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Towards Sustainable Wildlife Management through Geospatial-Temporal Visual Exploration

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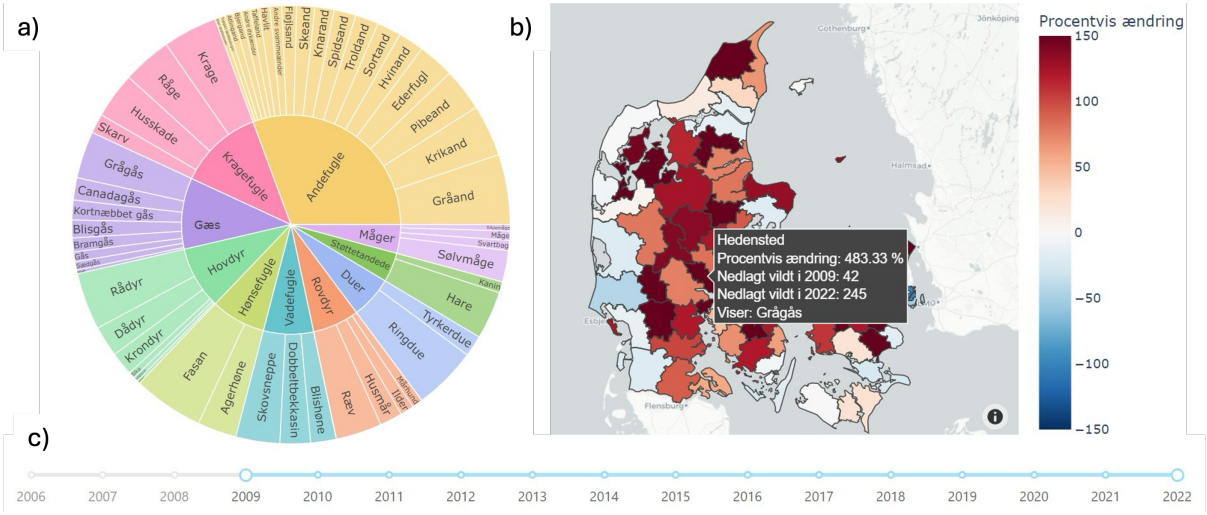

Figure 1: *DWPD Dashboard in its initial state, where two visualizations are visible.* ***a)****: Sunburst - showing the relative size distribution of all species,* ***b)*** *Choropleth map - showing bag size in percentage change in the initial period.* ***c)*** *Timeline - showing the period of all available years.*

Abstract

Amidst increasing human activities disrupting natural ecosystems, there is a pressing need for sustainable wildlife management. This paper introduces a multiple-linked view system, an interactive tool designed to visualize wildlife populations, with a focus on hunting game, to foster discussions and developments towards greater sustainability. Two data sets are used throughout the paper reporting the hunting bag per year in Denmark. National and international reports are used to exemplify the tool's features and usability and to provide insights into the health and trends of huntable species populations. Through user-friendly interfaces featuring geospatial choropleth maps, temporal charts, and sunburst diagrams, the overarching application facilitates the exploration of wildlife population dynamics across species, municipalities, and years. The tool aims to assist policymakers, researchers, and the public in making informed decisions to preserve sustainable wildlife through visual analytics. Our approach's development, design, and usability highlight the potential of interactive visualizations in environmental policy and conservation efforts. The paper discusses the implications of human activities on wildlife, the significance of sustainable management, and how our visualizations contribute to addressing the biodiversity crisis.

CCS Concepts

• ***Human-centered computing*** → ***Visual analytics; Information visualization;***

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1. Introduction

Over the last centuries, the increasing development of human activities has disrupted and restricted the natural ecosystems and habitats for organisms and wildlife [LSS*21]. Among others, reasons for this decline are overexploitation of natural resources and space requirements for an increasing human population [Shi22]. This development has led to a rapid decline of diverse species in the wild nature and is usually referred to as a *biodiversity crisis* [SNHH*21, MTS*23].
The situation is not limited to remote areas of the globe; even in Denmark, biodiversity faces considerable pressure, as highlighted in a recent report by the *Danish Environmental Protection Agency* (DEPA) [Mil24]. Here, the most prevalent pressures stem from agricultural activities, intensified land management practices, and the abandonment of traditional extensive management approaches [Ejr09].

The urgent need to address the decline in biodiversity calls for effective strategies to ensure the feasible use of wildlife. Sustainable wildlife management, as outlined by the *United Nations Environment Programme* (UNEP) in 2018 refers to the long-term stability or persistence of populations within natural systems [UNE18]. It entails fostering diversity, productivity, and the capability to support healthy wildlife populations while also considering the socioeconomic needs of human populations. In essence, sustainable wildlife management requires the implementation of legislation informed by the most current and reliable scientific knowledge in a trans-disciplinary manner. This holistic approach aims to preserve nature and promote social, ecological, and economic sustainability and all of their complex inter-dependencies [MCM*21].

For most wildlife species, there is currently no systematic population assessment. One of the exceptions is the set of huntable species, of which tentative population estimates are obtained indirectly through yearly reports of the number of animals killed, usually called *game bag* or *hunting bag*, provided by hunters in Denmark [MCM*21]. Exploring bag statistics for huntable species, regardless of the reasons for hunting (e.g. population management, invasive species control, or as a hobby activity) can provide valuable insights into the health of wildlife populations. Adopting a data-driven approach to this along various dimension such as their geospatial distribution and historical and current developments could play an important role. However, those different data dimensions need to be brought into context and should be processed and depicted in an understandable way so that they reach audiences of various backgrounds. Interactive data visualizations can be a feasible tool to visually detect patterns and outliers throughout the exploration to discuss future trends then and raise further research questions [KH13]. This is why we propose an interactive, visual representation of juxtaposed but interlinked data views that enable policymakers, stakeholders, and laymen to gain valuable insights into the current sustainability of huntable wildlife.

2. Background

In Denmark there are approximately 175.000 hunters with a total game bag of 1.75 million in the 2021/22 hunting season [AUM*23, Mil23]. The hunters are known for contributing to wildlife conservation to maintain a healthy population of species by habitat restoration, species monitoring and by protecting areas [fHC24]. The hunters report an annual hunting bag by law and its a crucial indicator of the sustainability of huntable species in Denmark [Mad21].

The gathered data is used to monitor the health of species and regulate hunting activities and thereby minimize the negative impacts on the sustainability of the species' populations [Mad21]. Overexploitation is regarded as an influential threat to wildlife and therefore it is crucial to obtain enhanced knowledge for policy makers and stakeholders for better decision-making with regards to hunting regulation. [WBGG13].

DEPA is responsible for monitoring wildlife population and gathers information from hunting bag. It is mandatory by law to report bag size for all species each season, which in return creates a structured timeseries - updated yearly by DEPA. *Danish Center for Environment and Energy* (DCE) [Aar23] is responsible for the dissemination of the data - providing the database *The Danish Game Bag* (DGB) containing information on hunting bag on all huntable species in Denmark from 1941 to present day [Chr23]. DCE also administer *The Danish Wing Survey* (DWS) to gain insights into sex and temporal distribution of game birds [CS24]. Overall DCE provides crucial information on species and their sustainability in Denmark. Both DGB and DWS are publicly available for researchers, organizations, and laymen to gain insight into the wildlife population for individual species.

Based on data from DGB, DWS and additional national and international population status reports DCE provide an extensive reports every fourth year, ordered by DEPA. These reports are used by the *Wildlife Management Council* (WMC) which represents key stakeholders and organizations with a vested interest in Danish wildlife conservation. The council utilizes these insights to formulate governance recommendations, which are subsequently submitted to DEPA for evaluation. Only those suggestions deemed beneficial for fostering social, ecological, and economic sustainability are adopted and implemented [Mad21]. This reveals the role of bag statistics visualization in facilitating informed political decision-making throughout this process. It highlights the importance of implementing clear and accessible visual representations of data to better support domain experts shaping environmental policy and management strategies.

Observations from national investigation and data from DGB and DWS has shown, that the wildlife population has been steadily decreasing since 1969 [MCM*21]. The main reason is a declining habitat quality in the wildlife populations [Lev16]. Several significant questions emerge in this context:
Is the observed trend specific to particular species or genera?
Which species are experiencing more pronounced declines, and which ones are showing signs of population growth?
Additionally, does this trend manifest uniformly across Denmark, or is it localized to certain areas?

3. Related Work

DCE provides two different types of web-based visualizations for communicating the broad bag statistics in the DGB data [Aar23]. One is a choropleth map of municipalities in Denmark [Sta23a]

where it is possible to filter down on either the season and/or the type of species. The coloring scheme used is continuous in different shades of red. The threshold for the value scale can be manually defined to either represent total bag size, logarithmic scale, or hunting bag pr km^2. The other is a bar chart [Sta23b] that provides temporal insights into the hunting bag over all seasons for all species or a filtered species. The common theme between the visualizations is the lack of interaction and interconnection. They are placed in different sub-pages which makes it difficult to link them together and the user is obligated to switch between the two sub-pages, hindering the comprehensive understanding of the data presented.

The *Biodiversity Indicators Dashboard* [Sat17] is an interactive visualization tool revolving around timeline chart and geospatial visualization of data on trends in biodiversity, ecosystem services, threats, and conservation actions. The tool allow users to select a subject of interest, and view the changes over a predefined period for all countries in the world. The *Biodiversity Indicators Dashboard* enables the user to investigate overall concepts of biodiversity, allowing 26 different layers to be displayed on the map. However, the granularity is low and the databases used can be questioned.

The *UN Biodiversity Lab* [Lab24] similarly to the *Biodiversity Indicator Dashboard* provides the possibility for users to investigate 159 different concepts globally, encompassing healthcare, biodiversity, nature and climate sustainability. However, the geospatial visualizations are not supported by other visuals, limiting the overall usability for in-depth investigation of these concepts.

A paper published by Jänicke, Beech, and Rivers employed a visual exploration system called *TreeeX*, investigating the visual representation of tree diversity and conservation status, both globally and nationally mainly using interactive choropleth maps [JBR19]. Their work highlights the potential of using interactive maps for the visual presentation of biodiversity and sustainability in trees.

There is currently no tool available to explore the data from the DGB interactively and intuitively for decision-making. Political decision-makers depend heavily on data-driven insights, making the visual representation of this information important for their process of formulating policies aimed at maintaining sustainable wildlife populations in Denmark. The absence of such a tool underscores the need for improved data visualization techniques to support effective and informed decision-making in wildlife management and conservation efforts. This project aims to develop an interactive visualization tool, *Danish Wildlife Population Dashboard* (DWPD), that enhances a visual representation of Danish wildlife population which assists the decision-making process for key stakeholders in the sustainability of Danish wildlife. DWPD is tailored for researchers, organizations with an academic and political aim of use and is suitable for hunters and the broader public with an interest in wildlife and its management.

4. Data

DCE provides statistical data on Danish hunting bag from the DGB database on their website. The DGB database provides detailed information on the bag size and for some species additional information on the sex and age distribution of the bag. The data was scraped from the website because of lacking integration of an API and stored in structured CSV format. A few species were excluded due to limited hunting bag data and would thereby not add additional information. These species are also not present in the latest report from WMC [MCM*21].

DGB is regarded as one of the highest quality data source in Europe but has certain limitations because of introduction of new regulations in the hunting law and how hunters should register their hunting bag [Chr23]. Prior to 2006 hunting bag was reported on county and from 2006 on a municipality level and its therefore difficult to compare and adjust hunting bag reports across these periods. Therefore, only data from 2006 and beyond are included for the purpose of developing DWPD. In the 2011/12 season adjustment was made to the hunting bag registration and it was now possible to report hunting bag on specific species, rather than a categorical classification encompassing multiple species. This is particularly evident for geese and is why a sudden decrease in hunting bag for geese is apparent in the season of 2011/2012. Furthermore, from the 2013/2014 season hunters were obliged to report their hunting bag in the end of a season to have their hunting license renewed. This resulted in an increase in registration from 56% to 97% of all hunters with an active license. Therefore multiple statistical adjustment was implemented by DCE to represent the true bag statistics in the years prior to these change [Mad21]. We wish to emphasize that we are going to use the Danish or English common names for species, genera and sets of them (e.g. families) in the following instead of the scientific Latin one. This also partially represents the actual work of practitioners with such databases and interfaces. The dashboard is implemented in Python using Dash and Plotly [Inc15]. In summary, we collected data representing bag size for 51 species across all 98 Danish municipalities, spanning the period from 2006 to 2022.

Season	Species	Genus	Municipal	Bag Size
2006	*Krikand*	*Andefugle*	Odense	412
2007	*Krikand*	*Andefugle*	Odense	491
2008	*Krikand*	*Andefugle*	Odense	461
...	...	...	...	...

Table 1: *Bag size for species, area and season.*

Season	Species	Detail	Municipal	Bag Size
2012	*Rådyr*	*Lam*	Ikast-Brande	65
2012	*Rådyr*	*Rå*	Ikast-Brande	53
2012	*Rådyr*	*Råbuk*	Ikast-Brande	83
2013	*Rådyr*	*Lam*	Ikast-Brande	51
...	...	...	...	...

Table 2: *Detailed information on specific subset of danish species.*

5. Visual Design

Ensuring the tool's user-friendliness and its alignment with specific domain knowledge and requirements is crucial. To achieve this, our initial consultation involved individuals holding hunting licenses and representatives from the DCE, enriching our understanding of

Figure 2: *Temporal visualizations: Showing **a)** the temporal bag size for Krondyr and **b)** Hovdyr for the municipalities Vejle and **c)** Silkeborg. The bar chart visualize the bag size distribution of sex and age for the selected species in the selected municipalities.*

DGB application in research and policymaking. The primary feature of interest was to investigate the development of wildlife populations for different species, and to consolidate all visuals within a single interface.

The primary tool in DWPD is the choropleth map, as shown in Figure 1 **b)**. It combines a temporal and geospatial component as it enables a comparison of areas and the development of hunting bag in a selected period. Additionally, the map functions as a filter for selecting one or multiple municipalities, consequently affecting the sunburst and line charts to present hunting bag in the selected area. This feature enhances the map's utility as a versatile tool for detailed analysis of DGB. To adhere more to the *information seeking mantra* by Shneiderman, we could have implemented regions as the first overview [Shn03]. A user found the choropleth map useful to get an overview of the hunting bag of geese. The choropleth shows a decrease in the hunting bag for *Grågås* in western parts of Jutland, whilst the hunting bag in especially the central and eastern Jutland increased, spanning the period from 2009 to 2022. Furthermore, the user was surprised to observe an increase of 483 pct. from 2009 to 2022 in Hedensted, hovering over the municipality (see Figure 1).

One of the essential elements of DWPD is to examine and compare the bag size for different species, as shown in Figure 1 **a)**. The sunburst diagram is particularly well-suited for the DWPD due to its clear, intuitive representation of hierarchical structures, enabling users to easily compare bag size across different species and genera. Their circular, space-filling design enhances task performance and is preferred by users for initial analysis, making them accessible to a broad audience, including those without extensive data visualization experience [SCGM00]. Furthermore, the sunburst diagram facilitates detailed exploration of data and interactive filtering, allowing for the communication of a comprehensive overview and detailed insights into wildlife populations. For example, by delving deeper into *Andefugle*, a user found the sunburst intuitive and observed the proportion of *Gråand* to be less than 10 pct. in Ringkøbing-Skjern, spanning the period 2006-2022. This feature aids in providing a visual overview when analyzing various species in relation to the overall wildlife population. Moreover, the sunburst act as a filter for species and genera and is interlinked with the other visualizations for the map, timeline and line chart visualization to present bag size for the selected species or genus.

The temporal graphs are intricately integrated with the map, sunburst, and timeline, offering a dynamic visualization experience following information visualization principles described by [YKSJ07] (see Figure 1). The dashboard flexibly displays either a single line chart, encapsulating the initialization of all species or a selected genus, or dual-line charts when a specific species, such as *Krondyr*, is chosen. This illustrates the utility of interactive dynamics for visual analysis as highlighted by [HS12] (see Figure 2). Showing two-line charts enables a comparison of a species with its corresponding genus highlighting trends and variances over time. The bag size in the line charts represents the selected option of the timeline and selected municipalities on the map - in this case, Vejle and Silkeborg, spanning the period 2013 to 2022. A user found the observed trend interesting with an increase in the bag size for *Krondyr* whilst the trend for its genus is decreasing - shown by the dashed trend line in Figure 2 **a)** and Figure 2 **b)**.

The bar chart in Figure 2 **c)** represents a distribution of specifications for selected species - in this case the distribution of *Krondyr* divided into *Kalv*, *Kronhjort* and *Kronhind*. The bar chart supports the line charts with additional information about proportion. The

user can hover over the charts to reveal exact bag size and proportion. All the charts updates based on user preferences - filtering on municipality, period and species. Multiple users were surprised by the proportional distribution of *Rådyr*, where one user observed the proportion of *Råbuk* to be more than 60 pct. for the last three years 2020-2022 in Sønderborg. Something that would have been difficult and time extensive to observe in the DGB. DWPD in its full extension is presented in Figure 3.

6. Results

As the development and trends of Danish wildlife are important to many stakeholders, (e.g. hunters and organization with vested interest in biodiversity) DWPD is designed with an easy-to-use interface featuring easily interpretable and consistent visualizations. DWPD can be used in other regions, countries, continents and globally, as long as data is available and formatted accordingly Table 1 and Table 2. The target users of DWPD are researchers, policy-makers, organizations, and laymen to observe trends, detect outliers, compare bag size between municipalities and spark the discussion of wildlife sustainability and conservation. To evaluate DWPD, we have conducted a pilot study including a questionnaire, inviting 11 participants from organizations represented in the WMC. The questionnaire was designed to assess the utility of DWPD in obtaining and communicating relevant information, solving problems, or use aiding political policy-making.

Representatives from organizations in WMC found DWPD to be useful due to its intuitively and direct way of visualizing tendencies, especially the use of the map to examine and compare municipalities on bag size for species and genus at different periods. This allows council-members to quickly access information in specific topic, rather than through extensive and often multiple reports. In consulting individuals holding a hunter's license, the DWPD proved useful in uncovering new insights. For instance, one hunter discovered that the *roe deer* population in Tønder has decreased significantly more than in neighboring municipalities over the last five years. Another hunter investigated the *roe deer* species and found that the proportion of *roebucks* in the total bag size has significantly increased compared to *does* and *fawns* in Herning, potentially leading to a less healthy population. Additionally, another hunter was surprised to learn that the bag size for geese has decreased in some parts of western Jutland, while it has increased in the eastern parts. These findings can generally foster interest in local and national wildlife sustainability while providing information to form opinions and stimulate discussion.

7. Discussion

The biodiversity crisis facing Denmark, as highlighted by recent reports from the DEPA, underscores the urgent need for effective strategies to safeguard wildlife populations and habitats [Mil24]. Human activities, ranging from habitat destruction to overexploitation, pose significant threats to the sustainability of wildlife species in Denmark. As such, there is a need to allow policy makers and stakeholders to make informed decisions to regulate the activities in Denmark towards maintaining a sustainable and healthy wildlife population.

The current usage of visualizations in this domain is limited to static visualizations or tools with lacking interconnection and interactions. This limitation restricts the user's capacity to explore and interact with the data, which may impede the effective communication of information to stakeholders and policymakers. Consequently, this could hinder the governance process of sustainability policies.

Our proposed visualization tool DWPD is a step towards gaining better informed knowledge on the current sustainability of huntable species in the Danish Wildlife with the DGB data. The tool allows the user to explore and interact with the DGB data and locate temporal changes down to municipality level in Denmark. The tool is currently lacking an interconnection between the huntable species and the general sustainability and biodiversity of wildlife populations in Denmark. Hunting is only allowed on limited species and therefore there is no available data for the rest of the species. There is currently no data sets to our knowledge available, which track the temporal change of the biodiversity down to municipality level in Denmark.

The data used in DWPD is currently limited to Denmark, but the decreasing biodiversity and wildlife population is a general tendency around the globe [SNHH*21, MTS*23]. To our observation there is currently only a few temporal data sets available about hunting bag on the same scale as DGB. The Canadian state of British Columbia has collected yearly hunting bag on *Big Game*, which is bigger mammals such as Bear and Wolf [WMU23]. It could be beneficial to incorporate the data set into DWPD and thereby compare the temporal changes between the different countries. Even though the animals might not be the same, it could still give an indication of the general decrease/increase of wildlife in different parts of the world, which could lead to new research questions. Our tool is designed as a general visualization tool and if data sets adhere to the structure as seen in table 1 and 2 they can be implemented in it. Thus scalability could become an issue and we would have to incorporate a more robust back-end system to handle larger data sets.

The questions from the introduction can quite intuitive be answered using DWPD. Within seconds, it becomes evident that the overall decline in the hunting bag is not uniform across all species, genera and across all municipalities. Thus, the bag size for predators is decreasing to a lesser extent, and in Jutland, there has generally been an increase. A comparison of species within the genera of deer's reveal, that the population of the larger deer's as *red deer* and *fallow deer* are increasing while the population of the most common *roe deer* is decreasing.

7.1. Limitation

A limitation of DWPD is the available data, as its altered throughout the temporal extent from 1941 to the present [Chr23]. We decided not to use data prior to 2006 because hunting bag registration was linked to counties, making it difficult to implement trustworthy visualization on hunting bag changes spanning both periods using different regional representation. For now, DWPD is suited for comparing hunting bag between municipalities and to a lesser extend for comparing bag size for different species as it is only

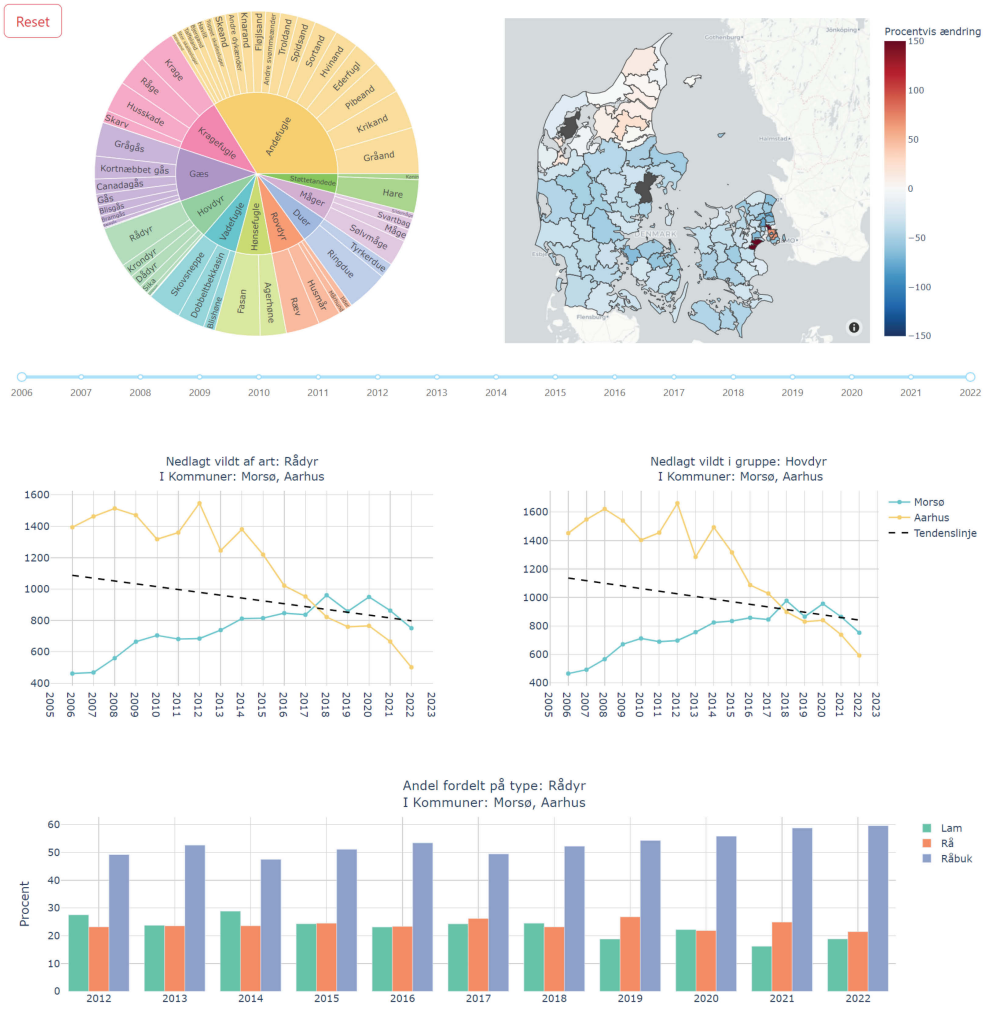

Figure 3: *DWPD Dashboard in its full extension. Action made for this view is, Rådyr on the sunburst, Morsø and Aarhus on the choropleth map and 2006 to 2022 on the timeline.*

possible to investigate one species at a time. Wildlife sustainability is a complex concept involving multiple aspects. These aspects include terrestrial ecoregions, available habitat, wetlands and a natural watercourses, among others. Currently, the DWPD does not incorporate these layers, which limits the users ability to thoroughly investigate these aspects and associations to wildlife sustainability.

7.2. Future work

Future work should address these issues cautiously. Temporal specifications, such as legislation, could be valuable to this project. Fluctuations in temporal data, such as that provided by DGB, can be explained by political or cultural changes. Future works should incorporate significant events that change how wildlife is preserved and managed. The limitation of species comparison may leave users with unanswered questions. In future updates, this would be provided such that, both municipalities and species comparisons is available. Further map layers such as the terrestrial ecoregions or urban vs. rural areas could facilitate visual presentation of correlations between available habitats and wildlife sustainability. Details for sex and/or adults/offspring is provided for certain species, mainly ungulates, however such details could be provided for birds as well using data from DWS. Further details could be provided from IUCN Red List for all species [IUC24]. This data is accessible from Institute for Ecoscience at Aarhus University, providing red list status for danish species [Moe23]. Both details about habitat and additional details for species could advance the dashboard further.

A case study and group interview should also be conducted to investigate the impact of DWPD on policymaking, identify where DWPD falls short, and explore how it can be extended to provide the necessary visual communication.

8. Conclusion

In this study, we presented the *Danish Wildlife Population Dashboard* (DWPD), a geospatial-temporal and visual exploration tool for the analysis of sustainable hunting management. DWPD allows for an exploration of hunting bag data to understand the dynamics of huntable wildlife populations and the temporal patterns within the country.

The used data sets stem from yearly reported data from Danish hunters, but our proposed approach is not limited nor fixed to specific countries. However, our research also highlights the limitations of current data collection methods and the need for more comprehensive, systematic assessments of global wildlife populations beyond huntable species. To address these challenges and improve the sustainability of wildlife management, future work should focus on expanding data sources, integrating additional environmental and ecological factors, and developing more sophisticated analytics tools.

Moreover, the principles and methodologies applied in this paper have the potential to be adapted and utilized in other regions and contexts, contributing to global efforts to combat the biodiversity crisis. Through continued innovation in data visualization and analytics, we can raise questions or enhance our understanding of wildlife populations and their interactions with human activities, leading to more effective conservation strategies and a more sustainable coexistence with nature. With this project we aim to make a step towards bridging the gap between data and decision-making in wildlife management, which could improve and impact the global sustainability of huntable wildlife.

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