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Visualization-based Scrollytelling of Coupled Threats for Biodiversity, Species and Music Cultures

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Abstract

*Biodiversity loss, land use change and international trade are the main causes for an increasing number of endangered species. As a consequence resource scarcity due to endangered species also threatens cultural heritage. To depict such coupled threats and their interconnections for the specific case of musical instruments of a symphony orchestra, the MusEcology project developed a platform to analyze dependencies between musical instrument manufacturing for symphony orchestras, and threat assessments to plant and animal species used as resources. Non-experts are rarely aware of this intertwined threat. Therefore, low-threshold information distribution is urgently needed. We extended the MusEcology platform with scrollytelling functionalities helping domain experts drafting stories that use the visualizations of different dimensions throughout various zoom levels. We outline the utility of our approach with a particular scrollytelling example of the threatened pau-brasil wood (*Paubrasilia echinata *(Lam.) Gagnon, H.C.Lima & G.P.Lewis), endemic to the Brazilian Mata Atlântica, ever since 1800 used for sticks of high-quality string instrument bows. The story of the natural material from forests to instrument-making workshops, musicians and audiences is told through informative texts, interviews, sound recordings, photographs, and schematic drawings. By bringing together expertise from different fields, this story highlights the interconnected dependencies between ecosystems, culture, and music. The interactive storytelling experiences are aimed at casual users and policy makers to raise awareness of the underlying complexity of biodiversity and instrument making, to support related and induce necessary decision making processes, and to unfold possible pathways towards a more harmonic and sustainable music ecosystem.*

CCS Concepts

• ***Human-centered computing*** → ***Information visualization; Geographic visualization; Visual analytics;*** • ***Applied computing*** → ***Environmental sciences;*** *Arts and humanities;*

1. Introduction

Biodiversity loss is one of the biggest threats to our natural world. According to the Red List of endangered species of the International Union for Conservation of Nature (IUCN), worldwide more than 42,100 species are threatened with extinction, which corresponds to 28% of all assessed species [The22a]. Threatened species worldwide form part of many different ecosystems and ecoregions also increasingly threatened by degradation and/or land use change. Many threatened species are important for cultural traditions and cultural objects, and provide important cultural and provisioning ecosystem services. Alone for the construction of orchestral musical instruments potentially 761 species may be used, according to the IUCN Red List about one third of them are threatened by extinction ([KLW*23] in submission). A symphony orchestra is composed of groups of musical instruments, each consisting of different instrument components made from various materials, similar to an ecosystem composed of its different organisms—an orchestra ecosystem.

The interconnection of species used for cultural objects to the objects themselves is rarely analyzed simultaneously as contextualized by Lichtenberg et al. [LHSRA*22] in a theoretical framework of cultural-ecological systems. Kusnick et al. ([KLW*23] in submission) developed *MusEcology* that provides interconnected contextual-environmental information about species distribution, species threats and their trade regulations on country, biome, ecoregion and range map level to a symphony orchestra with its musical instruments in a visual analytics system designed for domain experts. The fragile cultural-ecological relation is threatened by trade and the complex global problems which is indicated by the fact that many species are already listed as threatened and trade-regulated. The preservation of the culture and endangered species should therefore be a declared goal and requires the cooperation of various experts in order to illuminate the complex connections from different directions. However, the continuously worsening situation regarding biodiversity and species loss calls for raising awareness that culture depends on nature with its intact ecosystems.

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To reach the above mentioned aim, we extended *MusEcology* by storytelling—considered as "the soul of science communication" [JDM19]—to make complex information about threats to biodiversity, species and culture intuitively accessible and comprehensible to a non-expert audience. The leading example throughout the paper will be the bow of string instruments, an ideal case to describe these interconnections, because many materials of the different bow parts originate from endangered species. The most important part of a bow is the bow stick and best suited as an example for a storytelling feature with the aim for an increased accessibility of our collected data and knowledge from *MusEcology* for target groups like instrument makers, musicians and interested public. The sticks of high-quality string instrument bows are exclusively made of pau-brasil (*Paubrasilia echinata*), Brazilians national tree, that is endangered and endemic to the Atlantic Forest, its wood has a unique set of characteristics relevant for string instrument bows [LHSRA*22].

Ultimately, our approach aims to give a better understanding of the complexity and huge geographical distances between the telecoupled systems by zooming and panning throughout a geospatial map central to the scrollytelling experience. We evaluated the utility of our approach in an informal user study, and gained confidence that it can play an important role to enhance decision making processes and to encourage initiatives for biodiversity conservation linked to species-specific preservation and restoration to preserve culture.

2. Background

The scrollytelling draws on the *MusEcology* platform ([KLW*23] in submission). It allows an interactive exploration on different levels in regard to the diversity, distribution and threat of species potentially used for musical instruments of a symphony orchestra. The storytelling feature accesses data sources of *MusEcology*, such as the map of orchestras worldwide, the distribution maps of species used for musical instruments of an orchestra, the databases of the IUCN Red List, Speciesplus of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [Con] and the Botanical Gardens Conservation International (BGCI) GlobalTreeSearch [Bot22a] and ThreatSearch [Bot22b].

The story of string instrument bows picks one example of a musical instrument part of utmost importance, the bow stick, that depends on a highly threatened species, pau-brasil (*Paubrasilia echinata*), to combine the interactive information provided by the platform with selected scientific findings on pau-brasil to contextualize the controversial situation of natural and cultural threats.

The variety of research findings about pau-brasil cover a wide range of aspects regarding this species that is relevant for the Brazilian local culture and for the classical music culture, more precisely for the sticks of string instrument bows and for the species itself. Few of these scientific findings are accessible and communicated in a way that allows comprehensive understanding for non-scientific, interested, and/or affected actors (e.g., bow makers, musicians, Brazilian population, violin makers, etc.). By bringing expertise of researchers with different disciplinary backgrounds (geographer and computer scientists) together with domain perspectives of violin makers this story gives insight into the tense situation of pau-brasil, following the way of the natural material from orchestras, via forests and instrument making workshops, back to the audience of concerts, highlighting the interconnected dependencies and interferences. Traditionally these information are gained by field trips, interviews and literature reviews and communicated for example by static maps or timelines. The bundled expertise of the team that developed the *MusEcology* platform draws on computational power to mass process, fuse data, and visualize the combined dimensions throughout various zoom levels or via juxtaposition resulting in an interactive data-driven storytelling, raising the awareness of the inter-connection and showing possible pathways towards a more harmonic orchestra ecosystem. We visualize different levels of detail in the map, where the distribution and diversity of species is shown in levels of countries, ecoregions and within an artificial hexagon grid. The ecological and trade-related threat assessments to the species are supplemented via summarizing icons and donut charts, whereby the histories of them are made clear by timelines. To convey the story, we move along these detailed levels through space and time to contextualize information with historical developments and their consequences regarding the story of the string instrument bow via scrollytelling. However, the narrative is told through informative texts and translated interviews with Brazilians and experts, accompanied by their original sound recordings, photographs and schematic drawings highlighting technical details and the interconnection of the manifold details from various domain perspectives.

3. Related Work

Geospatial Views. To represent particular values, such as the population density of a certain species, in specific areas Choropleth maps are commonly used [JBR19, MSM21, D*17]. The use of hexagonal tiling is preferred when an artificial grid is utilized to divide individual areas [MH17]. Also visualizations for global forest loss [Viz22] or the habitats of selected species can be presented geographically through the use of geospatial heat maps [The22b, Tel11, Glo22, JNZ*16]. Glyph-based maps can be designed to communicate various aspects of fruit tree species distributions, as demonstrated in Albania [GDH*14]. Additionally, the distribution of tree species in a limited spatial area can be displayed effectively using tag maps, which show the most common species in an aggregated spatial area [RCSJ18, RFN*08].

Temporal Views. Time-based visual depictions of species tell stories like the life cycle of the Japanese beetle [Tuf01] or overviews of the evolution of dinosaur species [HJ07] and a timeline-metaphor is telling stories of musical instruments and their matched musical compositions [KKFJ20].

Visualization-based Storytelling. Since centuries stories are told to communicate information in an understandable and memorable way, and are just as long depicted by for example rock wall paintings [Bol10]. Through the ongoing digitization and visualization nowadays the topic remains of high interest and creates value in a broad variety of economy branches and research fields. Storytelling is considered as "soul of science communication" [JDM19], increasing comprehensibility and involvement of recipients, especially by interactions [MLF*12]. Sequences of changing circumstances of characters throughout the story thread create in

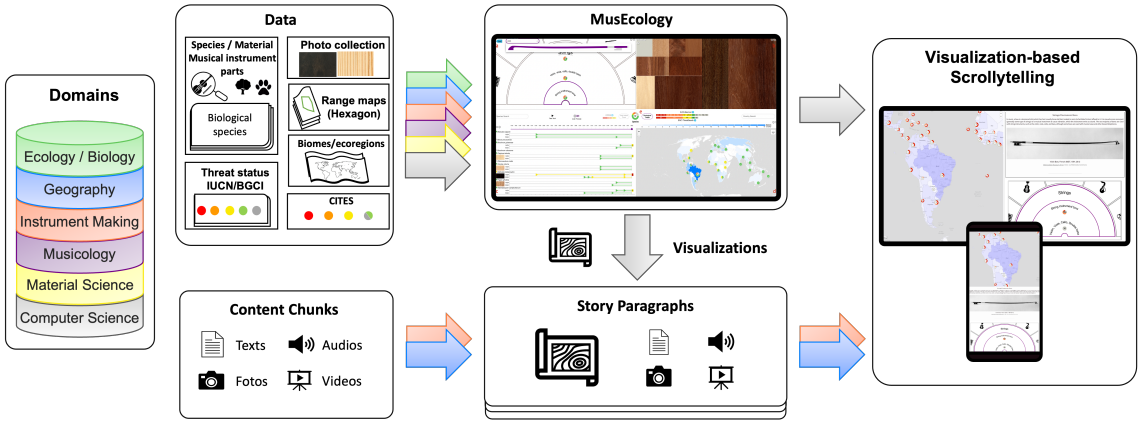

Figure 1: *Overview of the diverse data repositories linked to our six key domains: ecology/biology (green), geography (blue), musical instrument making (orange), musicology (purple), material/wood sciences (yellow), computer science (gray) and their merged processing towards the four different interconnected views: Orchestra, Material, Threat Assessment Timeline, and Diversity Map of MusEcology and the enhancement by the stories' paragraphs which incorporate the visualizations, and content chunks.*

their unique combination a comprehensive storyline [MLF*12, TRB*18]. These episodes are often told with the support of temporal and geospatial views. General discourses and surveys on visual storytelling [TRB*18, Kos17, SLHRS04, MHRL*17] analyze and categorize visualization techniques for scientific stories or journalistic data stories [SH10]. Kusnick et al. report on narrative visualization techniques for person and object data on cultural heritage [KJD*21] and focus on "visualization-based" storytelling. They review music culture-related stories on teacher-student and album-instrument relations within network graphs and data-comics [JF17, KHRB*19], and also encounter environmental stories on micro-climate within the streets of Vienna, Austria via mixed reality. The affirmation of the use of storytelling as an memorable outreach for such data is originating from the ongoing research and development of comprehensive multi-modal systems regarding cultural heritage object and person data such as "InTaVia" [MWL*22]. Storytelling also gains importance in the communication of insights from the environmental science especially for specific target audiences such as on world heritage and biodiversity for children [Ron, FPO*22] or people older than 55 [NSS].

Scrollytelling. One of the common visualization-based storytelling implementations such as "annotated chart", "data comic" or "slide show" is called "scrollytelling" where the main interaction is implemented through scrolling. This technique is often used by online articles in combination with illustrative videos or three-dimensional renderings such as the fire outbreak at the Notre-Dame cathedral published by New York Times [New]. Scrollytelling that incorporates maps as a central part and the locations to which certain information can be connected is widely used, e.g., in a recent newspaper regarding illegal logging and the timber mafia [Sü]. Photographs are also widely used, especially in connection to cultural objects [Phi]. In summary, none of the related works supports the visual analysis of the interrelation of endangered species and the interconnected threat of natural and cultural heritage across continents.

4. Methodology & Visual Design

This visualization-based scrollytelling resulted from a participatory visualization design process [JKKS20] within our core team of two computer scientists together with a geographer, who also is a violin maker, in a design by immersion approach [HBH*20]. Additionally, our decisions are based on findings of the long-lasting collaboration with a co-creation team (two computer scientists, one ecologist, one geographer, two biologists) and external domain experts from the creation of *MusEcology* 1. Cultural actors, objects and groups of them (e.g. orchestras) are traveling around the world and so do the resources used for culture, whereby the involved craft traditions represent an intangible cultural heritage on their own as well. *MusEcology* tries to inform about these aspects by focusing on globally consistent information details, but it lacks all the (intangible) information and the socio-cultural meanings hidden in the stories all around. Especially music is touching, often very personal and almost everyone has a connection to it. But these complex and rather intangible details and side-stories remain hidden and are waiting to be told and put into context. The interactive storytelling added to *MusEcology* tries to encounter this and is meant to create an additional specificity for the creation and perception of memorable and immersive stories on the diversity, distribution, threat of natural species used for the production of musical instruments and the distances between the interlinked levels and multi-modal (story) characters of touched systems. Therefore, we decided for the geospatial map as main visualization on the left side of the equal divided screen. To minimize the distraction and keep the orientation we decided for a static two column layout where the right screen half is a scrollable content area to tell the story by a variety of content chunks (see Figure 2). As a first story we choose to implement the "Story of the String Instrument Bow" because we wanted to approach the complex topic from the symphony orchestra as entry point and since the bow stick is made from the endangered pau-brasil, it is currently facing controversial discussions. The driving interaction throughout the story thread is scrolling, as it allows for direct, responsive, and bidirectional control and is widely used on

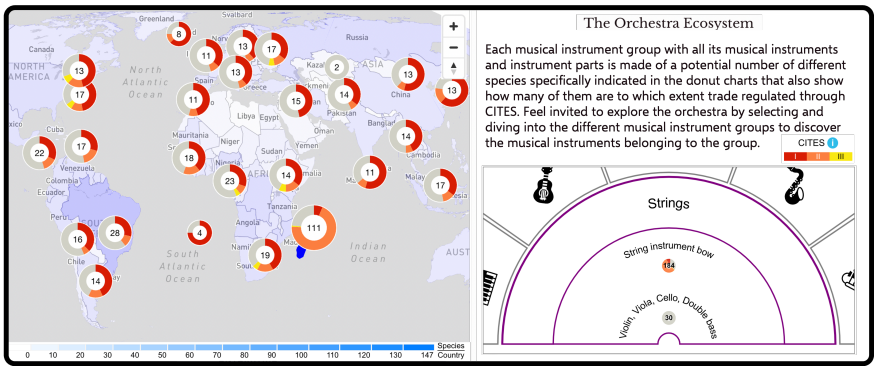

Figure 2: *On the left side the map is showing the materials/species used for string instrument bows and their trade regulations in the threat donuts. On the right side a schematic orchestra is shown zoomed in the string instrument group that consists of violins, violas, cellos and double basses. All instruments consist of different musical instrument parts. In its connection to the species the instruments are made of and under consideration of the orchestra functioning this is can be called an orchestra ecosystem.*

Figure 3: *Left: Map with hexagons showing the distribution of pau-brasil along the Brazilian coast within the Atlantic Forest (Mata Atlântica - in yellow). The map is switched to a satellite view automatically to reveal insights into topology and vegetation. Right: Explanations to the pau-brasil tree and photographs of its unique flowers and bark.*

social media and mobile apps [MBS22]. By the reach of story paragraphs within the focus area of the content half on the right side, the map view on the left is "flying" to a given position and zoom-level by smooth transitions of zooming and panning. Just as in MusEology, we used *JavaScript* libraries such as *React* and *D3.js* to create our web app and visualizations, but for the maps we used *Mapbox GL JS*, because it allows for useful projections (e.g. 3D globe) and "fly-to" animations.

4.1. Map & Layers

Already *MusEcology* has a map that includes a variety of "map modes" defining which information is visualized by which polygons and clustered glyphs within each mode. The map offers seamless switches between these modes, "fly-to"-transitions and zoom ranges from overview of the whole world to single buildings. Each map mode consists of three layers: (1) base map (e.g. light, dark, satellite), (2) polygons (countries, ecoregions, artificial hexagon grid), and (3) additional statistical and clustered glyphs (e.g. threat donuts, orchestra clusters) on top of them. Thereby the amount per entities within the polygons is depicted by a blue shaded heatmap. In case of the country mode these entities are either the various species used as resources for musical instruments or orchestras worldwide. On top of the countries capitals are "Threat Donuts" symbolizing either the overview of trade regulations by CITES or the assessed ecological species threat that is provided by IUCN and BGCI by colored circle segments (see Figure 2). In case of switching the map mode to ecoregions and hexagons the entities remain the species as heatmap and the threat markers are placed on the surrounding ecoregion's center point. The map modes can be easily changed by the activation of the according content chunks and the interactive legends are explaining the visual elements and allow for details-on-demand through filtering and hovering. During our example story on *Paubrasilia echinata* we are progressing from an global perspective on symphonic orchestras over trade regulations

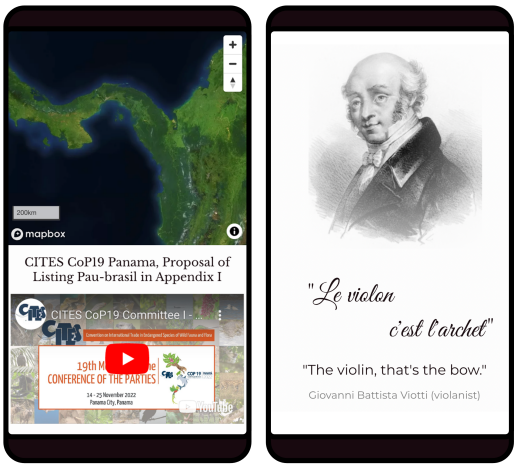

Figure 4: *Left: Responsive mobile portrait view with stacked map and content area including a video, documenting the CITES CoP19 in Panama [CIT22]. Right: Fullscreen quote by violinist Giovanni Batista Viotti [Wik20] to emphasize the importance of string instrument bows.*

in Brazil, focusing on the ecoregions close to the coast, towards the reveal of pau-brasil's distribution as hexagons (see Figure 3). To minimize the distortion of areas, we chose the equal area projection by *Mapbox*.

4.2. Content Chunks

To tell and illustrate the story we offer a variety of multi-media "Content Chunks" as building blocks consisting of textual, medial and interactive visualizations as seen in Figure 1. They can be used, customized, and combined to craft an author-driven story within a JavaScript Object Notation (JSON) stating all the different stations and appearances throughout the story in a list of "Story Paragraphs".

Texts & Quotes. The easiest way to convey a story is by narrative text. Therefore we offer a selection of harmonizing font-family pairs for headlines and text contents. Special cases for texts are width filling Titles, Quotes, End Cards with further information such as subtitle, translation and authors. Worth to mention is that all the textual content definitions are able to handle HTML as markup language to customize the contents even more. An embedding of e.g. tables is becoming possible by it as well. This can also be used to reformat text so that it becomes e.g. a transcript of an interviewing dialog of story characters.

Images. To illustrate stories, multi-media data is broadly used in storytelling approaches. Therefore we allow to embed single and/or multiple online available images as galleries by the statement of link urls. More explanatory context is given by the images through their optional captions and copyright statements.

Videos & Audios. Similar to the images the data is defined by link urls to the used media source and optional captions, and copyright information. By indicating the starting time in seconds, the story editor can skip unwanted parts of available contents such as an intro of audios or videos. Since embedded media files allow to be automatically played on websites, they can be used to convey the story, or increase the atmosphere and immersion by enhancing video material, insightful interviews or background sound effects. But because automatically starting media can be potentially disturbing, this functionality remains an opt-in at the beginning of the story, while the recipient remains in control of the playback by the visual interface.

Visualizations. Building on top of the system architecture of four juxtaposed but linked visualizations of *MusEcology*, the story also allows to make use of the already implemented visualizations and visual glyphs. Thereby, the visualizations stay linked to the map, so that interactions within one content visualization on the right could alter the appearance of the map to the left. This fact can be used to create breaks within the linear story flow and allows for higher degrees of freedom for the recipients. The case of the nested orchestra view enables on demand an exploratory analysis of distributions and threats of species used for the various musical instrument groups and their containing instruments as shown in Figure 2. Similar to this, the Timeline View can create insights into the history of trade-related and ecological threat assessments of selected species. All these building blocks can be combined, allowing the creation of rather complex stations within the story.

4.3. Interactions

The inter-linkage between story paragraphs and map is given by an annotation of the story contents with a desired map base-layer, map modes and specific geolocations to fly-to when the story paragraph is scrolled into the focus area. Additional filter for the data shown in the selected map layer such as "Filter for only hexagons of *Paubrasilia echinata*" allow the focus on its rather limited distribution with the option to switch to a satellite map-base, revealing a first impression of the vegetative circumstances in that area. This mechanic also drives the interplay between the additional visualizations and story map, such as the Orchestra View applies filter for species used for user-selected musical instruments and instrument groups. Furthermore, the activation of story paragraphs by scrolling enables for rather artistically effects e.g. the change of background color as used in the orchestra hall to simulate the dimmed lights for the audience. During the development we considered a responsive design of our visualizations and Story Paragraphs, so that the story can also be presented on mobile devices in portrait-mode, whereby the map view is positioned above the scrollable content area, as depicted on the left side of Figure 4.

5. Informal Evaluation

We conducted an informal evaluation in order to investigate if our approach suits to educate casual users on the interconnections between biodiversity and instrument making, using the implemented story on the string instrument bow stick, whereby the participants received no training and no information on the story's theme.

Participants. The setup as an online evaluation helped us to reach a good number of interested participants for feedback on our first prototype. We invited people with different backgrounds to gain a heterogeneous group. We received 19 responses from participants

of different age groups (see Figure 5) having diverse professional backgrounds. We ensured that none of the participants had a background in biology and musicology.

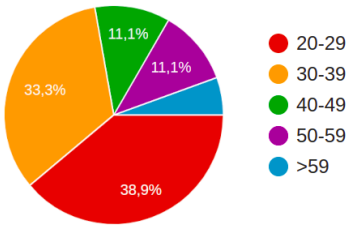

Figure 5: *Age distribution of the participants.*

Scrollytelling Experience. We wanted to know from participants how well the scrollytelling supported to learn about the underlying concept. On a 7-point Likert scale from *strongly disagree* (1) to *strongly agree* (7), we firstly asked them how intuitive the scrollytelling was. With an average of 5.4, the majority of participants found the approach rather intuitive, only two participants found the bow stick story counterintuitive (see Figure 6). We secondly asked on how valuable the visualizations were to understand the concept and to facilitate the learning experience. Although a majority of eleven out of 19 participants were on the positive side, the answers were mixed with an average of 4.7 (see Figure 7). One reason would be that next to the visualizations diverse contents like rich media were used to tell the story, which may lower the perceived importance of the visualizations used. However, users who gave a lower score for intuitiveness also tended to give a lower score when rating the importance of the visualizations.

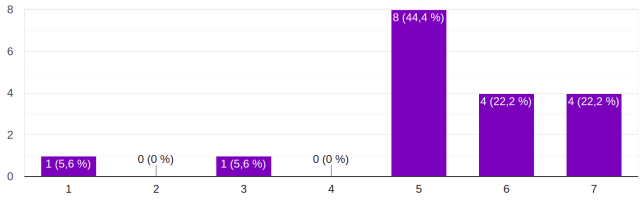

Figure 6: *Intuitiveness of the scrollytelling approach.*

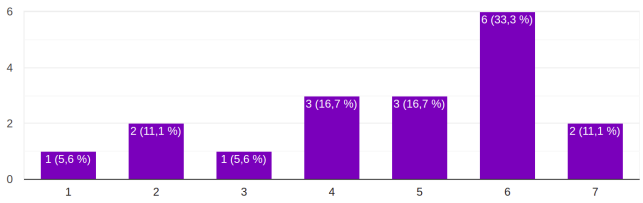

Figure 7: *Importance of visualizations in the scrollytelling.*

Learning Effect. With an average of 5.8 on a 7-point Likert scale from *strongly disagree* (1) to *strongly agree* (7), nearly all users confirmed to have learned something new through the scrollytelling. We asked them what they had learned. 13 of 19 participants directly replied that they were not really aware of the threats

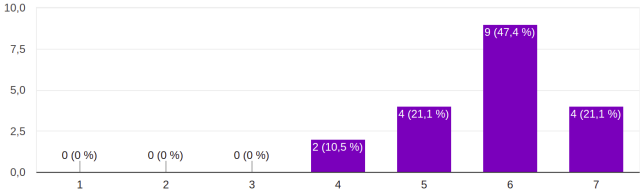

Figure 8: *Learning effect through the scrollytelling.*

to the natural resources musical instruments are made of (see Figure 8). One of the replies was exactly what we wanted participants to learn: *"History about something I had no idea about - and never really thought about before."* Other participants mentioned they learned about illegal trades, the composition of orchestras or the scrollytelling technique itself.

General Feedback. Nearly all participants gave constructive feedback and suggested improvements, which we consider an indicator for user engagement. While we received some comments on how to improve the structuring of the story itself, participants also suggested to improve the technological features of the scrollytelling approach. While some of these were due to the circumstance that we used the first story draft during the evaluation, other suggestions made us aware of obstacles for users during the scrollytelling experience. Overall, the feedback can be turned into general recommendations:

- The story must be carefully introduced at the beginning.
- The relation between visualization and content has to be clear.
- Visualization and content need to be balanced.
- There has to be a red thread between two subsequent story items.
- Using rich media like sound and video enhances the experience.

6. Discussion and Limitations

The main strength of digital storytelling in general as well as in our case is mixing fact based information with multi-media impressions and personal stories delivered through interviews to address emotions and foster connection and identification with the story [MHRL*17]. Part of our outreach intention is to break down expert knowledge often collected by single researchers into understandable and memorable facts communicated by memorable narrations. For captivating storytelling of such expert knowledge user-adapted text formulations and a good story flow are key elements [TRB*18]. This process of storytelling alone requires a lot of knowledge and effort, but to depict the story by interactive visualizations the domain-experts also need to have (technical) understandings of visualizations. Therefore, data-driven story creators and storyboarding tools should support the editor to craft narrative visualizations [KHRB*19,KJD*21,MBS22], but often lack the possibility to use already customized visualizations, such as the artificial hexagon grid and the ecoregions with threat levels of the *MusEcology* platform. Moreover, as a challenge and finding within our interdisciplinary collaboration, we figured out that domain experts often prefer to continue their research and storytelling elaboration within tools they already know. This is why our approach so far relies on the collaborative conversion of stories drafted in

slide shows and spreadsheets by the domain-experts into the JSON-configuration of story paragraphs and their contents with the help of computer scientists. To overcome this limitation one avenue for future work could be to include a story editor interface or the possibility to make *MusEcology* and its elements available though e.g. url parameters to use them in stories crafted in external tools. Even though small visual elements like the interactive color legend might be difficult to integrate into other editor tools. We opted for a linear story design with specific use cases because the entire system might be too complex and overwhelming for a broader public audience, not used to exploratory visualization approaches. Nonetheless, all of the interactive visualizations can be used within the stories as interactive breaks within the story flow and function also as starting point for exploration and future stories on instruments, regions, materials, and species. Therefore, our scrollytelling allows to reach casual users and to draw their attention also beyond the specific case to the general problem of an increasing number of threatened species due to its connection to the existing *MusEcology* platform. The connection between music cultures, their musical instruments and threatened species, specifically the string instrument bow and the threatened pau-brasil tree, brings environmental concerns together with cultural values. This allows casual users that have a relationship either to the cultural value or to nature to personally relate to the described cultural-ecological threat. Current global environmental challenges, such as biodiversity loss and species extinction require linking such large, hard to grasp topics to the personal level to trigger careful decision making processes as well as biodiversity and species conservation activities. Our visuals and system are based on the data and visualizations already available in *MusEcology*, and are therefore able to provide scalability and generalizability as the platform was developed with a global and multi-zoom-level approach in mind. However, remaining challenges are the ambiguity of (common) trade names. The lack of scientific explorations or limited or insufficient scientific findings for some musical instruments and their species complicate the creation of stories for each musical instrument. Albeit these challenges domain experts currently develop stories about other musical instruments and their parts being resourced from fragile ecosystems, e.g., African blackwood (*Dalbergia melanoxylon*) that is used for clarinets and oboes, or the vulnerable Bahia rosewood (*Dalbergia nigra*) being the most valued material for high-end guitars.

7. Conclusion and Future Work

We developed an interactive digital scrollytelling to narrate complex interconnection of cultural and natural heritage across large geographical distances. The first story example drafted about the string instrument bow not only addresses the main goal and succeeds to raise awareness for this intertwined challenge of species threat and the threat for the tradition of bow making, it in particular highlights the potential of a more user-friendly introduction for casual users to complex data sets offered through the *MusEcology* platform. Our approach gives the domain experts the opportunity to tell these stories using complex data for the first time.

Future developments of our storytelling interface include a deeper zoom level on the specific protected areas with occurences of target species' to more impressively demonstrate how rare species like pau-brasil are nowadays. We will further adopt several narration techniques provided by the InTaVia storytelling suite [MWL*22] that are suitable for the *MusEcology* project, such as facilitating user engagement with gamification elements [HCL13] like small riddle questions or quiz elements, or reshaping the story arc by choosing different story entry points.

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