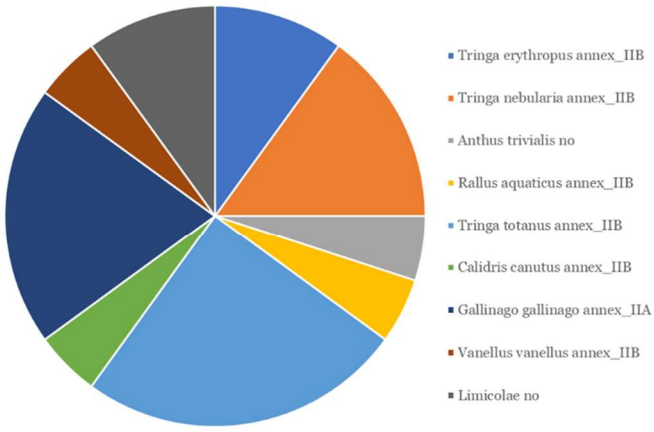
Pluvialis apricaria (listed in Annex I)

- **Total deliberate killed= 1904**
- **Total mismatched= 42**
- **N wrong species=14**



Philomachus pugnax (listed in AnnexI)

- **Total deliberate killed= 1205**
- **Total mismatched= 20**
- **N wrong species=9**



10. Closing remarks

The results of this research module contribute to a better knowledge of history and historical changes, categories of species affected and methods used, spatio-temporal distribution and cultural perspectives in deliberate killing and trapping of birds by man across the whole Eurasian-African flyway. When considering in particular illegal killing and trapping, this general overview can be a useful reference within the intense activities carried out by CMS and the Berne Convention to contrast this conservation issue, especially within the Mediterranean region through actions and priorities firstly outlined in the Larnaca Declaration, adopted at the 1st European Conference on illegal killing, trapping and trade of birds (IKB), the Tunis Action Plan, the setting up of the CMS Intergovernmental Task Force on Illegal Killing, Taking and Trade of Migratory Birds in the Mediterranean (MIKT), with the Cairo Declaration and a detailed PoW and, more recently, the Rome Strategic Plan. The opportunity offered by the analyses of the long-time series of data on intentional taking of birds by man along a whole flyway is useful also to consider changes of attitude towards bird harvesting across different geographical areas and cultures. In particular, this is also important to reflect, through the opportunity of looking along a bit more than one century, on drivers which still nowadays lead to illegal killing and trapping of birds. A very general pattern in frequency of recoveries due to intentional killing and trapping across most European countries during the last ca 120 yrs. shows peak values in the '60ies and '70ies, despite ringing activities (i.e. numbers of ringed birds) were not equally peaking in the same years; hence, we may infer that those years have seen a real maximum in harvesting intensity within our study period, followed by progressive and also significant decreasing trends.

In terms of legal aspects of harvest, this module offers new insights into the role plaid by international environmental legislation, as exemplified by the EU Wild Birds Directive, in setting principles of sustainable harvest and in improving bird conservation across the European Union. The historical patterns of relative frequencies in different circumstances and methods of intentional killing within the EU, in particular when considering the shooting of birds, provide support to a positive effect of the entry into force of the EU Birds Directive. This is particularly true when considering species which are listed in Appendix I and the situation recorded before and after the implementation of the Directive (*see* also Suppl. Material B). Also when considering areas of particularly intense intentional killing of birds, be it legal or illegal, here defined as "black spots", the geographical distribution and intensity of harvesting show positive changes after the onset of the Birds Directive, although intense activities still remain in large areas (*see* also Suppl. Material A). Despite a negative trend is recorded also when considering species listed in Appendix IIA, which are legally huntable across the EU, the rate of decline is significantly less pronounced compared to protected species. The large geographical area considered in the analyses and the similarity of historical patterns across many different countries suggest the differences recorded between species with different legal status under the Directive should be an indicator of a positive effect of compliance towards this important legal instrument and not a bias due to avoidance of reporting the intentional taking of a legally protected species.

Intentional killing and trapping of birds by man has deep roots related to the role birds had in human subsistence during millennia. The time series and geographical scope of the dataset analysed indicate significant differences across countries in intentional taking, together with methods used and categories of species affected. The geographical scope of initiatives carried out by Multilateral Environmental Agreements (Berne Convention, CMS with MIKT) to contrast illegal activities in particular are confirmed by our analyses, with the Mediterranean including North Africa and the Balkans as critical areas. Also within Africa, the relative frequencies of intentional killing have an uneven distribution, with areas of high intensity, as in West African countries, largely matching wintering quarters of many species and populations breeding and moving across Europe.

The description we provide of general historical and geographical patterns in time and space of intentional killing offer a useful perspective to consider the maps offered by this atlas, together with information on spatio-temporal return movements of huntable species during a particularly delicate phase of their annual cycle, as well as on connectivity, as provided by a specific module, for a large array of species.

The trends in deliberate killing recorded in our analyses suggest a positive attitude, across major components of the flyway and also within areas which still show critical levels, towards decreasing harvesting and increasing compliance to international legislation. From this respect, several of our results confirm a significant and positive role of the EU Birds Directive, the first example of environmental legislation within the EU, which has positively contributed to influence the general attitude towards intentional harvesting from wild bird populations.

AKNOWLEDGMENTS

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