What's the Point? Use of image repositories in rhino research

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4817 words

Abstract

The five extant species of rhinoceros are all threatened by habitat loss and human hunting for their horns. Traditionally, museum collections have been used for baseline assessments in conservation and evolutionary biology research, but online image repositories offer an alternative. The Rhino Resource Centre holds a collection of 4,441 images of rhinos, both photographs (from 1862 onwards) and artistic portrayals (from 1481 onwards). I used this collection to assess how human-rhino relationships have changed over time, in terms of the species composition of images, the relative depiction of conservation and hunting, and the emotions artists assigned to rhinos. I used a Principle Component Analysis (PCA), to demonstrate differences between the five species, and performed an ANCOVA for each species to assess changes in horn length over time. I found that African rhinos have become better represented in more recent years, whereas the smaller Asian rhino species continue to be underrepresented. During the age of European imperialism, rhinos were commonly portrayed as hunting trophies, but since the mid-20th Century they have been increasingly portrayed more positively and within the context of conservation. Horn length has significantly decreased in Indian rhinos relative to other body proportions, but there was no significant trend in other species. The changes in human-rhino relationships suggest there is cause for conservation optimism, though increasing efforts are required to raise awareness of the two smaller Asian species. Decreasing horn size in the Indian rhino may be evidence of directional selection in response to biases in human hunting. Taken together, these results demonstrate that image repositories could be an important tool for the study of the conservation and evolution of large mammals.

1. Introduction

Historical collections are critical tools in the fields of evolutionary biology, ecology and conservation science. Collections provide us with baselines against which to measure change (Waits et al., 1998). Museum catalogues are invaluable but are not the only dataset on natural history available to researchers. Humans have been producing images of nature for over 40,000 years (Aubert et al., 2018), and these images can be used to reconstruct both our changing relationships with nature and changes in the natural world itself. Large mammals are often considered the most charismatic species by observers (Luque and Courchamp, 2018), and therefore are particularly well represented in imagery, resulting in a high utility for image-based research. The rhinoceros (ranked as the seventeenth most charismatic animal species) is one such example.

There are five extant rhino species in four different genera, each with its own independent relationship with humanity. These are the white rhinoceros (*Ceratotherium simum*), black rhinoceros (*Diceros bicornis*), Indian rhinoceros (*Rhinoceros unicornis*), Javan rhinoceros (*Rhinoceros sondaicus*) and Sumatran rhinoceros (*Dicerorhinus sumatrensis*). They are a member of the Perissodactyla, alongside modern horses and tapirs (Steiner and Ryder, 2011). Three of the five

species lie within the top twelve Evolutionarily Distinct and Globally Endangered (EDGE) species (Isaac et al., 2007), demonstrating the distinctiveness of the Rhinocerotidae lineage. *C.simum* is the only species not currently threatened according to the IUCN Red List. The plight of rhinos worldwide is an area of active conservation efforts and further understanding of the history of human interactions with these animals could help to support conservation projects.

In addition to the opportunity for conservation, rhinos provide a unique chance for image-based research, given their cultural significance in art. In 1515, an Indian rhino drowned during transport from Lisbon to Italy, and inspired a woodcut by Alfred Dürer, which following the invention of printing, spread throughout Europe (Quammen, 2000). Later, travelling menageries brought more rhinos into the public eye, conjuring fascination with these animals that contributed to a vast artistic record of rhinoceros imagery. In particular, one Indian rhinoceros named Clara toured Europe between 1741-1751, inspiring a huge volume of artwork (Rookmaaker, 1973). It is because of such captive animals that a strong historical record of images exists; it is this record that can be used to track rhino-human relationships through time.

One of the gravest threats to all species of rhinoceros is human hunting. Modern poaching of rhinos is driven by high demands for horns, particularly in Asian markets. One estimate suggested that 12,750 black rhinos had been killed to provide the 36 tonnes of horn sold between in Yemen between 1970 and 1986 alone (Leader-Williams, 1992). In Kenya, there were an estimated 20,000 black rhinos in 1991, but only 631 in 2014 (Thuo et al., 2015). This is one of the most precipitous declines of any extant mammal species. All species are also threatened by habitat loss, and a combination of these threats has already led to the extirpation of the Sumatran rhinoceros in mainland East Asia (Lander and Brunson, 2018). Conservation strategies seek to minimise population losses in rhinos through both these extinction drivers.

Both modern poaching and trophy hunting during the days of the European empires have been selective in their slaughter. Given the high price of rhino horn, and the social status for hunters of killing those with the largest horns, rhinos with the longest horns tend to be targeted. In other organisms, selective harvesting can lead to directional selection, whereby a strong selective pressure imposed by wildlife utilisation leads to a reduction in the frequency of the desired trait (Coltman et al., 2003). Directional selection due to trophy hunting has been shown to cause declines in tusk size in elephants and horn length in wild sheep (Garel et al., 2007; Festa-Bianchet et al., 2014; Chiyo et al., 2015) In situ measurements of these organisms and studies of museum collections have been used to establish these trends, but photographs also have the potential to be used alongside these methods to demonstrate directional selection. In the case of the rhinos, we predict a decrease in horn length through time in response to the selective pressure of hunting.

The Rhino Resource Centre (RRC) (http://www.rhinoresourcecenter.com/.) was founded in 2005 and as of March 2019, represents a compilation of 23,123 files containing literature relating to any rhinoceros species, and 4,441 images (Rookmaaker, 2019). The images are given species designations and an associated date and location where possible. The nature of the RRC provides a powerful opportunity for research, with a high number of pieces of artwork that may be used to assess historical changes in rhino-human relationships, and a large collection of

photographs, dating back to 1862. In many cases, the literature collection allows further investigation of the provenance of these images.

In this study I used the RRC as a source of images to test the utility of such collections for large mammal research. I focused on five key questions: (i) how the relative importance of artwork and photography changed over time, (ii) how species composition in imagery has changed over time, (iii) the comparative prominence of both trophy hunting and conservation in depictions of rhinos over time, (iv) how the emotions assigned to rhinos by human artists change over time and (v) whether any rhino species have demonstrated a decrease in horn length over time. Underlying all five questions is an assessment of the efficacy of such online image repositories as a tool for understanding changing human-wildlife relationships, with potential applications in the fields of conservation and evolutionary biology.

2. Methods

2.1. The Rhino Resource Centre

All images used were taken from the RRC website: http://www.rhinoresourcecenter.com/. I used for my analysis all valid images available on the site as of the 19th March 2019. I systematically examined each image in the order they appeared in the RRC's Rhino Image Gallery. All dates and locations were drawn from the descriptions given underneath each image on the RRC website.

2.2. Artwork

Any image depicting any species of rhinoceros not produced using a camera was defined as a piece of artwork. Artwork was ignored where no age could be inferred, where no species identification was possible or where repetition was obvious. In many cases, repetition could not be ruled out because superficially similar artwork had alternative dates associated with it. In these cases, both pieces of artwork were included in the analysis.

The RRC contains a range of artwork, with many themes. A subset of this artwork is shown in Figure 1. For all artwork, I recorded the species, date and location. The depiction of the artwork was defined as the key theme of the image. Using the qualitatively judged key theme of the artwork, and any supplementary information provided by the artist, I placed each image into one of three categories: 'Hunting', 'Conservation' and 'Other' (Table 1).

Table 1. **Broad depiction categorisations for artwork on the RRC and the corresponding narrow categorisations**

Categorisation	Included depictions	Definition
Hunting	Hunting	Any image featuring a human with a weapon aimed at a rhino is pictured, or a rhino that has been killed
Conservation	Conservation	Image made to publicise the plight of rhinos or that depicts conservation management
Other	Advert, academic, captivity, cartoon, charge, curiosity, educational, fetishism, nature	Any image which cannot be categorised as depicting either hunting or conservation

Figure 1. **Representative images for artwork on the RRC and the categorisations they were assigned to.** Names taken from the RRC A) Rhinos, movie (1964) (Other, Advert) B) Out of the Hurly-Burly (Other, Charge) C) Kuhnert 1926 (Other, Nature) D) Grandville Fables 1842 (Other, Cartoon) E) Sumatran one-horned rhino (Other, Educational) F) Muller 1839 (Other, Academic) G) Last of the Northern White Rhinos (Conservation) H) Death of a black rhinoceros (Hunting) I) Johnstonius' rhino 1657 (Other, Curiosity) J) Mercurio 1991 (Other, Fetishism) K) Begum arrives at the London Zoo (Other, Captivity)

Each piece of art was additionally assigned an emotion in order to assess how the portrayal of rhinos has changed through history. Again, I allocated these emotions based on the content of the image, the title and supplementary information. Because this categorisation was so subjective, I erred on the side of neutrality, and when it was unclear whether the artist intended to imply a given emotion upon a rhinoceros, it was 'Neutral'. I reclassified all narrow categorisations into the broad categories of 'Positive', 'Negative', 'Impacted' and 'Neutral' (Table 2). Representative images are shown in Figure 2.

Table 2. **Broad emotion categorisations for artwork on the RRC and corresponding narrow categorisations.** Coarse categorisations were introduced to reduce the element of subjectivity in describing rhinoceros' emotion

Broad Emotion Categorisation	Included Emotion Categories	Definition
Positive	Beautiful, Compassionate, Cute, Determined, Distinguished, Grateful, Happy, Hopeful, Inquisitive, Majestic, Peaceful, Powerful, Wise, Wonder	Any image of a rhino that illustrates affection for the animal by the artist. The rhino may be behaving positively towards humans or be portrayed as an important and beneficial part of the ecosystem
Negative	Angry, Fat, Stupid, Ugly	Any image of a rhino that is in any way perjorative, either in the way they interact with humans or their appearance
Impacted	Dead, Distressed, Ill, Injured, Sad, Scared	Any image of a rhino that shows it having been negatively impacted by the action of a human
Neutral	Heavy, Hungry, Neutral, Strong, Surprised, Tough, Wary	Any image of a rhino where an emotion intended by the author is not discernible

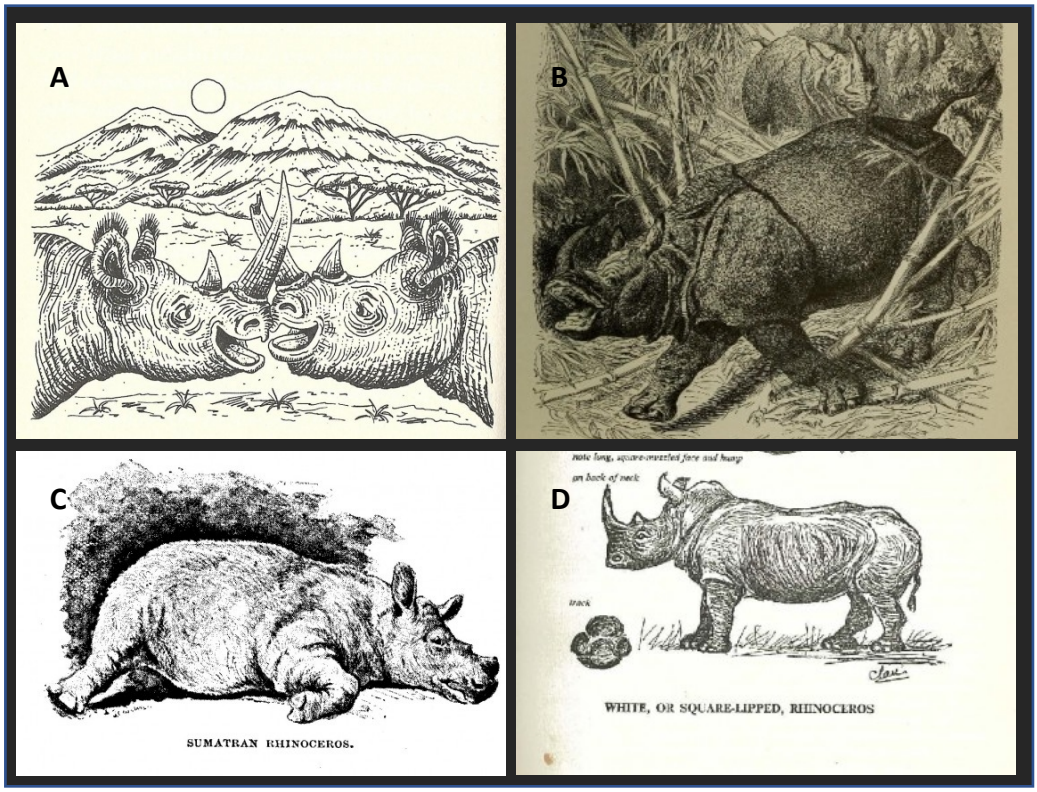

Figure 2. **Representative images for the 4 coarse emotion categorisations for artwork on the RRC.** A) Positive (Nero Nashorn 02) B) Negative (Riverside Rhinoceros indicus) C) Impacted (Sumatran in Tring) D) Neutral (Astley Maberly White Rhinoceros)

2.3. Photography

Images produced using a camera were classified as photographs. All photographs were included in my analysis, regardless of whether they depicted a rhinoceros which was depicted in any other photograph. Location data was recorded at a country level, and where this was not possible, documented as 'Unknown'. Species was again recorded, as was the status with regards to captivity. Rhinos could be either 'Wild', 'Captive' or within a. 'Sanctuary.' Depiction was quantified through the categories 'Conservation', 'Hunting' or 'Other' to allow comparison with data from artwork (Table 3). Representative photographs from the RRC are shown in Figure 3. Poaching was difficult to place because many images of poached animals were used for conservation publicity. I separately performed analysis with poaching included in either 'Hunting' or 'Conservation' and found no significant difference, so poaching was retained within the hunting category.

Table 3. **Depiction categories for photographs on the RRC, with corresponding definitions**

Categorisation	Included categories	Definition
Hunting	Hunting, Poaching	Photograph where the rhino is either being hunted by humans or has been killed, for a trophy or illegally for its horn
Conservation	Conservation	Photograph used to promote conservation efforts or which depicts any conservation management
Other	Captivity, circus, nature	Any photograph which does not fit into the 'Hunting' or 'Conservation' categories

Figure 3. **Representative images for photographs on the RRC and the categorisation they were assigned to.** A) Roosevelt in East Africa 3 (Hunting) B) Namibia horn removal (Conservation) C) Kaziranga (Other, Nature) D) Honolulu Zoo (Other, Captivity E) Rhino and tiger in circus (Other, Circus) F) Nepal 2009 (Hunting, Poaching)

2.4. Morphometric measurements

In order to assess how aspects of rhinoceros morphology had changed over time, I measured several features of morphology on photographs of adult rhinos available on the RRC. Photographs were selected where the animal was side-on to the camera so that measurements could be taken directly. I discounted any individuals where the horn had been cut by humans. All measurements were conducted using Fiji for ImageJ (Schindelin et al., 2012). Horn, body and head length, as well as stomach, shoulder and hip height were all measured (Figure 4).

Skin folds provided anatomical markers for these measurements. The head length was defined as the length from the end of the snout to the first skin fold of the neck. The body length was defined as the length from the last skin fold of the neck to the most posterior point on the body.

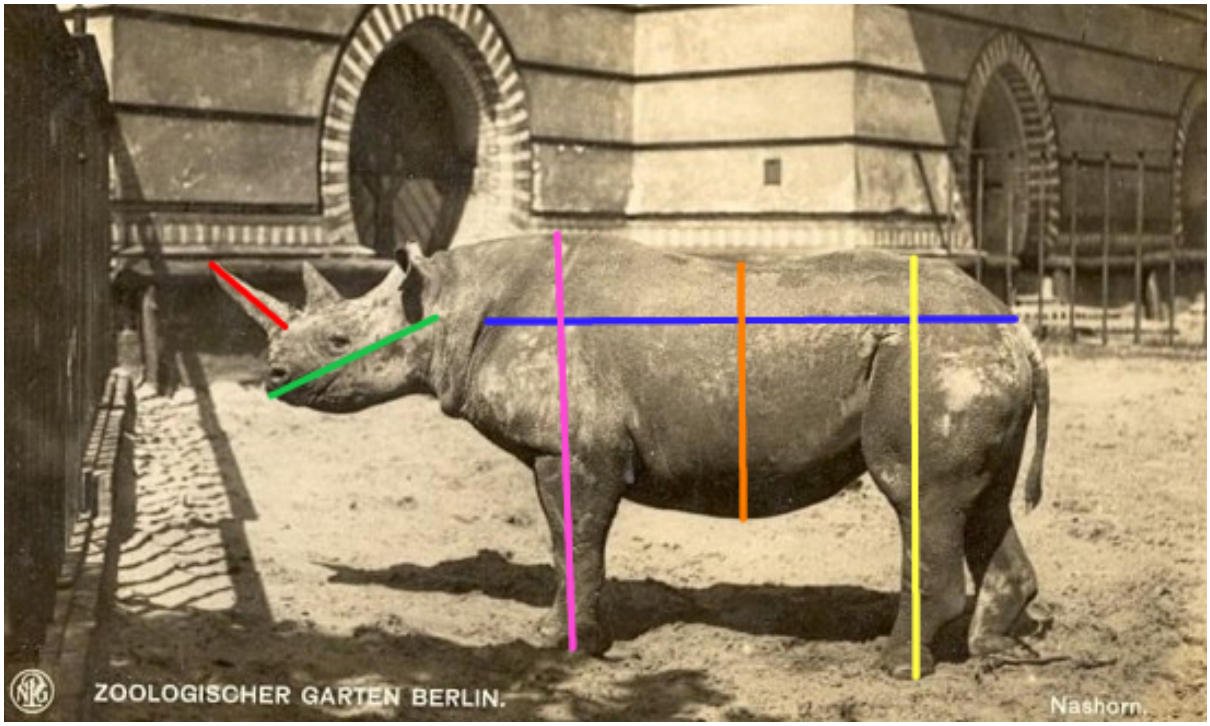

Figure 4. **Measurements taken for each side-on rhino photo.** Red = Horn Length, Blue = Body Length, Green = Head Length, Orange = Stomach Height, Pink = Shoulder Height, Yellow = Hip Height. Figure produced using GIMP 2.8.20. Image from Dr Nuno Carvalho de Sousa Private Collection

2.5. Data Analysis

I performed all data analysis using RStudio Version 1.2.1181(RStudioTeam, 2018). Figures were generated using packages ggplot2 (Wickham, 2016) and rworldmap (South, 2011).

I produced histograms for image frequency over time for artwork, photographs and combined images. Bin width was 20 years for artwork, and 10 years for photographs. Where possible, I used Chi-Squared tests to determine statistical significance for changes over time, with $p < 0.05$ set as the benchmark for significance. In order to perform this statistical test, I constructed contingency tables with four coarse time bins. For artwork, these bins were 'Pre 1850', '1850-1900', '1900-1950' and '1950 onwards'. For photographs, the bins were 'Pre 1920', '1920-1960', '1960-2000' and '2000 onwards'. Where a cell in the contingency table had a value of 0, the statistical test used was a Fisher's Exact Test. I produced a map of the location of photographs

taken of rhinos to a country level. This was not possible for artwork because of the low level of geographic resolution.

To test how well represented each species of rhinoceros was in the RRC, I plotted the number of images of each species against the in-situ population size. These in-situ population values were obtained from Save The Rhino (https://www.savetherhino.org/rhino-info/population-figures/). Where there was a population range, I took the mean of the upper and lower bounds as an estimated population size. I used a Chi-Squared test to evaluate differences in the representation of species in actual populations and in the RRC.

Using the raw measurements from each rhino, I performed a Principal Component Analysis (PCA) to extract any possible differences between the rhino species. To evaluate changes in morphology over time I performed a PCA again for each species, removing horn length as a variable. I then used an Analysis of Covariance (ANCOVA) to assess significance, using PC1 scores from this PCA as a co-variable and date as an explanatory variable, with raw horn length measurement as the response variable.

3. Results

3.1. Images on the RRC

I recorded 3,158 images on the RRC, 1,531 pieces of artwork and 1,627 photographs. The first recorded piece of art was from 1481 and the first recorded photograph was from 1862. Indian rhinos were the most well represented in the RRC in total (1,273 images) and Javan rhinos the least well represented (123 images). White rhinos had 603 total images, Sumatran rhinos 308 and black rhinos 851 (Figure 5).

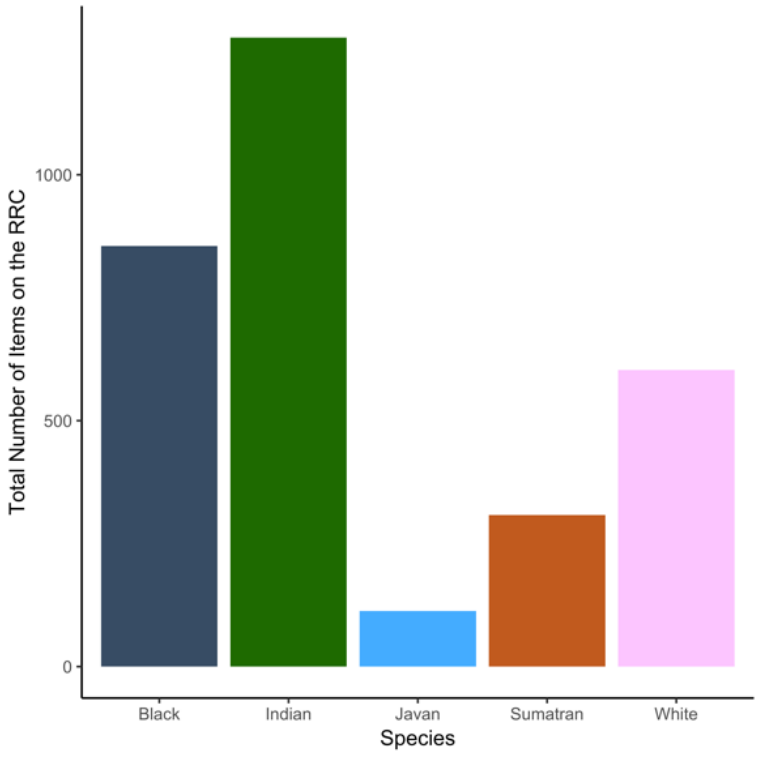

Figure 5. **Total number of images of each species on the RRC**. This includes both artwork and photographs

3.2. Media use

Since the first recorded photograph in our dataset in 1862, photography has become proportionally more widespread compared to artwork. There has been a statistically significant shift in the medium used (Fisher's Exact Test, n = 3,158, p <0.0001) (Figure 6).

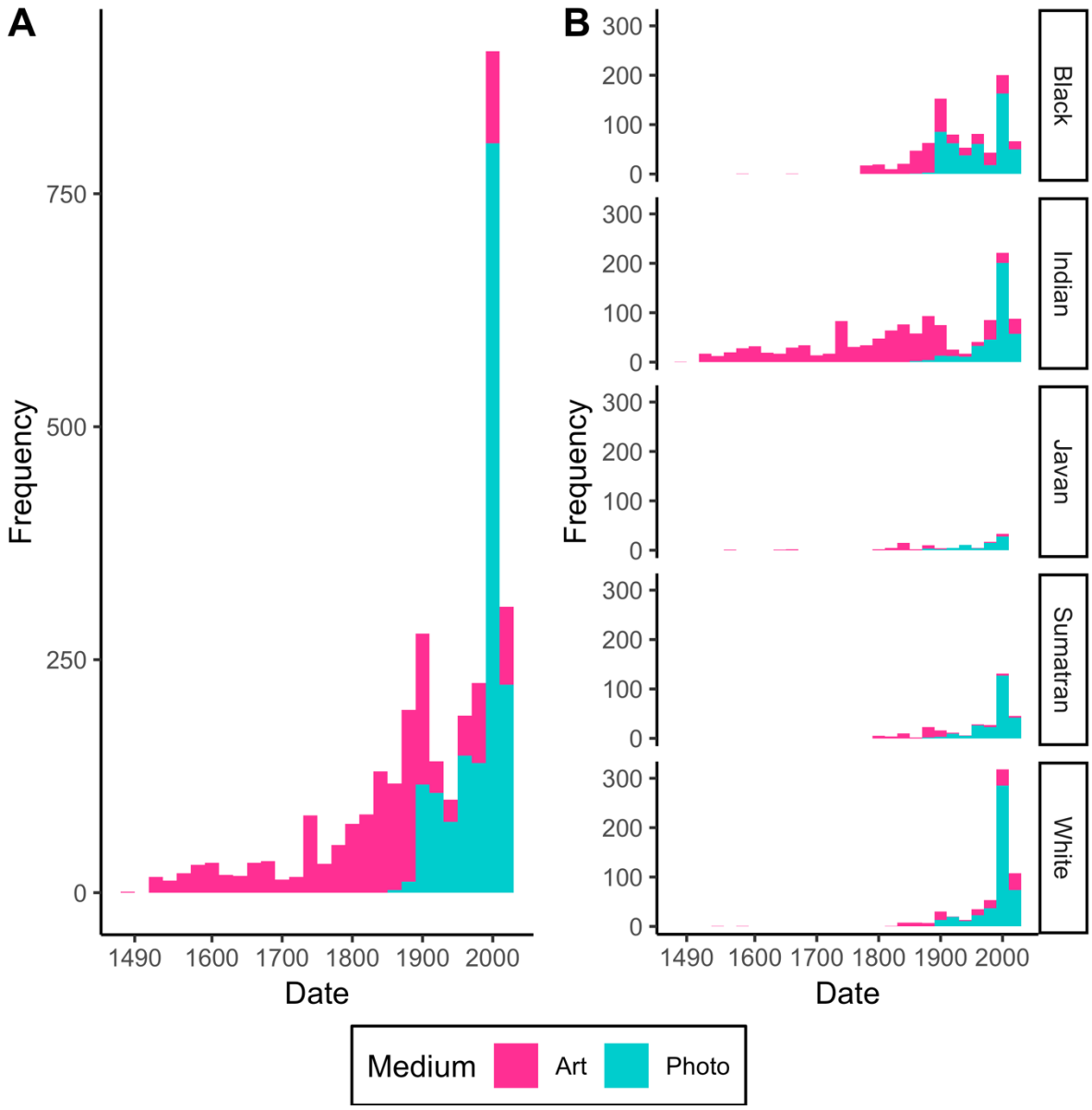

Figure 6. **Change in media used to produce images on the RRC** A) The frequency of artwork and photographs for all species B) The frequency of artwork and photographs for each species individually

3.3. Locations

59 countries were recorded with at least one photograph of a rhino. Some countries produced many more photos than others, with the USA, Indonesia, Kenya, India and Germany being the countries with the highest number of photographs (Figure 7).

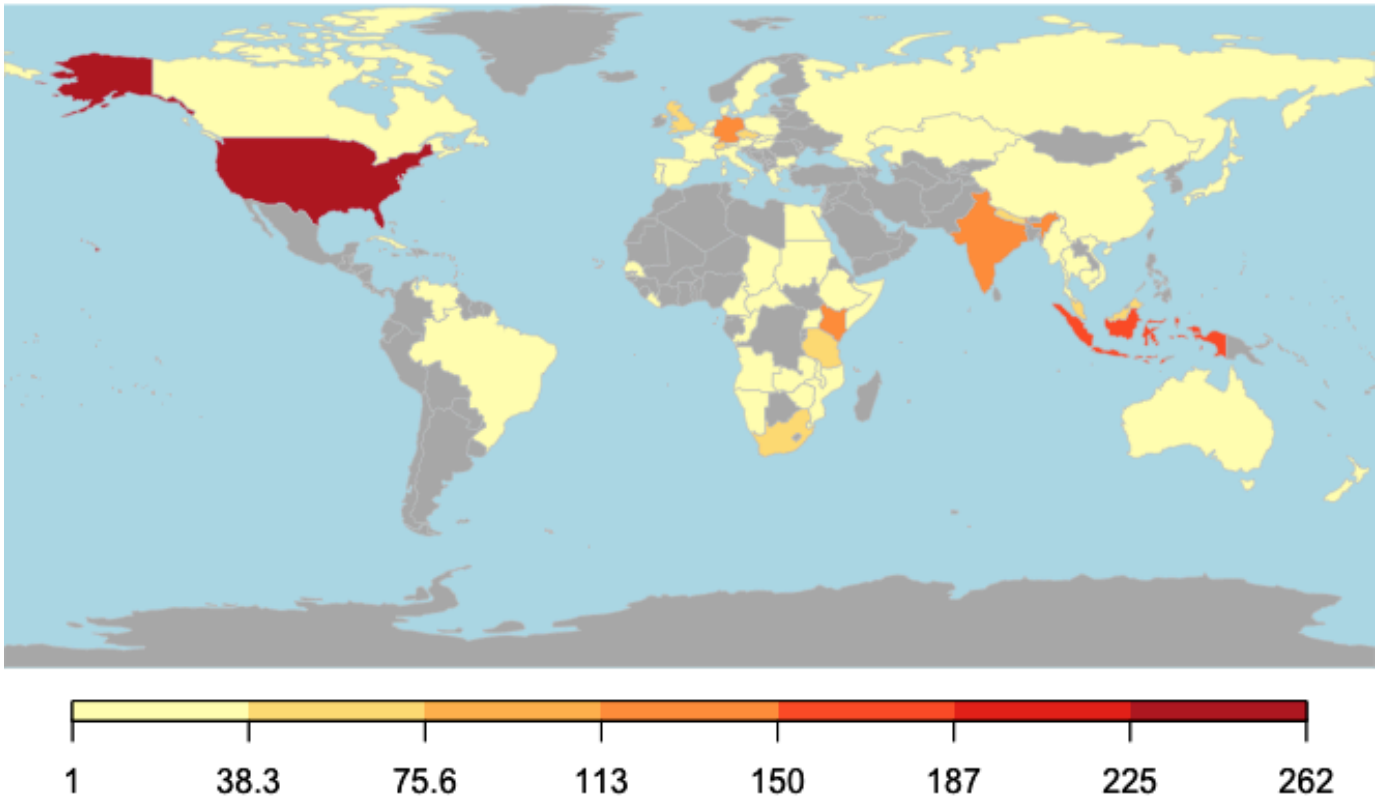

Figure 7. ***World map displaying the global distribution of photographs of all species of rhino****. Alaska is included as part of the USA, which has 262 rhinoceros photos. There are no photographs from Alaska itself within the RRC repository*

3.4. Species Representation Over Time

Artwork on the RRC shows a statistically significant change in the proportional representation of different rhinoceros species (Chi-Squared Test, n = 1,531, χ^2 = 481.61, $p < 0.0001$) (Figure 8A). Early artwork had disproportionate representation of Indian rhinos, but the number of other species has been increasing. In particular, there has been a marked increase in the depiction of white rhinos in artwork since the mid 19th Century. Photographs similarly show a significant change in the representation of different species over time (Chi-Squared Test, n=1,623, χ^2=336.31, $p < 0.0001$) (Figure 8B). There has been a recent increase in the number of white rhinos pictured in photographs, and similar increases in Sumatran and Javan rhinoceroses.

The number of images of a species of any medium is not correlated with the number of individuals of that species surviving in in situ populations (Figure 9) (Chi-Squared Test, n = 52,814, χ^2=10,708.72, $p < 0.0001$). White rhinos make 82% of the in-situ rhino population, but only 19% of the images on the RRC for example. All other species are significantly overrepresented given their actual in-situ population size.

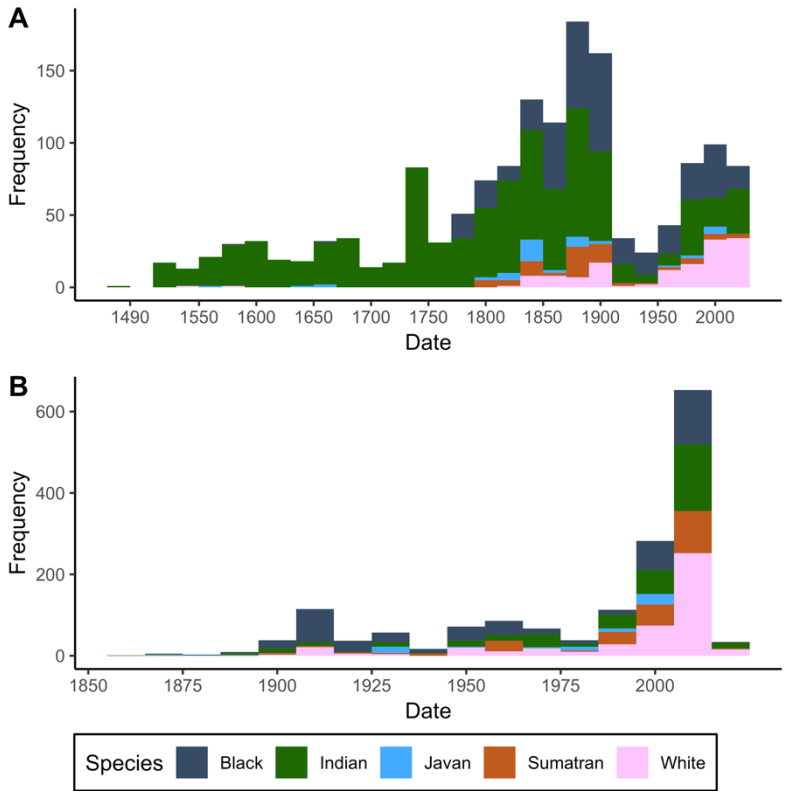

Figure 8. **Changes in the representation of different rhino species in images on the RRC over time.** A) Species representation within artwork on the RRC B) Species representation within photographs on the RRC

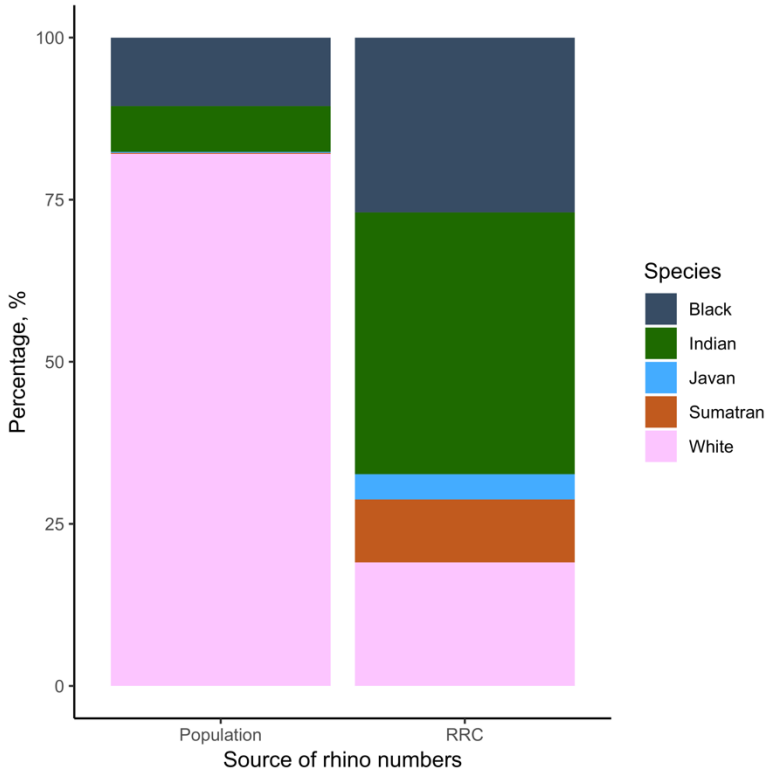

Figure 9. **Number of images on the RRC for each medium and in total compared to the estimated in situ population size of each species.** Percentage is the number of actual or portrayed rhinos of a given species as a percentage of the total number of actual or portrayed rhinos

3.5. Depiction over time

There has been a change in the proportional representation of conservation and hunting scenarios in rhino artwork over time (Fisher's Exact Test, n = 186, $p < 0.0001$) (Figure 10A). In particular there is a marked drop in depictions of hunting in the early to mid 20th Century, at which point there is a rise in conservation depictions. Similarly, photographs have seen a statistically significant change in the relative depiction of hunting and conservation scenarios (Fisher's Exact Test, n = 385, $p < 0.0001$) (Figure 10C). There has been a decrease in the proportion of hunting photographs and an increase in the proportion of conservation photographs through time, especially since the start of the 21st Century. Different species show different trends, with most hunting images of black rhinos, and proportionally most conservation images of Sumatran rhinos (Figure 10B, 10D).

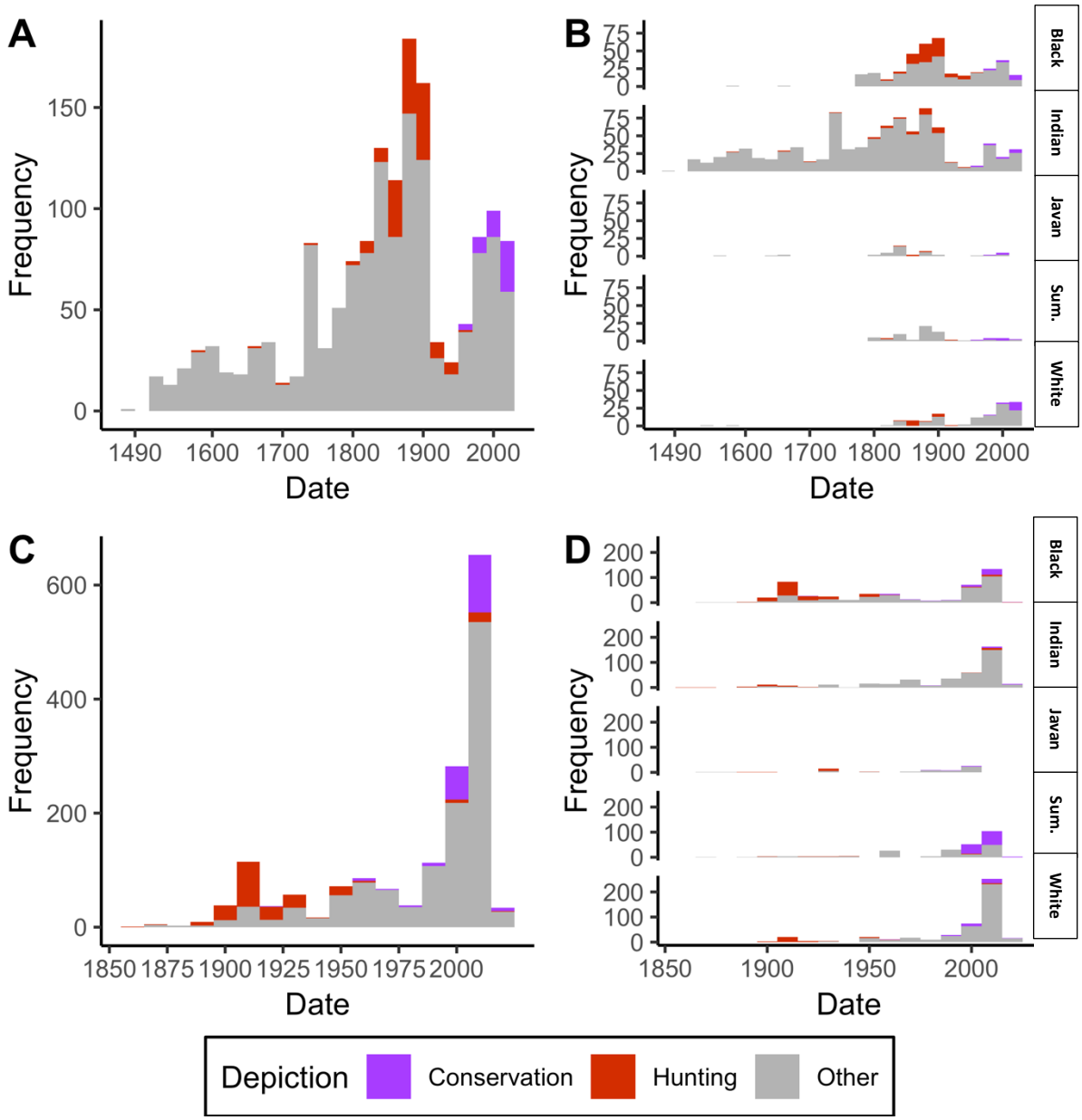

Figure 10. **Changes in the depiction of conservation and hunting of rhinos over time from images on the RRC.** A) Relative depictions of conservation and hunting in artwork for all species B) Relative depictions of conservation and hunting in artwork for each species individually C) Relative depictions of conservation and hunting in photographs for all species D) Relative depictions of conservation and hunting in photographs for each species individually

3.6. Emotion over time

The emotion with which rhinos are depicted has shown a statistically significant change from proportionally more negative to more positive, with this shift occurring in the middle of the 20th Century (Chi-Squared Test, n = 1,531, χ^2 = 336.31, p < 0.0001) (Figure 11A). Rhino species differ in way they are portrayed in art, with black rhinos being most negatively portrayed, particularly between 1800-1950. Sumatran rhinos have been portrayed proportionately more recently (Figure 11B).

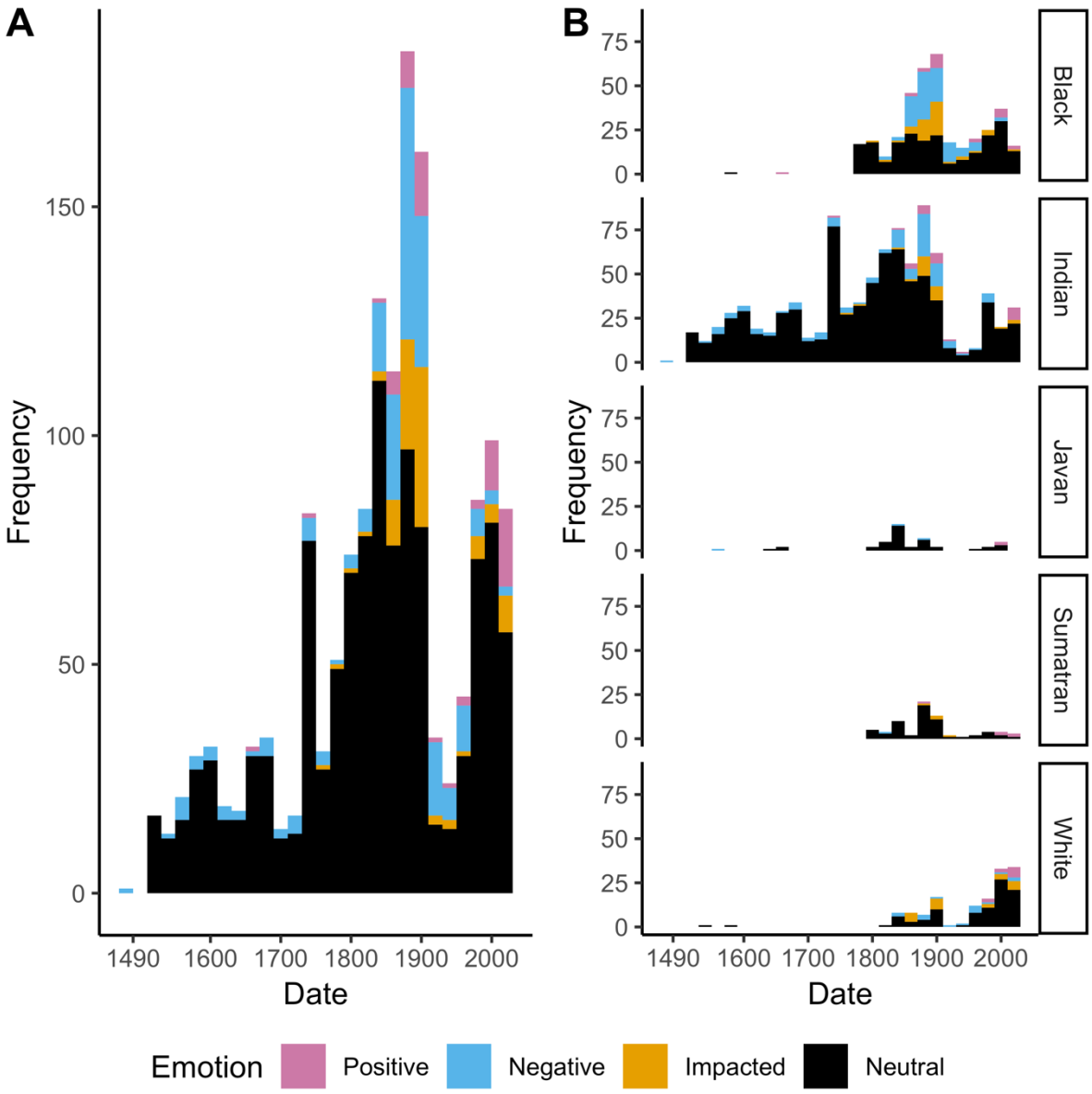

Figure 11. **Changes in the emotion projected onto rhinos in artwork on the RRC over time.** A) Changes in emotion over time in all rhino species B) Changes in emotion over time in each rhino species individually

3.4.1. Principal Component Analysis

The first three PCs account for 98.81% of variation in the rhino morphology measured. It is possible to reconstruct some differences between species using PCA analysis (Figure 12). Differences between the species appear most related to horn length. Sumatran rhinos are most distinct, whilst there is most overlap between the African species. Javan rhinos and Indian rhinos also demonstrate significant overlap. PC1 takes into account all body measurements except horn length and represents 95.07% of variation, suggesting PC1 represents a reasonable approximation of body proportions. An increase in PC1 relates to a decrease in body size.

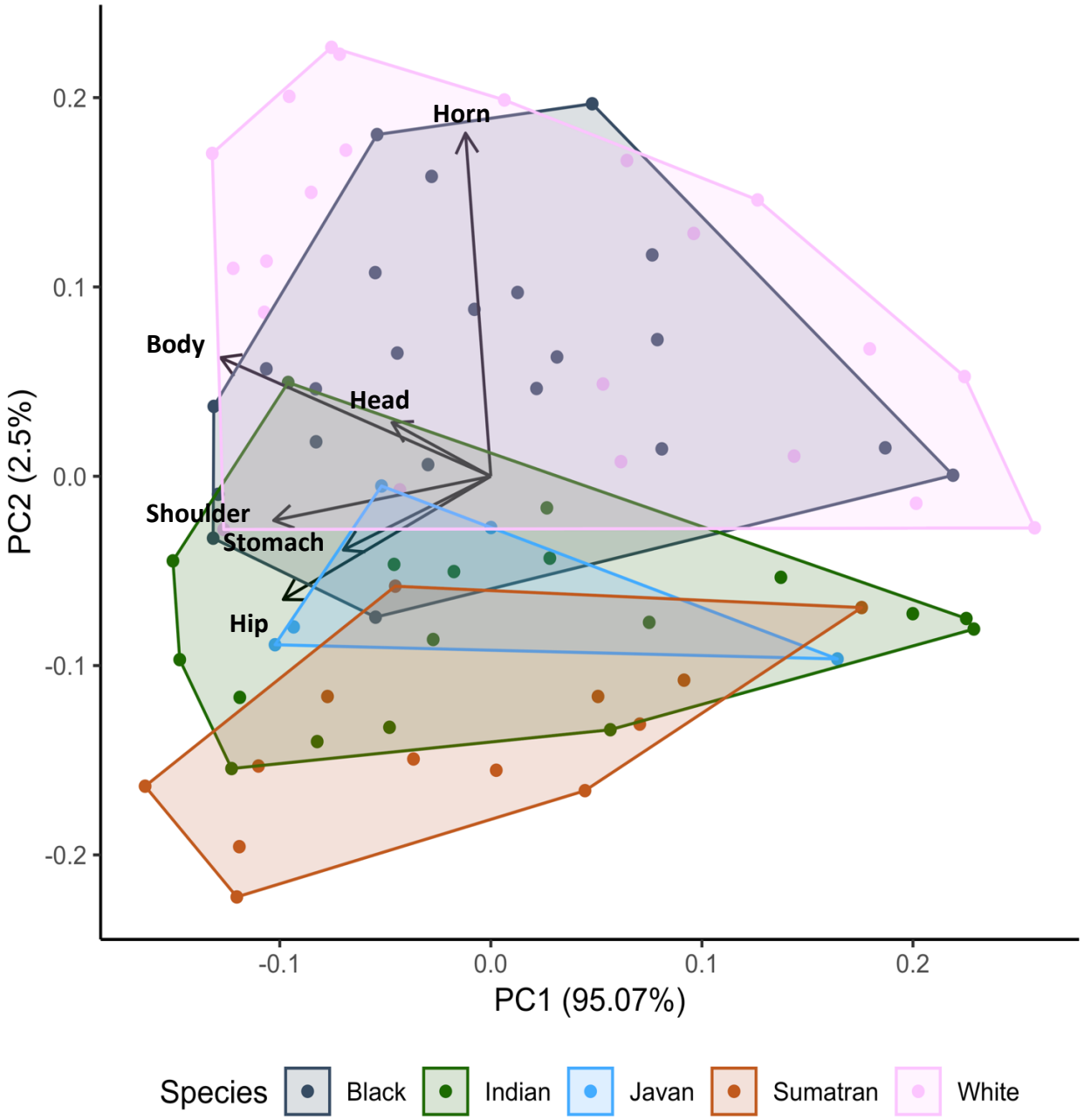

Figure 12. **Principle Component (PC) Analysis of Rhino Morphology based on photos from the RRC.** Whilst there is overlap between the different species, morphological differences may be reconstructed from this PCA. The species which may be considered to look most superficially similar, (white and black rhinos or Indian and Javan rhinos) are reconstructed to show the greatest overlap, whilst Sumatran rhinos demonstrate the least overlap. These measurements fail to include other important aspects of rhinoceros morphology, including horn number, posterior horn length and presence or absence of a prehensile lip

3.4.2. Horn length over time

For each species, when a second PCA was performed excluding horn length, PC1 explained the majority of the variation and was therefore a valid approximation of body proportions (Table 4). I found that Indian rhinos showed a statistically significant decrease in horn length (relative to PC1) over time. All rhino species showed a negative relationship, albeit only significant for Indian rhinos (Table 5, Figure 13).

Table 4. **Percentage of variation explained by PC1-3 for each rhino species for Principle Component Analysis (PCA) performed using body proportions other than horn length**. All species show that PC1 explains the majority of the variation in morphology and therefore represents a reasonable approximation for body proportions

Species	**Percentage of variation explained by component, %**		
	PC1	PC2	PC3
Black	97.23	1.55	0.77
Indian	97.87	1.29	0.51
Javan	95.45	3.09	1.41
Sumatran	98.35	0.77	0.50
White	94.26	2.86	1.58

Table 5. **Results of Analysis of Covariance (ANCOVA) for each rhino species with date as the explanatory variable and PC1 as the other covariable**. Only Indian rhinos show a statistically significant decline in horn length over time

Species	**n**	**Intercept**	**Variable**	**Slope**	**Sum Sq.**	**F**	**p**
Black	22	219.39410395	PC1	-0.05440782	610.8	4.42	< 0.05
			Date	-0.09011165	252.7	1.83	0.19
Indian	18	276.21353698	PC1	0.05466582	1104.8	26.02	< 0.001
			Date	-0.12932880	560.9	13.21	< 0.01
Javan	5	5366.79505232	PC1	-0.03595401	199.5	4.14	0.18
			Date	-2.67559808	524.0	10.88	0.08
Sumatran	13	134.68529856	PC1	-0.02766105	141.8	2.65	0.14
			Date	-0.06236361	32.5	0.61	0.45
White	22	225.14913288	PC1	-0.10161218	4152	23.01	< 0.001
			Date	-0.08891592	26	0.15	0.71

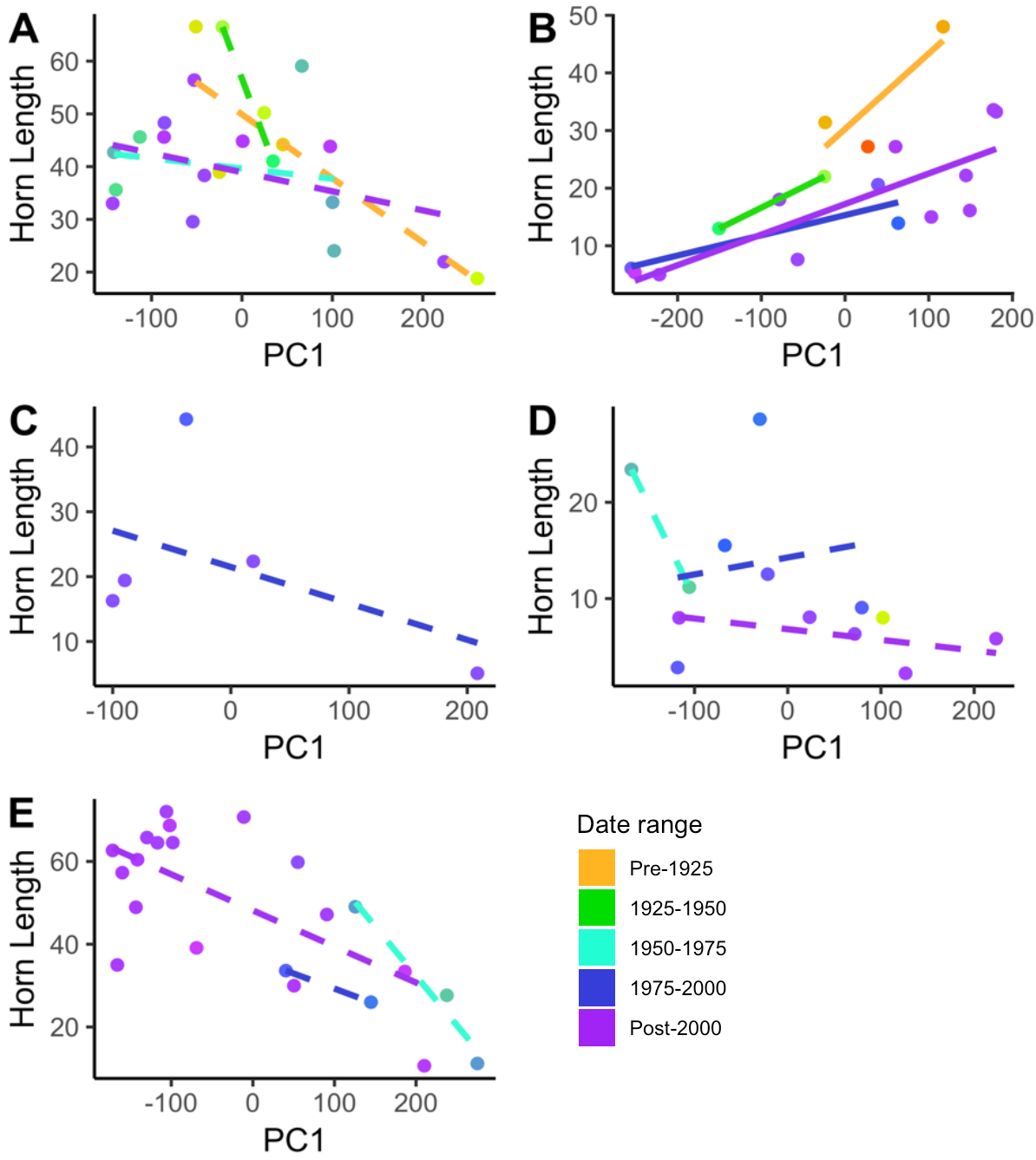

Figure 13. **Scatter plots for each rhino species showing relationship between horn length and PC1 and between horn length and date.** Units of horn length are arbitrary. A. Black rhino B. Indian rhino. C. Javan rhino D. Sumatran rhino E. White rhino. Dashed lines denote a statistically insignificant relationship between horn length and date. In both black rhinos and Indian rhinos, an increase in PC1 is associated with an increase in body size, whereas in Javan, Sumatran and white rhinos, an increase in PC1 is associated with a decrease in body size

4. Discussion

4.1. The human-rhino relationship

4.1.1. Artwork vs Photography

There has been a shift towards a greater representation of photography in the images on the RRC in more recent years (Figure 6). This can be explained by a number of factors. Firstly, improvements in technology mean that handheld cameras, particularly incorporated into mobile phones, are increasingly widespread, facilitating image production. Secondly, older artwork is more likely to be lost or damaged so is less likely to have survived to be uploaded to repositories. Thirdly, as availability of transport has improved, humans have become more able to travel to rhinos, as well as bring animals into captivity, thereby increasing the number of images that would be expected. This is also reflected in the fact that the most rhino photos of any country came from the USA, which has no native species (Figure 7). Together these factors suggest that the number of pictures should increase over time. The stark transition between artwork and photographs at the start of the 20th Century illustrates the importance of the emergence of photography in recording wildlife. This change was supported by increasingly portable equipment.

4.1.2. Species composition

Analysis of the images available on the RRC demonstrates that there are changes in the species composition of rhinos through time. Early depictions feature a high number of Indian rhinos as a result of the availability of Dürer's rhinoceros, a woodcut produced after the death of a rhino transported to Europe in 1515 (Quammen, 2000). The invention of the Gutenberg printing press allowed transmission across Europe, so that it became the accepted representation of an idealised rhinoceros. When Clara, another Indian rhinoceros, toured Europe during the 18th Century, this produced another surge of rhino artwork (Figure 8).

It was only determined by 1780 that there were two rhino species in Africa (Rookmaaker, 2005), so the dominance of Indian rhinos in historical portrayals fits with the accepted European understanding of taxonomy at the time. The number of representations of African rhinos initially increased during the early 19th Century as Europeans further explored Africa. According to written accounts at the time, both African species were extremely abundant, and one English captain saw over 60 black rhinos in a single day (Harris, 1838). Black rhinos are depicted more often during this period, perhaps because they are able to survive in a greater variety of habitats and had a more continuous distribution across Africa. The first black rhino is thought to have been held in captivity in Antwerp in 1858 (Rookmaaker, 1998a), whilst the first captive white rhino was in 1946 (Rookmaaker, 1998b). There is an increase in white rhino representation beyond this point, suggesting that captivity became a major source of inspiration for rhino imagery. Sumatran and Javan rhinos have been kept in captivity far less often, with only 96 and 22 known specimens respectively by 1994 (Rookmaaker, 1998c, 1998d). These animals do not breed well in captivity and often experience very short lifespans, so are housed in collections far less often than the other, larger species. These two species are consequently underrepresented on the RRC.

4.1.3. Depictions and Emotions

Between 1800-1950, hunting of rhinoceros species for sport was common, as reflected by spikes of hunting depictions (Figure 10) and negative emotions (Figure 11) during this period. Whilst both emotion and depiction categories had some level of subjectivity, I believe that the sample size means that discrepancies in the placement of any individual image should have negligible effects on the overall results. Some species were hunted more than others, with the black rhino depicted being hunted most often. We know from fossil sites that hunting of this species has occurred since the Palaeolithic (Gautier et al., 2012), but hunting during the 19th and 20th Century was at a level that drove precipitous declines in rhinoceros numbers (Rookmaaker, 2005). This hunting was associated with a rise in the 'Empire mentality', whereby killing of big game was symbolic of the perceived dominance of Europe (often Britain) over other countries (MacKenzie, 1988). A dramatic collapse in the total number of pictures of rhinos during the early to mid 20th Century may be associated with the outbreak of successive world wars, but the decline in the depiction of hunting occurred only in the 1950s, during the collapse of the British Empire. By 1960, the vast majority of African countries were independent of Europe (Pearce, 2009), which severely limited the ability to trophy hunt on the continent. The peaks of hunting elucidated through images on the RRC appear to be linked to the presence of European empires.

The decline in big game hunting has been associated with an increase in the depiction of conservation of rhinos towards the latter part of the 20th Century and with an increase in the positive portrayal of rhinos. The hunters were aware of the decline of rhinos and aimed to reduce the slaughter of all big game to sustainable levels through the implementation of strict hunting regulations and the formation of the Society for the Preservation of the Empire, which those involved saw as being pivotal in preventing extinction of African megafauna through hunting (Hobley, 1935). One hunter even wrote on the issue, "our grandchildren have to be thought of"(Champion de Crespigny, 1905), suggesting a change in attitudes, even before a change in the way that wildlife seems to have been depicted. These conservation efforts were rooted in imperialist values, driven by fears that indigenous populations would somehow be more likely to cause extinction of the animals than Europeans. There remains intense debate surrounding the possible utility of trophy hunting in conservation. It can be argued that big game hunting is likely to provide local communities with the income required to provide more effective conservation of their animal life (Adcock and Emslie, 1994; Di Minin et al., 2016), though this is heavily disputed (Telecky, 2014). The rise in the abundance of more positive conservation imagery is as a result of increasingly active conservation efforts in the field, through translocation and management, as well as public awareness campaigns. There are several celebrity-led campaigns today documenting the dangers of poaching. These campaigns can be effective. One WildAid campaign in Vietnam reduced the number of people who believe that rhino horns have medicinal value by 67% in only three years (WildAid, 2017). There is certainly hope for the conservation prospects of the African rhinos.

4.2. Morphological change

Rhinos were analysed on a species-by-species basis according to the results of my PCA. I was able to reconstruct morphological differences between species using this PCA, and morphology mirrored phylogenetic relationships, with Sumatran rhinos reconstructed as morphologically distinct, whilst black and white rhinos and Indian

and Javan rhinos showed similar morphology. These pairs are considered subclades in the rhinoceros phylogeny (Willerslev et al., 2009).

My results demonstrated that Indian rhinos show a statistically significant decrease in horn length over time relative to their other body proportions. Other species all show a negative trend, but it was not significant. Measurements obtained through a photograph repository can be used to demonstrate a decrease in the relative horn length and therefore represent a possible tool in identifying directional selection. These results should be combined with genetic studies and analyses based on other methods to demonstrate a causal mechanism, as these methods have been shown to be effective in other species (Garel et al., 2007; Festa-Bianchet et al., 2014; Chiyo et al., 2015). However, my results show that in one rhino species, there is an apparent evolutionary response to hunting pressure in a short number of generations. Directional selection must be taken into account when considering wildlife utilisation, as the decline in a desired trait is likely to decrease the value of the given commodity (Coltman et al., 2003). Farming of rhinos, where horns may be removed without killing the individual, would be likely to remove selective pressures. Widespread rhino farms are increasingly likely (Uys, 2017). Image repositories such as the RRC can be utilised by researchers to understand evolutionary change and allow better informed conservation decisions.

To assess historical morphological change, I used only individuals which were directly side on to the camera, allowing more complete data collection. However, this significantly reduced the sample size and increased the relative abundance of the photos that were taken in captivity. Until the end of 1994, 68% of black rhinos, 57% of white rhinos and 65% of Indian rhinos in captivity had been imported from the wild (Rookmaaker, 1998a, 1998b, 1998e), and so would have been subject to the selective pressures of hunting, but there does not appear to be any evolutionary advantage to having smaller horns when in captivity. The high number of wild-caught captive Indian rhinos add validity to my results, though further study should be performed with wild rhinos only. The photos which were used for these measurements were subject to biases in their production. Given the restrictions placed on hunters, they would have targeted the largest animals with the largest horns to maximise their trophy value, and therefore taken photos of such large-horned individuals. In captivity, visitors have no such preference about horn sizes. My results are therefore probably subject to regression to the mean, where large horns in the early 20th Century images are unlikely to be followed by larger horns on average, producing a perceived decrease in horn size. Combining photographic evidence with museum specimens or genetic studies are likely to reduce the effect of such biases within the data.

4.3. Conclusions

My results demonstrate that the relationship between humans and rhinos over time is ever-changing. We have portrayed different species more regularly at various times in history, from the dominance of the Indian rhino during the Early Modern Period, to the rise of African rhinos in hunting scenes throughout the age of European imperialism. The number of depictions of a species appears unrelated to its conservation status, and it is clear that in order to save the two critically endangered Asian rhinoceros species, further publicity is required. We are fortunately now in a period where depictions of rhinos are dominated by themes of conservation and nature, associated with increasingly positive portrayals. The threat to all rhino species through human overhunting is grave. However, I see reason to

be hopeful of an improvement to their current situation: my results show an increased level of focus towards conservation in recent years, and all species, other than perhaps the Sumatran rhino, show an increasing population trend as a result of conservation efforts (Emslie, 2006; Lees, 2013; Yadava, 2014; Haryono et al., 2015). The use of images allowed a clear identification of periods of change in the rhino-human relationship.

Indian rhinos demonstrate evidence for a reduction in horn length in relatively short timescales on the basis of measurements taken from historical and contemporary photographs. This is the first evidence of such evolution in rhinos and the implication is that this could be an adaptive response to human hunting. Further reason is required to elucidate a causal mechanism, though my results are an illustration that non-invasive methods like photography may be used to assess evolutionary trends in large mammals like rhinos.

Because of the historical significance of the rhino in Europe, and its abundance in classical artwork, it represented an ideal taxon with which to test the usefulness of image repositories for such research. My research has suggested that there is utility to these methods, when it comes to assessing change, through providing baselines for both morphology and perception. The Rhino Resource Centre currently represents a unique repository for such studies. If similar collections were to be collated for other large mammals such as elephants, saiga or hippopotamuses, I believe that similar research could be carried out on these taxa. Online repositories offer an extremely valuable opportunity as a tool for conservation and evolutionary biology research.

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Appendix 1. Categorising poaching

I investigated whether poaching would be better placed within hunting or conservation as a broad depiction categorisation for the photographs on the RRC. Poaching is not synonymous with hunting, as trophy hunting is generally legal. Many of the photos which did depict poaching were used to publicise the importance of conservation. I found that there was no change in the relative significance of the change through time using either categorisation, so I decided that it would be more appropriate to place poaching within the 'Hunting' broad categorisation, on the basis of the end result to the rhino population. Performing a Fisher's Exact Test with both arrangements led to a result of $p < 2.2e^{-16}$, so the trend was highly significant, regardless of the categorisation.

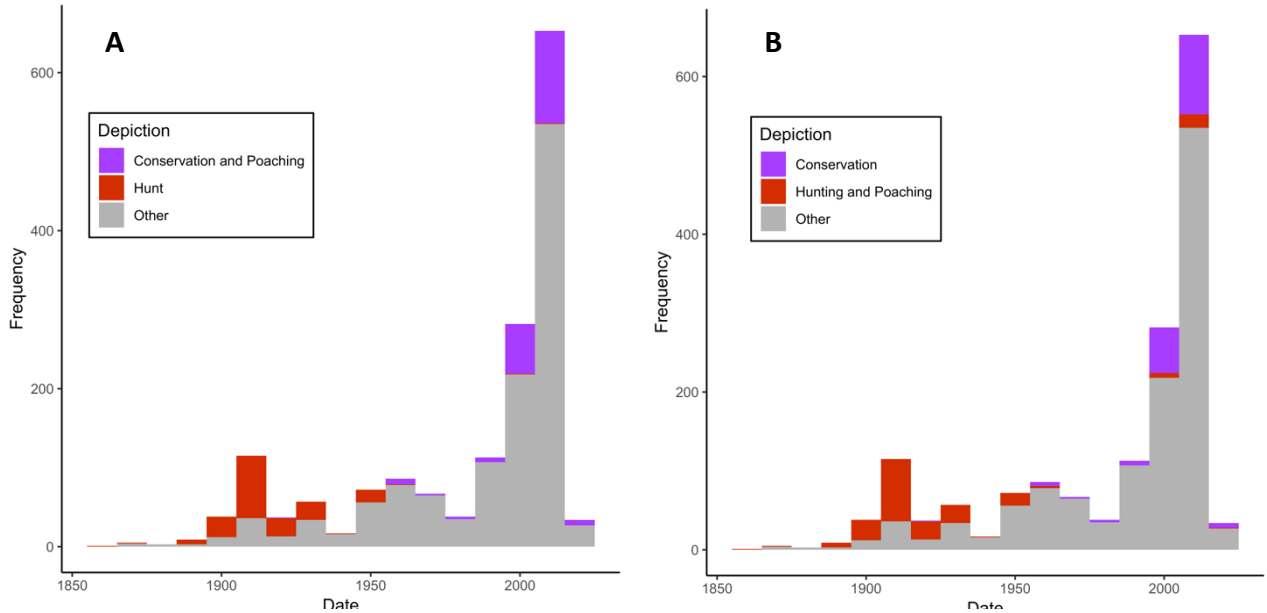

Figure 14. **Assessing the significance of the categorisation of poaching within either the 'Hunting' or 'Conservation' broad categorisations.** A) Poaching included within conservation, B) Poaching included within hunting

Appendix 2. Group size over time

Using a combined dataset of all images on the RRC, I assessed whether any change in group size was seen in any rhino species in the wild, perhaps as a result of behavioural evolution to avoid human hunting. I performed an ANOVA test on each species and found that only Indian rhinos showed a statistically significant change over time, with their group size increasing (Figure 18) (Table 6).

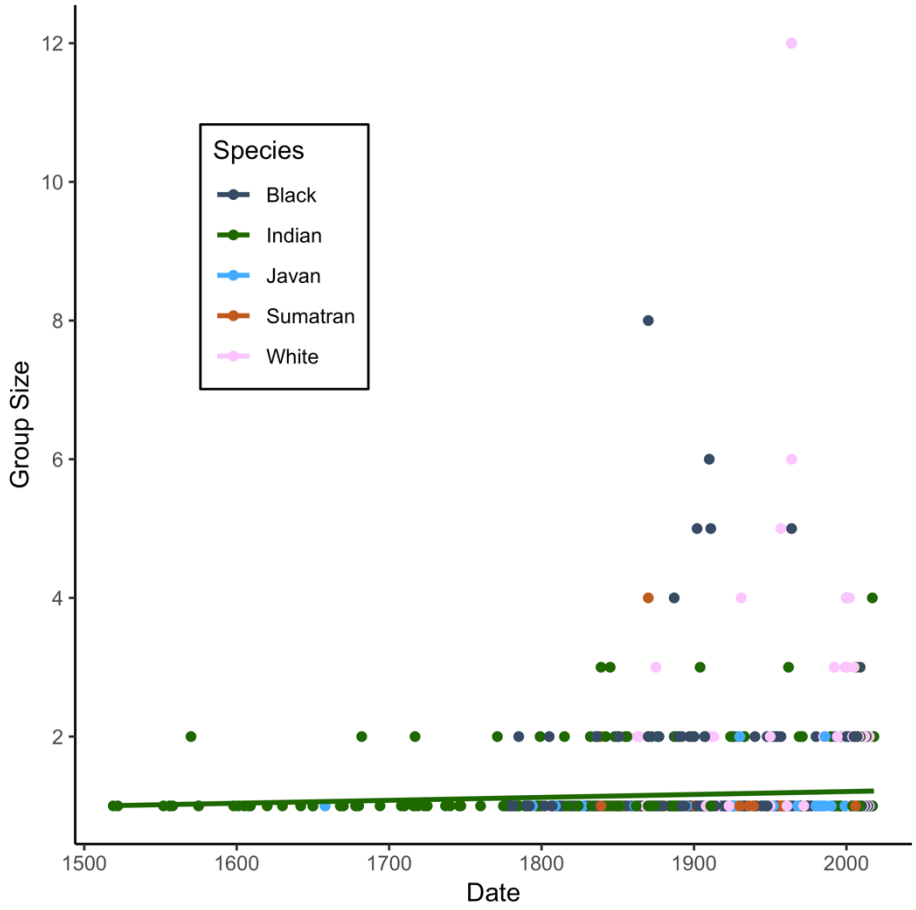

Figure 19. **Group size over time for each species, based on a combined dataset of both photographs and artwork on the RRC.** Indian rhinos show a statistically significant increase in group size, denoted by the solid line

Table 6. **Results for Analysis of Variance (ANOVA) of group size changes over time in each rhino species**

Species	Intercept	Slope	n	F	p
Black	-0.773057	0.001028	497	2.9	0.089
Indian	0.3632763	0.0004219	389	5.1	< 0.05
Javan	1.9071909	-0.0004252	94	1.5	0.23
Sumatran	4.234071	-0.001629	40	1.6	0.22
White	-2.319093	0.001926	188	1.5	0.22