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A framework to evaluate animal welfare implications of policies on rhino horn trade

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ABSTRACT

There is currently fierce debate among rhino conservation stakeholders, scientists, and policy-makers over the legalisation of trade in rhino horn. Despite the prominent voice of animal welfare organisations in this debate and conservation more broadly, the welfare implications of a legal trade versus a trade ban have not been addressed. To explore this gap, we developed a framework to assess the welfare implications for white rhino (*Ceratotherium simum*) under different rhino horn trade policies. We surveyed rhino stakeholders in order to rank eleven welfare issues under a hypothetical legal trade versus a trade ban, and then calculated the resulting rhino welfare compromise under each policy. Results from expert input suggest that welfare compromise of legally-dehorned rhinos is substantially lower than welfare compromise of a poached animal. This is largely due to the differences in a rhino's physiological and psychological distress in response to being shot versus being immobilised with anaesthetics. Through a sensitivity analysis, we show how rhino welfare compromise changes with respect to the degree poaching levels could respond to legal trade (or a continued ban), from the scenario of low poaching pressure to the alternative scenario of increased poaching pressure. This analysis suggests that the policy that leads to the least poaching is likely best for improving rhino welfare because welfare compromise to poached individuals is much higher than the compromise from legally-dehorning a rhino. Our paper provides a framework to estimate and assess the welfare impacts of a hypothetical trade in rhino horn to inform policy debates.

1. Introduction

The poaching crisis facing Africa's white rhino (*Ceratotherium simum*) populations is one of the continent's foremost conservation concerns. Over 1000 rhinos have been poached annually since 2013 (Save the Rhino international, 2018; Department of Environmental Affairs, 2017). Poaching levels are driven by the high value of rhino horn on the black market, increasing from ~US$4700 in 1993 to a peak of US$65,000 (consumer purchase price) for every kilo sold in 2012 (Biggs et al., 2013a; Somerville, 2017; Truong et al., 2015).

Despite the international ban in the trade of rhino horn that has been in place for 40 years, poaching continues due to high levels of demand for horn (Ayling, 2013; Biggs et al., 2013a). Annual poaching levels in South Africa – which is home to over 80% of the continent's white rhinos (Kennaugh, 2015) – are currently approaching the 6–8% annual rhino population growth rate (Ayling, 2013; Ferreira et al., 2015). Consequently, some conservationists are warning of the possibility that rhinos may be extinct in the wild within decades (Ayling, 2013; Biggs et al., 2013a; Ferreira et al., 2015; Haas and Ferreira, 2016). These predictions, along with the exorbitant costs of protecting rhinos from poachers (Di Minin et al., 2015), have led to calls for an international legal trade in rhino horn (Biggs et al., 2013a; Di Minin et al., 2015), involving non-lethal and sustainable harvesting of horn from live white rhinos.

Trade legalisation proponents argue that legalising the rhino horn trade would shift market control into legal channels, and horn supply would be steady and relatively large (possibly varying between 5319 and 13,356 kg per year) (Taylor et al., 2017), therefore likely

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reducing or eliminating the black market and stabilising rhino horn prices (Biggs et al., 2013a; Child, 2012). Furthermore, a trade in rhino horn could be an income-generating conservation endeavour that would avoid over-reliance on international donor support (Biggs et al., 2013a; Di Minin et al., 2015). Conversely, critics of a legal trade argue that trade will legitimise rhino horn as a product and hence, worsen poaching levels (Collins et al., 2016; Dang Vu and Nielsen, 2018; Kotze, 2014). Critics also argue that a legal trade could serve as a route for the laundering of poached horn if monitoring and enforcement are inadequate (Save the Rhino International, 2013).

Previous studies have modelled the potential socioeconomic (Di Minin et al., 2015) and conservation (Child, 2012; Crookes and Blignaut, 2016; Koen et al., 2016) outcomes of a trade ban and a legal trade. However, animal welfare has not been considered in the rhino conservation debate, despite animal welfare non-governmental organisations (NGOs) being vociferous, powerful, and influential in determining policy debates and outcomes (Daut et al., 2015; Duffy and Moore, 2011; Rothwell, 2013). Our paper addresses this important and pertinent knowledge gap.

Our study assesses the animal welfare implications of an international legal trade, and compares it with a continuation of the trade ban. Under a trade ban, horn from poached rhinos is the only source of supply; whereas under a legal trade, horn harvested from live rhinos can also be sold. We assess three sub-scenarios under both a continued trade ban and the legal trade scenarios: a) decreased (low) poaching pressure; b) poaching numbers showing no change (baseline); and, c) increased (high) poaching pressure. Currently, the world population of white rhinos sits at ~20,000 individuals (Save the Rhino International, 2017). Our study focussed on South Africa's wild white rhino population which constitutes approximately 75% of the world population (estimated at 15,000 individuals) (Kennaugh, 2015; Martin, 2011; Save the Rhino International, 2017). We define free-living wild white rhinos as the population that resides in a natural, non-domesticated state (The American Heritage Medical Dictionary, 2007). Our analysis therefore does not include individuals kept for intensive ranching or breeding purposes where supplementary food is provided on a regular basis as part of standard management practice.

2. Methods

This study consisted of two components: a) the development of a welfare assessment framework, and, b) obtaining stakeholder input on the level of welfare compromise under an international legal trade and a trade ban of rhino horn. Our study aimed to compile expert opinion using a stakeholder survey to identify the rank and relative importance of eleven welfare issues pertinent to a trade ban and/or a legal trade of rhino horn. To do this, we created a welfare assessment framework to assess the degree of welfare compromise imposed on South Africa's wild white rhino population when subjected to these two conservation schemes. Furthermore, we then investigated the magnitude of welfare compromise under each scenario in order to reveal which scenario has the highest (most concerning) welfare implications, and, due to the unique calculation of magnitude in this study, aimed to advance current knowledge regarding which scenario should be considered most favourable for welfare alongside the associated potential conservation outcomes.

2.1. Welfare assessment framework

Using existing welfare assessment frameworks, we synthesized an assessment framework to evaluate and compare the welfare outcomes of various conservation policies imposed on South Africa's wild white rhino population when under a trade ban and a legal trade of rhino horn. This framework, largely combining concepts seen in Kirkwood et al. (1994) and Sharp and Saunders (2011), comprises five key steps: 1. a list of all likely welfare implications[1] (with an associated relative ranking of each issue to highlight which parameters are – according to stakeholder opinion – of higher concern for welfare status than others); 2. discussion of the implications occurring under each scenario (and the effect each has on welfare); 3. a grade of impact given for the five domains of suffering (these domains namely being an animal's nutritional, behavioural, environmental, health, and mental needs) when under each scenario; 4. an overall impact grade; and, 5. the calculated magnitude of welfare harm under each scenario.

The welfare assessment framework of Kirkwood et al. (1994) mentioned above attempts to scale the degree of harm imposed on free-living wild animals from anthropogenic activity. This scaling is proposed to be completed by looking at the nature and duration of caused harm, the number of individuals affected, and their suffering capacity (Kirkwood et al., 1994). The assessment model of Sharp and Saunders (2011), however, is a two-stage general model created to assess the welfare implications of pest-control methods, and then consequently, rank each assessed method. The two stages involved in Sharp and Saunders' (2011) model involve looking at the impact and duration of a control method on an individual's overall welfare, and then examining the intensity and duration of suffering caused by a killing method.

For our newly synthesized assessment framework, first, using pertinent literature, we identified all key welfare issues and their respective levels (these represented the range of conditions, physiological responses, and/or procedure techniques apparent under each scheme) that are mentioned as being of concern under a trade ban or a legal trade conservation scheme (or both). These were used for a questionnaire asking stakeholders to indicate which welfare measures would result in higher compromise to an individual's quality of life. This resulted in all welfare issues and levels having a rank of relative importance as indicated by the resulting utility value of each level (see Section 2.4).

We assessed welfare impact under each scenario in two parts [using the humaneness assessment model seen in Sharp and Saunders, 2011 and adapting them where needed to better fit wild animal welfare assessment]. For our wild rhino welfare assessment, just as in Sharp and Saunders (2011), Part A assessed the overall welfare impact from a conservation method, and Part B involved deducing welfare impact that arises from the mode of death (when pertinent). Both Part A and B used a five-step process. For Part A, the overall welfare impact of poaching and/or legal-dehorning methods for both survivors and rhinos that are killed was surmised. This process involved: 1. listing all likely welfare levels to occur from poaching and/or legal-dehorning methods on individual rhino for both survivors and rhinos that are killed; 2. recording the grade/impact category that the stakeholders assigned for each level; 3. assigning the highest occurring grade in each domain as the impact grade for the respective domain (see following paragraph for further information); 4. then, assigning domain 5's grade (mental needs) as the overall welfare impact grade[2]; and, 5. assigning an overall numerical welfare impact score (1, most humane – 8, least humane) using the overall impact grade and the duration of welfare compromise.[3]

When allocating the individual impact grades for each domain (under Part A) for poached individuals, the category assigned by the

[1] The framework of Sharp and Saunders (2011) includes the creation of separate lists of welfare implications for Parts A and B; our suggested framework, however, utilises a list of all potential welfare implications from parts A and B and from both conservation scenarios. This change, in combination with our addition of adaptive conjoint analysis, should allow a more robust understanding of the relative ranking of all welfare parameters being assessed during this welfare assessment.

[2] Domain 5s grade is assigned to be the overall welfare impact grade because domain 5 represents and summarises "the outcome of the impacts in the other four domains" and also integrates the effect on any external influences on welfare (Sharp and Saunders 2011).

[3] Box 6 on pg. 49 in Sharp and Saunders (2011) was used as a grading device in this step.

stakeholders was the one used for individual welfare levels. However, any levels under the "physiological effects of immobilisation" attribute that appear to affect legally-dehorned individuals were scaled down. This was done by carefully considering the length of time each welfare level would occur, and then using boxes 1–5 in Sharp and Saunders (2011) as guides to grade each domain. This decision was made because physiological welfare perturbations that occur during the legal-dehorning process are monitored and treated by veterinary teams (see Section 3.1.3.2 for a referenced discussion of how and why veterinary teams treat rhinos when they are being legally-dehorned). Therefore, many of these compromises do not occur throughout the whole legal-dehorning procedure. This is unlike any physiological welfare compromise that occurs when rhinos are poached, because such individuals do not receive treatment. Hence welfare compromise applies for the whole length of exposure.

In Part B, we evaluated welfare compromise due to the mode of death and included this for individuals likely to face mortality. The first four steps in the process above were completed for Part B but steps 1 and 5 were altered. For step 1, this involved listing only the occurring welfare implications (and their respective impact grades) from the moment the mode of death is determined, along with the likely time to insensibility. Then, for step 5, we assigned an overall impact score ranging from A, most humane to H, least humane, using the respective overall impact grade and the duration of welfare compromise (time to insensibility).[4]

2.1.1. *Creation of a humaneness score for poaching methods and legal-dehorning methods*

For any rhinos faced with mortality from either poaching or legal-dehorning methods, a humaneness score was assigned ranging from 1A to 8H (most to least humane) by combining the impact scores from Part A and Part B for the respective assessment for poached or legally-dehorned individuals.

2.1.2. *Magnitude of welfare compromise*

All steps previously described only assess welfare impact imposed on individual rhinos. Hence, to make this framework relevant to conservation, the likely magnitude of welfare impact on the population was then calculated. This stems from the study of Kirkwood et al. (1994), which suggests that the magnitude of a situation should be calculated using the number of animals affected multiplied by the mean duration of harm. To make the magnitude calculation suggested in Kirkwood et al. (1994) relevant to the rest of this framework, and to appropriately assess the magnitude of welfare impact under all possible future scenarios, we made three changes to Kirkwood et al.'s (1994) calculation. Firstly, we did not look solely at whole numbers affected, but instead converted this to percentages to give a relative result. Second, we did not look at stagnant numbers/percentages, but instead modelled likely welfare outcomes under each scenario if poaching levels were to decrease, stay the same, or increase (by extension, the percentages affected by welfare harm under both Part A and Part B in each scenario were also modelled). Finally, instead of looking solely at duration, we looked at the combination of the welfare issues occurring and their duration (which was summarized into a welfare score). Therefore, while duration is not directly included in this calculation in the way that it is in Kirkwood et al.'s (1994) study, it is included indirectly through the consideration of the duration of welfare compromise when estimating the overall impact score for Part A and/or B (see Section 2.1.2.1 for more detail).

In summary, the potential magnitude of welfare impact was incorporated into this framework by combining the percentage of animals affected (from Part A and Part B) with the respective impact grade (for Part A and Part B):

$$M = n_p i_p \tag{1}$$

where, M is the magnitude of welfare compromise arising from each conservation method; n_p is the percentage of animals affected under Part A or B; and i_p is the overall welfare impact score calculated for Part A and/or B. The values used for n_p and i_p were from the respective Parts (i.e. the number/percentages affected and the impact grade for Part A were not mixed with that of Part B). This calculation of the magnitude of welfare compromise, linked with the humaneness scores, enabled the severity of harm relevant to a population of animals to be determined. This facilitated the integration of welfare considerations (individual level effects) into the issues considered of more vital importance by conservationists (population level effects).

2.1.2.1. Duration of welfare compromise. The duration of welfare compromise under each scenario was calculated by estimating chase duration and the semi-narcotized state (if relevant), and the length of time needed to dehorn and safely administer a reversal agent or to poach a rhino. For individuals faced with mortality from being poached or legally-dehorned, the time to death was estimated (that is, the time between the application of a method that caused consequent welfare compromise to the time of insensibility), and for survivors, the time to ending the welfare compromise. The 'worst-case' principle was assumed when calculating the total duration of welfare compromise for both poached and dehorned individuals, following the advice from Sharp and Saunders (2011) that where little evidence or knowledge exists, "one should assume that the worst will happen".

2.2. *Identification of key welfare issues and levels, and subsequent questionnaire design*

Using knowledge gained from the welfare assessment framework discussed above, key welfare issues and levels were identified as candidates for the questionnaire. The levels represented the range of conditions, physiological responses, and procedure techniques apparent under each scheme. We identified the welfare issues and levels from pertinent literature using Google Scholar and the University of Queensland's online library. Key search terms were as follows: 'rhino', 'conservation', 'welfare', 'dehorning', 'legal trade', 'trade ban', 'procedure', and 'poaching'. We noted any potential welfare issues that were mentioned in any of the articles gathered from this first search and integrated them into our key search terms. This was done until all information and studies gathered overlapped, and it appeared we had sufficient information to complete the welfare assessment for each scenario. These additional search terms included, but were not limited to: 'immobilisation', 'physiology', 'reproductive', 'anaesthesia', 'butorphanol', 'cardiopulmonary', 'recumbency', 'stress', and 'behaviour'.

A total of 125 sources were identified and accessed – all of which broadly related to animal welfare, rhino conservation, legal-dehorning, and/or poaching. In relation to sources pertinent to the welfare implications of poaching and legal-dehorning, only 15 were found to have relevant information to this study. Of these 15 sources, seven were peer reviewed journal articles, and the remaining eight were grey literature. A majority of the grey literature sources were funded by the Department of Environmental Affairs or rhino conservation groups.

Eleven key welfare issues were identified from the literature and each of these issues had two to four levels assigned.

2.2.1. *Questionnaire design*

A questionnaire was dispersed via email to all potential participants, selected as described below. Part 1 of the questionnaire recorded information on the respondent's profession (stakeholder group). Following this, part 2 invited the relative prioritisation of the key welfare issues and levels (identified through the literature search, see Section 2.2) when faced with two differing profiles (combinations of

[4] Instead using box 8 on pg. 52 in Sharp and Saunders (2011) as a grading device in this step.

Table 1
Likely poaching and legal-dehorning numbers to occur under each scenario, with associated stated assumptions behind each of these figures.

Scenario	Poaching numbers (percentages)	Reasoning	Legally-dehorned numbers (percentages)	Reasoning
Trade ban	Low (decreased) poaching levels: P = 973 (6.49%)	Poaching numbers reached a total of 1028 individuals in 2017 (Save the Rhino international, 2018). On average, poaching has fallen approximately 5.35% (r) each year over the past 3 years (Save the Rhino international, 2018). Therefore, (if poaching numbers decreased in 2018 according to this pattern), we assumed that the likely lower limit = 1028 × (1 - 0.0535).	0 (0%)	Due to the illegality of selling rhino horn derived from dehorning procedures to the international market under the current trade ban, the welfare implications of legal-dehorning were not incorporated.
	Baseline poaching levels (no change in poaching pressure): P = 1028 (6.85%)	We set our baseline poaching numbers to be equivalent to the poaching numbers of 2017 (1028). This is due to our baseline scenarios representing situations in which poaching levels show no change in comparison to the previous year.		
	High (increased) poaching levels: P = 1215 (8.10%)	Poaching numbers in 2014 were the highest ever recorded in South Africa (Save the Rhino international, 2018), so this likely resembles the most severe poaching pressure possible.		
Legal trade	Low (decreased) poaching levels: P = 13 (0.087%)	This number reflects poaching numbers in 2013 (Biggs et al. 2013a; Save the Rhino international, 2018), a time at which rhino poaching was at its historical minimum (Biggs et al. 2013a).	1597 (10.65%)	Taking into consideration the proportion of horn able to be harvested (non-lethally extracted/cut off) per white rhino from a legal-dehorning procedure (h = 2/3) (Martin 2011), and the number of rhinos poached in 2016 (assuming the weight obtained from these poaching events is equal to demand), we calculated that 1597 wild white rhinos need to be dehorned to meet demand under the legal trade scenario in the first year. $N = P/h$ $= 1054 \div 0.66$ $= 1596.96$ $= 1597$
	Baseline poaching levels (no change in poaching pressure): P = 1028 (6.85%)	The same reasoning stated in the baseline section for the trade ban stands for the baseline value under a legal trade.		
	High (increased) poaching levels: P = 1215 (8.10%)	The same reasoning stated in the upper limit section for the trade ban applies to the baseline value under a legal trade.		

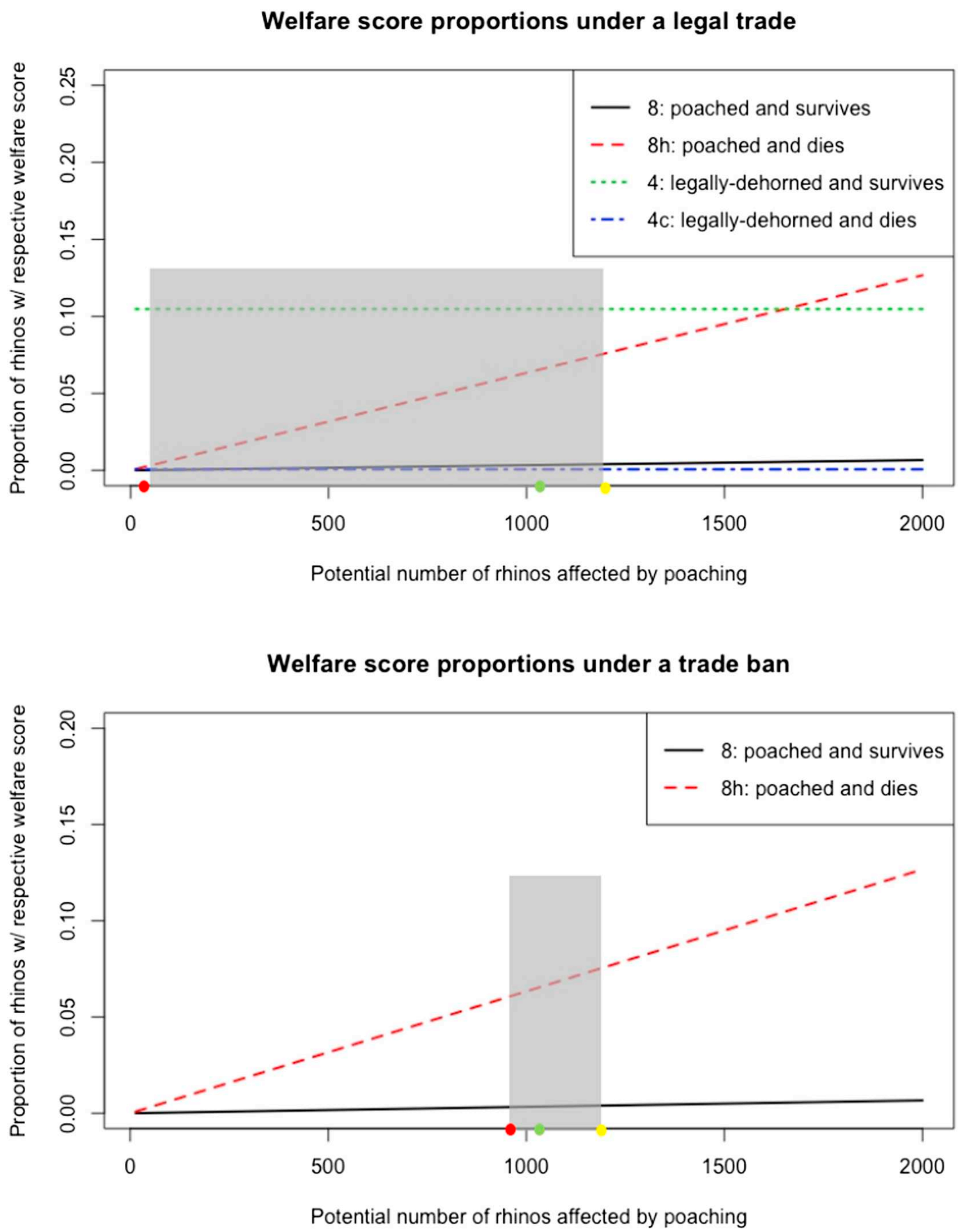

Fig. 1. Predicted proportion of South African white rhinos in each welfare score class under a potential international legal trade (top graph), and the current trade ban (bottom graph), as a function of the number of rhinos poached. Red circles denote our low poaching assumptions, yellow circles represent the high poaching assumptions, and green circles represent our assumed baselines (the point where there is no change in projected poaching levels). The grey area highlights these assumed poaching bounds. See Table 1 for an explanation of the origin of values for the red, yellow, and green circles under each trade scenario. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

two of the same issues with different levels). Stakeholders were not asked what welfare issues they thought would arise under each scenario. Lastly, part 3 requested that each participant assign a grade of welfare impact (no impact, mild, moderate, severe, or extreme impact) to each level within the key welfare issues presented.

2.3. Stakeholder selection

Relevant stakeholders were identified and selected from the same scientific literature that was accessed when reviewing the welfare issues and levels to integrate into the questionnaire. Eight stakeholder groups were identified: welfare scientists; conservation scientists; animal welfare NGO employees; conservation NGO employees; national park employees; government conservation authority; game farm employees; and, wildlife veterinarians. A total of 74 stakeholders were identified and contacted.

2.4. Questionnaire delivery and completion

The questionnaire was constructed using two online platforms and was designed to allow anonymous participation. Parts 1 and 3 were delivered using Survey Monkey (www.surveymonkey.com), an online survey software and questionnaire tool. Part 2 was constructed with appropriate on-line software (www.1000minds.com) using just the conjoint analysis section.

Conjoint analysis is most commonly a marketing tool used to analyse customer preferences when faced with different concepts (a combination of issues and alternative levels within) (Hansen and Ombler, 2008). More recently however, conjoint analysis has been integrated into animal welfare studies [e.g. Fernie et al., 2012; Gurusamy et al., 2014], both of which used adaptive conjoint analysis to gather stakeholder opinion and identify the relative ranking of key welfare issues pertinent to great ape and elephant welfare, respectively, in zoo settings.

The conjoint analysis software utilised in this study employed a statistical process called the PAPRIKA method. This method involved each stakeholder ranking two hypothetical welfare compromise alternatives (with successively more criteria adapted and incorporated with each decision) until all undominated pairs were ranked (see Appendix A for more information regarding the PAPRIKA method). Upon completion, the ranking and relative importance (represented by individual part-worth utility values) (see Section 2.4.1) of all issues and levels were calculated by the software using mathematical methods based on linear programming (Hansen and Ombler, 2008).

Each participant had two alternative ways to complete the questionnaire. Firstly, a link to the online questionnaire was embedded in the invitation email. When completed online, each participant started with a link to the survey which took them to the Survey Monkey site to complete parts 1 and 3; once complete, the survey automatically redirected them to the 1000minds site to complete part 2. Secondly, due to many of the stakeholders residing in South Africa (and having unreliable internet), a word document version of the questionnaire was attached to the invitation email.

The layout of the questionnaire in the Word document was almost identical to the online questionnaire, except for Part 2. Due to the inability to predict what concepts would be displayed in the online questionnaire, Part 2 in the word document instead requested that each level within the eleven welfare attributes be numbered from 1 to however many levels each attribute had. The answers for parts 1 and 3 were entered into the online questionnaire as they appeared in the word document. Completing Part 2 of the questionnaire (using the answers in the Word document) involved calculating the product of the 2 levels presented in each concept and selecting the option with the highest number. The rating of levels used the assigned numbers in the completed document, if a participant noted they were unsure of the number to assign to each level then all levels within that attribute were marked as equal. If the product of both concepts was the same then the "both are equal" option in the online questionnaire was selected.

2.4.1. Issue ranks and level utility values

The ranking of each issue was used as an indication of how concerning or damaging each issue is to an individual's welfare. The 1000minds software ranked each issue from most important (highest welfare concern) to least important (lowest welfare concern) by using the respective mean criterion ranking, with lower values representing higher importance. We did not integrate a cut-off point for acceptable versus not acceptable welfare outcomes.

2.5. Scenario modelling

Potential numbers of affected individuals under a trade ban and a legal trade of rhino horn were inferred using a set of stated assumptions relating to potential poaching and legal-dehorning numbers under each scenario (see Table 1). See the grey boxes in Fig. 1 for a graphical representation of the poaching bounds (assumed low to high poaching occurrences) under a trade ban and a legal trade of rhino horn.

2.5.1. Trade ban

2.5.1.1. Poaching bounds. Low poaching occurrences under a trade ban were estimated using projected numbers based on previous poaching trend lines for the past three years (973) (see Table 1) and poaching numbers for 2017 as the baseline value (1028). The highest poaching levels recorded (1215 individuals) were set as the high poaching numbers likely under a trade ban of rhino horn.

Currently, there is no primary literature on poaching methods, and little exists on the short- and long-term implications of poaching, making the assessment of welfare for poached rhinos difficult. Because of this gap in the literature, we used online information from the Stop Rhino Poaching website [see StopRhinoPoaching.com 2015], the Wildlife Detective website [see Wasserman 2016] and the Saving the Survivors website [see Save the Survivors 2016] to inform on the likely welfare implications for illegally-poached rhinos.

To comprehensively assess the welfare impacts of poaching incidents on individual rhino, we considered the method of immobilisation and horn removal. It is reported that a large majority of poachers immobilise rhinos on-foot using high-calibre hunting rifles (StopRhinoPoaching.com 2015; Save the Survivors 2016). The horn removal by poachers is most commonly done using a machete or an axe (StopRhinoPoaching.com 2015).

2.5.2. Legal trade

2.5.2.1. Legally dehorned numbers. First, the number of rhinos needed to be legally-dehorned to meet demand[5] was considered and calculated to be 1597 individuals (see Table 1). The true demand for rhino horn cannot be calculated due to unquantifiable factors involved in the illegal trade of rhino horn (such as how much is being stockpiled by syndicates, how much actually reaches consumer countries etc.). While the number of rhinos poached and the weight of horn obtained does not necessarily correlate with true demand, this is an appropriate estimate to consider how many white rhinos may be affected by legal-dehorning if an international legal trade was put in place.

2.5.2.2. Poaching bounds. Second, because it is highly improbable that poaching will terminate entirely if an international legal trade is implemented (Di Minin et al. 2015), the welfare implications of poaching were also incorporated into this scenario. We modelled the effect of decreased poaching (from hereon in referred to as low poaching) and increased poaching numbers (hereon in referred to as high poaching occurrences), along with no change in poaching (1028) (baseline poaching numbers). The assumed low poaching scenario was based on historical poaching trends – in 2007, before poaching started escalating, only 13 rhino were poached (Biggs et al. 2013a). The high poaching scenario is from the historical maximum number of poaching occurrences (1215 individuals in 2014) in South Africa (Save the Rhino international, 2018). See Table 1 for further information. In addition, we test the effect of poaching numbers, beyond the low and high values (poaching bounds), on consequent welfare score percentages in case our current projections of poaching are incorrect.

2.5.3. Sensitivity analysis

We developed a model and performed a sensitivity analysis to examine the effect of various poaching estimates on the proportion of rhinos with each welfare score under the ban and legal trade scenarios. From the parameters in Table 2, we can compute the proportion of rhinos in the two poached categories (those that survive or die from a poacher encounter, p_8 and p_{8h} respectively) after the intervention, as follows:

[5] Assuming that the previous year's poaching numbers – and the total weight of rhino horn collected across all of these poaching incidences – represent demand (D). That is, $D = Pm$.

Table 2
All parameters considered and/or integrated into the sensitivity analysis model.

Parameter	Description	Baseline value
n	Wild population size	15,000
N	Number of rhinos to be legally-dehorned to meet demand	1597
h	Proportion of rhino horn harvested per individual when legally-dehorned	2/3
P	Number of poached rhinos	1054
D	Amount of rhino horn demanded (kg)	6197.52
m	The average mass of a rhino horn (kg)	5.88
s	Probability of rhino surviving dehorning	0.994
s_d	Probability of rhino surviving poaching	0.05
r	Proportional reduction in poaching	0.05

$$p_8 = \frac{s_d\, P}{n},$$

$$p_{8h} = \frac{(1 - s_d)\, P}{n}.$$

In the above formulation, s_d represents the probability of a rhino surviving a poaching event, P the number of poached rhinos under the scenario (trade or ban), and n the wild population size.

Under the scenario where rhinos are legally-dehorned, the proportion in the dehorned categories, p_4 and p_{4c} respectively, are

$$p_4 = \frac{sD}{nmh}$$

$$p_{4c} = \frac{(1 - s)D}{nmh}$$

The variable D represents the amount of rhino horn demanded (in kg), m is the average mass of a rhino horn, and h the proportion of a horn harvested from a rhino during legal dehorning. Therefore, D/m is the amount of rhino horn demanded, measured in units of full rhino horns, and $D/(mh)$ is equal to the total number of rhinos legally-dehorned under a legal trade. The parameter s represents the probability of an individual surviving a legal-dehorning procedure, and n the wild population size. Note, we assume that only enough rhino horn to satisfy the demand from current poaching levels is produced through legal dehorning. Additionally, poaching is assumed to possibly continue, because it is unlikely that all poaching will necessarily be eliminated if this amount of rhino horn is legally supplied to the market. Therefore, we let P vary in the trade scenario beyond our stated poaching bounds, from 0, eliminated poaching, to 2000, representing even potential increases in poaching due to hypothetical, unexpected perverse outcomes of legalising trade.

2.6. A comparison of the two conservation scenarios using consequentialist conservation concepts

Frameworks to assess and compare both the conservation and welfare implications of conservation management schemes are uncommon in the primary literature. However, Hampton et al. (2018) have recently proposed that in order to minimise harms while still achieving conservation goals for overabundant herbivores, a conservation management method should utilise consumptive in situ killing. The authors label this method 'consequential conservation' and argue that the benefits of this proposal are six-fold: "1) imposing negative welfare states for only very short durations on animals being killed, 2) not depriving the remaining animals of positive welfare states (e.g., linked to rearing offspring), 3) preventing overpopulation and poor welfare states facing overabundant populations (e.g., starvation), 4) preventing welfare impacts imposed on heterospecifics through resource depletion (i.e. competition), 5) harvesting meat and thereby not requiring other (agricultural) animals to be raised to supply that meat, and 6) incurring minimal costs and thereby maximizing funding available for other wildlife management and conservation priorities" (Hampton et al., 2018). The adoption of welfare consequentialism need not only result in the application of lethal approaches, but can also lead to the implementation of non-lethal methods or no method at all. Most importantly, Hampton et al. (2018) state that no management methods should be disregarded, and instead, the consideration of which conservation strategy will likely result in the best aggregate welfare outcome should guide decision making pertinent to conservation management implementation.

Table 3
Summary data of the eight stakeholder groups that answered the questionnaire.

Answer options	Response percent	Response count
Welfare scientist	3.3%	1
Conservation scientist	33.3%	10
Animal welfare NGO employee	6.7%	2
Conservation NGO employee	6.7%	2
National park employee	3.3%	1
Government conservation authority	3.3%	1
Game farm employee	3.3%	1
Wildlife veterinarian	30%	9
Other (please state in ten words or less)	10%	3

3. Results

A total of thirty completed surveys were returned, eleven using the Word document and nineteen using the online URL, representing an overall response rate of 40.5%. Respondents included representation across eight stakeholder groups (see Table 3). A total of ten respondents were conservation scientists, nine were wildlife veterinarians, two were animal welfare NGO employees, and two were conservation NGO employees. The remainder of respondents was from diverse stakeholder groups including a welfare scientist, national park employee, government conservation respondent, and a game farm employee. Three respondents stated 'other'. The participants had an average of 18.27 years of experience (SD = 10.70; SE = 2.1) in their respective fields, with 4 years being the lowest experience level.

3.1. Understanding the welfare implications of poaching in comparison to legal-dehorning

3.1.1. Issue ranks and level utility values

The mean issue ranking for each of the eleven welfare issues ranged from 3.15 to 9.78, out of a maximum possible score of 10 (Table 4). Sensory damage post horn removal was the issue regarded as most important for the welfare of rhinos exposed to poaching or legal-dehorning, followed by the physiological effects of immobilisation, chase, semi-narcotized state, horn removal technique, horn appearance post removal, health problems post removal, and immobilisation method issues, respectively. The issues of anaesthetic/chemical dosage, immobilisation time, and use of anaesthetic reversal agent were the three issues regarded as least important (Table 4). Table 4 includes all possible welfare issues and their respective levels that are likely to occur when a rhino is poached and when legally-dehorned under a legal trade, thus outlining all welfare issues to consider under both a legal trade of rhino horn and a trade ban.

3.1.2. Impact grades for welfare levels

We determined the impact grade for each level within an issue by using the grade most selected by the stakeholders. However, some levels had a similar number of selections for two closely rated impact grades, hence a scaled grade (e.g. mild-moderate) was assigned.

Impact grades for each welfare issue ranged from mild impact to extreme impact (see Table 4). No welfare issues were deemed by the stakeholders to have no welfare impact.

Table 4
All potential issues and levels (gathered from the literature) included in the questionnaire and the resulting issue ranking mean, utility values, and impact grades.

Issue	Issue ranking mean[a]	Level	Utility value[b]	Impact grade
Chase	3.53	1. Chase before immobilisation occurring over rough terrain	0%	Moderate
		2. Chase time before immobilisation being excessive/extensive	13.6%	Severe
Immobilisation method	6.95	1. Immobilisation using injected/darted anaesthetic	0%	Mild
		2. Immobilisation using purely paralysis-inducing drugs (no anaesthetic administered)	3.0%	Severe-extreme
		3. Immobilisation by bullet	6.0%	Extreme
Semi-narcotized state	3.67	1. Semi-narcotized state less than 6 min	0%	Mild-moderate
		2. Semi-narcotized state above 6 min	12.8%	Severe
Anaesthetic dosage	9.78	1. Dosage administered being too low	0%	Moderate-severe
		2. Dosage administered being too high	3.0%	Severe
Immobilisation time	9.78	1. Being under anaesthetic and immobile; consequently, not able to access food or water, or escape the elements	0%	Mild
		2. Not being under anaesthetic yet still immobile; consequently, not able to access food or water, or escape the elements	3.0%	Severe-extreme
Horn removal technique	4.88	1. Horn removal above the germinal layer, and rhino not conscious (or waking) during horn removal	0%	Mild
		2. Horn removal above the germinal layer, and rhino conscious (or waking) during horn removal	3.0%	Moderate-severe
		3. Horn removal below the germinal layer, and rhino not conscious (or waking) during horn removal	6.0%	Severe
		4. Horn removal below the germinal layer, and rhino conscious (or waking) during horn removal	9.0%	Extreme
Horn appearance post removal	4.97	1. Deformed appearance of horn regrowth	0%	Mild-moderate
		2. No horn regrowth, or lack of horn	10.2%	Moderate
Health problems post horn removal	6.36	1. Long-term infection to horn and nasal cavity/area	0%	Severe-extreme
		2. Difficulty breathing	7.2%	Severe
Sensory damage post horn removal	3.15	1. Damage to eardrums from the sound of the chainsaw	0%	Moderate-severe
		2. Retinal damage from exposure to the sun/other elements	7.6%	Moderate
		3. Damage to the rhino's olfactory system (smelling abilities).	16.2%	Severe
Physiological effects of chemical immobilisation	3.15	1. Hypertension and hyperthermia.	0%	Moderate-severe
		2. Capture myopathy/muscular myopathy.	8.4%	Extreme
		3. Cardiorespiratory system compromise.	16.0%	Severe
Use of anaesthetic reversal agent	9.78	1. Use of an anaesthetic reversal agent, and hence decreased likelihood of residual sedation and consequent injuries.	0%	Mild
		2. No anaesthetic reversal agent used, and hence increased likelihood of residual sedation and consequent injuries.	3.0%	Severe

[a] Lower values for the issue ranking means indicate that the respective welfare issue has a higher impact on rhino welfare than one with a higher-ranking mean.
[b] The utility value informs on the severity of a level within each parameter. Higher utility values indicate welfare levels that are likely to have a higher negative impact on welfare.

3.1.3. Likely occurring welfare factors for poached and legally-dehorned rhinos

Potential welfare implications to arise when a rhino is poached or legally-dehorned, based on primary scientific literature, mainly involved dehorning, ungulate immobilisation and anaesthesia, poaching, and any other relevant welfare issues. Our results indicate that when a rhino is poached, a total of eight welfare issues are likely: chase, immobilisation method, immobilisation time, horn removal technique, horn appearance post-removal, health problems post horn-removal, physiological effects of immobilisation, and sensory damage. Conversely, if a rhino is legally-dehorned, six welfare issues are likely. These welfare issues are: immobilisation method, semi-narcotized state, immobilisation time, horn removal technique, physiological effects of immobilisation, and the use of an anaesthetic reversal agent are the likely occurring issues. Table 5 summarises the occurring welfare issues and levels for each rhino directly-affected by poaching or legal-dehorning. Table A1 in the appendix provides further details to Table 5, with the domains of each welfare issue and levels, and references that were used to support which anthropogenic activity (poaching or legal-dehorning) they occurred in.

Our analysis identified eleven key welfare issues likely to occur under either conservation scheme, and we discuss these below (in order of their importance as indicated by the results of the ACA issue rankings) and highlight which issues occur under each conservation scenario and why. See Table 6 for a glossary of terms relating to the discussed welfare issues.

3.1.3.1. Sensory damage post horn removal. This was the issue with the highest ranking and, hence, is the most concerning welfare parameter, but it only occurs when rhinos are poached due to the lack of precautions to prevent such welfare damage. Conversely, it is standard practice when legally-dehorning a rhino to cover its eyes with cloth to prevent retinal damage from elemental exposure and from the hot chainsaw exhaust. Additionally, the rhino's ears and nose must be blocked to try to ensure no damage occurs to the eardrum from the noise of the chainsaw and that no exhaust blows into the rhino's nostrils (Lindsey and Taylor, 2011; Morkel and Kennedy-Benson 2007; Radcliffe and Morkel 2014). It is because of these aforementioned precautionary procedures, that sensory damage may not occur when rhinos are legally-dehorned. Poached individuals, however, are likely exposed to the two highest levels of this welfare issue, revealing that sight and smell – and all associated functions – are likely to be compromised.

3.1.3.2. Physiological effects of immobilisation. All three levels of the issues 'physiological effects of immobilisation' occur when a rhino is poached, while only hypertension and hyperthermia, and cardiorespiratory system compromise eventuate for legally-dehorned individuals. The physiological effects of capture vary greatly, and the consequences often depend on the degree of stress and its duration. Stress is believed to be induced by a number of noxious stimuli: physical (e.g. trauma and surgery), chemical (e.g. decreased supply of oxygen, acid-base imbalance), physiological (e.g. shock, pain, infection), and emotional (e.g. fear, anxiety) (West et al. 2008). Based

Table 5
Summary of the probable welfare issues and the levels for each affected rhino when poached and legally-dehorned, according to the literature.

Scenario	Attribute	Levels
Poached individuals		
Part A	Chase	Chase before immobilisation occurring over rough terrain
	Immobilisation method	Immobilisation by bullet shooting
	Immobilisation time	Not being under anaesthetic yet still immobile; consequently, not able to access food or water, or escape the elements
	Horn removal technique	Horn removal below the germinal layer, and rhino conscious (or waking) during horn removal
	Physiological effects of immobilisation	Hypertension (high blood pressure) and hyperthermia
		Capture myopathy
		Cardiorespiratory system compromise
	Horn appearance post-removal	No horn regrowth, or lack of horn (only for survivors)
	Health problems post horn-removal	Long-term infection to horn and nasal cavity– only for survivors
		Difficulty breathing
	Sensory damage (only applies to survivors)	Retinal damage from exposure to the sun and other elements
		Damage to the rhino's olfactory system (smelling abilities)
Part B	Immobilisation	Immobilisation by bullet shooting
	Immobilisation time	Not being under anaesthetic yet still immobile; consequently, not able to access food or water, or escape the elements
	Horn removal technique	Horn removal below the germinal layer, and rhino conscious (or waking) during horn removal
	Health problems post horn-removal	Difficulty breathing
	Total number of attributes exposed to: 8	
Legally-dehorned individuals		
Part A	Immobilisation	Immobilisation using injected/darted anaesthetic
	Semi-narcotized state	Semi-narcotized state less than 6 min (we assumed that 50% of immobilisation procedures will result in a semi-narcotized state of 6 min or less)
		Semi-narcotized state above 6 min (we assumed that 50% of immobilisation procedures will result in a semi-narcotized state of above 6 min)
	Immobilisation time	Being under anaesthetic and immobile; consequently, not able to access food or water, or escape the elements
	Horn removal technique	Horn removal above the germinal layer, and rhino not conscious (or waking) during horn removal
	Physiological effects of immobilisation	Hypertension (high blood pressure) and hyperthermia
		Cardiorespiratory system compromise
	Use of an anaesthetic reversal agent	Use of an anaesthetic reversal agent, and hence decreased likelihood of residual sedation and consequent injuries
Part B	Immobilisation	Immobilisation using injected/darted anaesthetic
	Semi-narcotized state	Semi-narcotized state less than 6 min (we assumed that 50% of immobilisation procedures will result in a semi-narcotized state of 6 min or less)
		Semi-narcotized state above 6 min (assumed that 50% of immobilisation procedures will result in a semi-narcotized state of above 6 min)
	Immobilisation time	Being under anaesthetic and immobile; consequently, not able to access food or water, or take shelter
	Horn removal technique	Horn removal above the germinal layer, and rhino not conscious (or waking) during horn removal
	Physiological effects of chemical immobilisation	Hypertension (high blood pressure) and hyperthermia
		Cardiorespiratory system compromise
	Total number of attributes exposed to: 6	

off assumed poaching methods (mentioned in Section 2.5.1), these individual examples represent the probable consequences for poached rhinos.

3.1.3.2.1. Hyperthermia and hypertension. While there is no specific source that outlines the physiological effects of immobilisation when a rhino is poached, West et al. (2008) highlight the common effects on an animal's physiology resulting from capture. For example, resistance to capture and immobilisation, restraint that promotes a struggle, and being exposed to prolonged fear stimuli (particularly distress) can all result in a build-up of lactic acid and increased body temperature (hyperthermia). Hyperthermia, however, can be prevented by limiting chase periods and can be relieved by providing shade and wetting and fanning of the animal, all of which would be usual practice during a legal-dehorning procedure (Radcliffe and Morkel 2014). Poachers do not respect welfare concerns and, consequently, this hyperthermia occurs for poached rhinos and for longer periods than in legally-

Table 6
Terms and definitions relating to some of the welfare issues that will likely arise when a rhino is poached or legally-dehorned.

Term	Definition
Acidosis and acidaemia	Increased acidity in blood and body tissues (The American Heritage Medical Dictionary, 2007)
Anaesthesia	A lack of all sensation, particularly sensitivity to pain. It can be induced medically or result from trauma, and it can be limited to a small area (local anaesthesia) or affect the entire body (general anaesthesia) (MSD Veterinary Manual, 2018)
Analgesia	Treatment given to control pain; a deadening or absence of the sense of pain without loss of consciousness (MSD Veterinary Manual, 2018)
Butorphanol	An opioid analgesic agent used to immobilise large mammals that results in marked sedation (Radcliffe and Morkel 2014)
Capture myopathy	Muscle damage, usually resulting from extreme exertion, struggle, or stress (Saunders Comprehensive Veterinary Dictionary, 2007)
Etorphine	An opioid drug used to immobilise large mammals (Radcliffe and Morkel 2014)
Germinal layer	A vascular, generative layer of epidermis covering the nasal bones from which the horns grow (Lindsey and Taylor, 2011)
Hypercapnia	Excessive carbon dioxide in the blood-stream (Mosby's Medical Dictionary, 2009)
Hypertension	High blood pressure (MSD Veterinary Manual, 2018)
Hyperthermia	Unusually high or increased body temperature (MSD Veterinary Manual, 2018)
Hypoxaemia and hypoxic	Low oxygen levels within the blood (MSD Veterinary Manual, 2018)
Physiology	Functions of a living organism and its parts, and of the physical and chemical factors and processes involved (Dorland's Medical Dictionary for Health Consumers, 2007)
Semi-narcotized state	A state of decreased locomotor control and manipulation due to the administration of a narcotic (American Heritage Dictionary of the English Language, 2007)
Tachycardia	Excessive, rapid resting heart rate (MSD Veterinary Manual, 2018)

dehorned rhinos (probably for the whole poaching event versus a maximum of 29 min for legally-dehorned rhinos). When immobilising a rhino, it appears hypertension is a common outcome as a result of etorphine anaesthetic administration (Haw et al. 2015), and hence is only likely when a rhino is legally-dehorned and not when they are poached. However, this may be resolved by intravenous butorphanol and oxygen administration (Haw et al. 2015). Furthermore, the hypertension that occurs when a rhino is immobilised with etorphine (when being legally-dehorned) can be corrected usually within the first 6 min of immobilisation (Haw et al. 2015).

3.1.3.2.2. Capture myopathy. As a consequence to the lactic-acid build up that is likely to arise when a rhino is poached, blood pH often declines (causing blood acidosis, which may result in insufficient oxygenation and ventilation). Multi-organ failure and capture myopathy may ensue. Capture myopathy and associated muscle damage are prevalent in rhinos that are exposed to prolonged chases and hyperthermia (Miller et al. 2013; Radcliffe and Morkel 2014), providing further evidence that this is probable in poached individuals. However, we assumed that capture myopathy is an unlikely occurrence under legal-dehorning programs because of the many procedures implemented to prevent it from occurring, such as the addition of sedatives/tranquilizers with opioids, treatment of hyperthermia, and quick induction times (Haw et al. 2015; Miller et al. 2013; Radcliffe and Morkel 2014).

3.1.3.2.3. Cardiorespiratory system compromise. Rhinos immobilised with etorphine develop severe physiological complications, however, many treatment options have been discovered that reverse multiple adverse reactions to etorphine immobilisation (Haw et al. 2015; Miller et al. 2013; Radcliffe and Morkel 2014). For example, immobilised rhinos injected with etorphine immobilisation cocktails have presented with hypoxemia, hypercapnia, tachycardia, and acidosis (Bush et al. 2004; de Lange et al. 2017; Miller et al. 2013). However, oxygen supplementation and/or butorphanol may be provided to improve oxygenation (Bush et al. 2004; Haw et al. 2015; Miller et al. 2013), reduce the likelihood and severity of hypercapnia and acidaemia (de Lange et al. 2017; Haw et al. 2015; Miller et al. 2013), prevent hypoxic muscular and organ damage (Bush et al. 2004; Haw et al. 2015), and attenuate tachycardia (Haw et al. 2015). Furthermore, administration of butorphanol and continuous nasotracheal oxygen insufflation can correct hypoxemia (one of the most significant life-threatening side-effects of etorphine) (de Lange et al. 2017), and the hypercapnia and severe acidaemia also affecting immobilised rhinos can be improved (de Lange et al. 2017). Therefore, if all legal-dehorning procedures are similar to these aforementioned studies, then it is likely that most cardiorespiratory implications will occur for a maximum of 10 min.

Nevertheless, capture myopathy and muscular damage, hypoxemia, hypercapnia, acidaemia, tachycardia, and hypertension persisted when no treatment was administered in all previously mentioned studies. Additionally, tachycardia also often arises as a result of insufficient analgesia/anaesthesia (West et al. 2008), consequently, due to the absence of any anaesthetic when a rhino is poached, tachycardia is a very possible welfare issue to arise under such circumstances. Therefore, poached rhinos are probably exposed to all these welfare compromises throughout the entire immobilisation period (and at more severe levels than legally-dehorned individuals due to the gunshot immobilisation implemented by poachers, and probably higher levels of stress).

3.1.3.3. Chase. Neither level within the 'chase' issue ensues during a legal-dehorning procedure. This is due to the use of fixed-wing spotter planes to locate rhinos for legal-dehorning before the use of a helicopter (thereby decreasing chase times), and the manipulation of the direction in which the chased individual may run (which ensures the rhino does not come upon undesirable terrain) (Lindsey and Taylor, 2011; Morkel and Kennedy-Benson 2007). Conversely, when rhinos are poached 'immobilisation occurring over rough terrain' is a resulting concern.

3.1.3.4. Semi-narcotized state. Both levels of the 'semi-narcotized state' issue have the potential to occur when a rhino is legally-dehorned. However, due to the addition of tranquilizers and/or sedatives that have synergistic effects with etorphine into the immobilisation mixture for legally-dehorned rhinos (de Lange et al. 2017; Haw et al. 2015; Miller et al. 2013), we believe that such individuals are not aware of any stressful surroundings and consequently, are less stressed during this semi-narcotized state.

3.1.3.5. Horn removal technique, horn appearance post removal, and health problems post removal. 'Horn removal technique' is one of the welfare issues with the most significant differences between poached and legally-dehorned rhinos. Due to the removal of the entire horn when rhinos are poached, both the germinal layer and the nasal cavity are damaged; in most cases the rhino is conscious during the poaching process (Wasserman 2016). However, during legal-dehorning the germinal layer is not impeded and rhinos are always sedated (Kock and Atkinson 1993; Lindsey and Taylor, 2011). Accordingly, because horn removal occurs below the nasal cavity when rhinos are poached, we surmised that the 'horn appearance post removal' and 'health problems post horn removal' issues only occur for poached individuals. For the 'horn appearance post removal' issue, only poaching survivors are exposed to either level within this issue. Both levels of the latter issue are inevitable for poached individuals, with only survivors being exposed to 'long-term infection to the horn and nasal cavity/area', and both rhinos that die and those that survive face 'difficulty breathing' (Save the Survivors 2016; Wasserman 2016).

3.1.3.6. Immobilisation method, anaesthetic dosage, immobilisation time, and anaesthetic reversal agent welfare issues. The last four welfare issues (immobilisation method; anaesthetic dosage; immobilisation time; use of anaesthetic reversal agent) are all intrinsically linked, so these are discussed together. Poached rhinos are exposed to the most damaging level within the first and third issues, but are not exposed to the 'anaesthetic dosage' or 'use of an anaesthetic reversal agent' issues due to the gunshot method used when rhinos are poached. In contrast to this, based on the literature on immobilisation and/or legal-dehorning protocols, legally-dehorned rhinos are only exposed to the lowest level of compromise within the 'immobilisation method', 'immobilisation time', and 'use of an anaesthetic reversal agent' issues (de Lange et al. 2017; Haw et al. 2015; Kock and Atkinson 1993; Lindsey and Taylor, 2011; Radcliffe and Morkel 2014). Neither levels of 'anaesthetic dosage' affect these individuals due to the well-established dosage guidelines for rhino immobilisation (Morkel and Kennedy-Benson 2007; Radcliffe and Morkel 2014).

3.1.4. Welfare compromise and humaneness scores

To assess the humaneness of poaching methods in comparison to legal-dehorning procedures, both the overall welfare impact (Part A) and the mode of death (if relevant, Part B) were examined (Table 7), both of which required a consideration of the duration of exposure to welfare compromise. For individuals that survived either procedure, a single numerical score ranging from 1 to 8 is reported below; for rhinos that die, a numerical and an alphabetical score is shown (1A-8H; most humane-least humane).

3.1.4.1. Duration of welfare compromise. We estimate that legally-dehorned rhinos will be exposed to a total duration of welfare compromise of ~29 min (see appendix *Bi* for further details). In brief, this is based on the approximate 5–9-minute chase period and induction of a semi-narcotized state (Haw et al. 2014, 2015; Lindsey and Taylor, 2011; Morkel and Kennedy-Benson 2007; Morkel et al. 2010; van Zijll Langhout et al. 2016), combined with an average recumbency period of 20 min when a rhino is immobilised and legally-dehorned (de Lange et al. 2017; Haw et al. 2014, 2015; Lindsey and Taylor, 2011; Morkel et al. 2010; van Zijll Langhout et al. 2016; Wenger et al. 2007).

Table 7
Assessment of the likely impact[a] to occur in each of the five welfare domains (Part A) and the level of suffering during death (Part B) imposed on individual rhinos under a trade ban and a legal trade scenario when exposed to poaching methods and/or standard legal-dehorning practices.

Scenario	Domain	Impact grade[b]
Trade ban	1. Water deprivation, food deprivation, and/or malnutrition	Extreme
poached individuals	2. Environmental challenge	Extreme
	3. Disease, injury, and/or functional impairment	Extreme
	4. Behavioural and/or interactive restriction	Extreme
	5. Anxiety, fear, pain, distress, thirst, hunger, boredom	Extreme
	Part A overall impact grade:	Extreme
	Part A overall welfare impact score for rhinos that die:	8
	Part B level of suffering and alphabetical humaneness score:	Extreme (H)
	Part A overall welfare impact score for rhinos that survive:	8
Legal trade[c]	1. Water deprivation, food deprivation, and/or malnutrition	Mild
legally-dehorned individuals	2. Environmental challenge	Moderate – severe[d]
	3. Disease, injury, and/or functional impairment	Moderate – severe[d]
	4. Behavioural and/or interactive restriction	Moderate
	5. Anxiety, fear, pain, distress, thirst, hunger, boredom	Moderate
	Part A overall impact grade:	Moderate
	Part A overall welfare impact score for individuals that die and that survive[e]	4
	Part B level of suffering and alphabetical humaneness score:	Mild (C)

[a] Likely impact levels were the same as those seen in Sharp and Saunders (2011): no impact, mild impact, moderate impact, severe impact, or extreme impact.
[b] The impact grade for each domain was decided upon by: 1. listing all likely occurring welfare levels for each domain under each method; 2. recording the grade (that the stakeholders previously assigned for each level) of these occurring levels; and, 3. then assigning the highest occurring grade in each domain as the impact grade for the respective domain.
[c] The same results for the assessment of overall welfare impact for poached individuals under the trade ban was applied to the number of poached rhinos under a legal trade scenario.
[d] Domain 2 and 3 receive the higher impact grade of 'severe' for legally-dehorned rhinos that are exposed to semi-narcotized states above 6 min. The maximum recorded semi-narcotized state when following legal-dehorning procedures appears to be approximately 9 min (Haw et al. 2015) (only 3 min above the ideal time-length of 6 min or less). Therefore, this small difference in the impact grade for individuals exposed to longer semi-narcotized states in comparison to those exposed to shorter semi-narcotized states (domain 2 and 3) had no effect on the overall impact grade and impact score. Therefore, individuals that are exposed to semi-narcotized state times of less than or more than 6 min receive the same welfare score.
[e] The same overall welfare impact score was applied to both survivors and individuals faced with direct-mortality under legal-dehorning procedures because both would be exposed to similar perturbations for the same length of time.

Regarding poached individuals, we estimated that they have a total duration of welfare compromise of approximately one day for rhinos that die and three days for poached survivors in these situations. This is estimated as a 15-minute chase until immobilisation (StopRhinoPoaching.com 2015; Wasserman 2016), 7 min for poachers to remove a horn (Wasserman 2016), and a one-day period for rhinos that bleed-out and die as a result of these poaching events or an additional two days of experienced welfare compromise for rhinos that survive (Save the Survivors 2016). See Appendix *Bii* for explanation of these time-frames and references.

3.2. Potential welfare implications of a legal trade versus a continued trade ban

3.2.1. Magnitude of welfare compromise under different scenarios

In order to understand which of the conservation scenarios of interest results in better overall welfare and conservation outcomes, we performed a sensitivity analysis on the probable magnitude of welfare compromise present under a trade ban and a legal trade. We calculated the percentage of the population affected per annum corresponding to each humaneness score (ranging from 1A-8H; most humane to least humane). See Section 2.1.2, and Tables 7 and 8 for further details.

Under a trade ban, 6.49% of the population would be affected by welfare scores of 8 and 8H if poaching occurrences were to follow the average ~5.35% annual decrease rate seen over the past three years (see Table 1). If poaching remained the same, 6.85% would receive such welfare scores. If poaching increased to the historic maximum, 8.10% of the population would be affected by welfare scores of 8 and 8H. Individuals faced with mortality under the trade ban comprise the majority of the affected population (6.16–7.69% depending on the poaching level) and are exposed to the most harmful welfare score possible (8H).

Conversely, under the legal trade scenario, if poaching levels were to decrease to our assumed low of 13, a total of 0.087% would be affected by welfare scores of 8 or 8H. If poaching numbers were to remain the same or increase to the assumed historic maximum this percentage would match the corresponding percentages under the ban. Furthermore, under the legal trade scenario, the percentage of the population exposed to mortality (from both poaching and legal-dehorning) ranges from a minimal 0.15% (decreased poaching), to 6.58% (baseline poaching), and 7.76% (increased poaching). Looking at the percentage of rhinos affected by legal-dehorning under the legal trade, this is 10.64%, regardless of poaching number (see Table 8 for a summary of all calculated magnitude percentages under each conservation scenario). Poaching welfare scores under both the trade ban and legal trade scenario could be higher or lower than the stated poaching decrease, baseline, or increase numbers stated due to the uncertainty surrounding annual poaching numbers. Therefore, we have projected poaching numbers to values much higher and lower than our stated poaching bounds in order to cover other potential outcomes as seen in Fig. 1.

All percentages in Table 8 refer to the percentage of South Africa's wild, free-living white rhino population estimated to be affected per annum under the respective scenario with poaching and/or legal-dehorning methods present. Calculations of the magnitude and the separate percentages for legally-dehorned and poached rhinos that die and/or survive per annum under each conservation scenario are presented in Appendices C and D.

3.3. Sensitivity analysis results and what they mean for conservation

Our results indicate an estimated 6.16% (low poaching), 6.51% (baseline poaching), or 7.69% (high poaching) of South Africa's wild white rhino population face mortality per year when under a trade ban. Therefore, even at the projected decreased (low) poaching levels, the percentage of South Africa's white rhino population likely to die

Table 8
A summary of the expected magnitude of welfare compromise to arise under a trade ban scenario in comparison to a legal trade scenario, both of which had various assumed poaching levels.

	Trade ban	Legal trade	Total faced with mortality
Legal-dehorning	None.	Number of rhinos legally-dehorned: 1597 (10.64%) Welfare score of 4: 1587 (10.58%) Welfare score of 4C: 10 (0.07%)	
Assumed low poaching levels	Number of rhinos poached: 973 (6.49%) Welfare score of 8: 49 (0.33%) Welfare score of 8H: 924 (6.16%)	Number of rhinos poached: 13 (0.087%) Welfare score of 8: 1 (0.007%) Welfare score of 8H: 12 (0.08%)	Total number and percentage of rhinos that face death[a]: 22 (0.15%)
Assumption of poaching numbers staying the same (baseline)	Number of rhinos poached: 1028 (6.85%) Welfare score of 8: 51 (0.34%) Welfare score of 8H: 977 (6.51%)	Number of rhinos poached: 1028 (6.85%) Welfare score of 8: 51 (0.34%) Welfare score of 8H: 977 (6.51%)	Total number and percentage of rhinos that face death[a]: 987 (6.58%)
Assumed high poaching levels	Number of rhinos poached: 1215 (8.10%) Welfare score of 8: 61 (0.41%) Welfare score of 8H: 1154 (7.69%)	Number of rhinos poached: 1215 (8.10%) Welfare score of 8: 61 (0.41%) Welfare score of 8H: 1154 (7.69%)	Total number and percentage of rhinos that face death[a]: 1164 (7.76%)

[a] The total number and percentage of rhinos that die was only calculated under the legal trade scenario due to the co-occurrence of both poaching and legal-dehorning. This was calculated by from the sum of the individuals with a welfare score of 4C and 8H for the respective poaching level being assessed.

exceeds the lowest population growth rate of 6% and is dangerously close to the optimal 8% population growth rate if poaching numbers increase to the stated high poaching levels. This supports the current prediction that rhinos may be extinct in the wild by 2023–2036 (Ayling 2013; Biggs et al. 2013a; Haas and Ferreira 2016).

Conversely, the total percentage of South Africa's wild white rhinos dying under a legal trade is estimated to be 0.15% if poaching decreases to the stated low poaching pressure, 6.58% if poaching pressure does not change, or 7.76% per year if poaching worsens to the high poaching level once a legal trade is introduced. All three estimates include mortality numbers from legal-dehorning and poaching procedures. Thus, under assumed low poaching pressures under a legal trade, a minimal 0.025% of the lower population growth rate is estimated to be affected, indicating that South Africa's wild white rhino population would increase in size and conservation initiatives be achieved if poaching pressure reduces to these levels. Similar conclusions regarding the probable benefits (e.g. reduced poaching pressure, and sustained rhino population levels) of an international legal trade of rhino horn are proposed in Ferreira et al. (2015) and Di Minin et al. (2015). However, if poaching levels were to increase to the assumed high poaching levels once a legal trade is enforced, then mortality would be ~0.07% higher than high poaching levels under a trade ban. Table 8 provides further details.

4. Discussion

Our paper presents a framework to evaluate the animal welfare implications of the long-standing debate on the international legalisation of the trade in rhino horn. Our results show that the individual welfare impacts of a legally dehorned rhino are significantly lower than for horn sourced through poaching. Overall animal welfare and conservation outcomes therefore depend on the extent to which poaching decreases under a legal trade. Our paper provides a framework to evaluate the potential animal welfare outcomes, which can support practical conservation implementation and policy discussion on the legalisation of trade in horn that aligns with a both a compassionate (sensu Wallach et al., 2018) and a consequentialist approach (sensu Hampton et al., 2018) to conservation. We discuss each of these issues in turn.

4.1. Uncertainty over welfare outcomes under a legal trade

Due to the differences in welfare issues and levels, and the duration of exposure to welfare compromise, for poached rhinos, in comparison to legally-dehorned rhinos, the humaneness scores for each method vary substantially (see Tables 7 and 8). Poached rhinos that die face welfare compromise at a level of 8H (the most inhumane score possible), while survivors are exposed to the maximum possible score of 8. Conversely, legally-dehorned individuals that survive face humaneness scores of 4, substantially lower than poached survivors. Welfare compromise for rhinos faced with mortality from legal-dehorning procedures is at the relatively low score of 4C. Evidently, welfare compromise is substantially higher when comparing poaching methods and legal dehorning methods; however, such a comparison only allows contemplation of which method (poaching or legal-dehorning) is preferable on an individual level.

Considerable uncertainty remains about the likely levels of poaching under a legal trade (Biggs et al. 2013b; Collins et al. 2013; Phelps et al. 2016). A potential reduction in poaching depends on factors such as consumer preferences and willingness to accept legally sourced horn as a substitute and the ability to effectively monitor, enforce and control a legal trade and not allow laundering of poached horn (Cheung et al., 2018a; Phelps et al. 2016; Wright et al. 2016). As mentioned above, the possibility exists that poaching is exacerbated by a legal trade that is poorly regulated and implemented. If this is the case, the number of rhinos poached may increase under a legal trade scenario (Prins and Oukita Ouma 2013 etc.). If there is an increase in the total numbers of rhino poached, then overall welfare outcomes would be worse under a legal trade.

In light of recent policy statements indicating increasing support for a legal trade from China (Cheung et al., 2018b), the framework presented in this paper provides guidance on how animal welfare outcomes could be considered together with population-level outcomes under a potential legal trade. The sensitivity analysis integrated into this framework shows how the proportion of rhinos in each welfare class is projected to change with different assumptions about poaching. A structured decision-making framework to assign stakeholder preferences to each welfare class can also be utilised. Stakeholder mental models of how poaching would likely change if a legal-dehorning is implemented – similar to those seen in Biggs et al. (2017) – could also be elicited. With projections of poaching and welfare class preferences in hand, basic optimisation methods can be used to choose the best management intervention (dehorning or maintaining the status quo ban) given uncertainties in stake holder projections. In addition, the sensitivity analysis presented, can be used as a basis for further analyses that can support deliberations among decision-makers over how varying levels of poaching under a potential legal trade will lead to better or worse overall welfare outcomes for rhino under a legal trade as opposed to a continuation of the trade ban.

4.1.1. Compassionate and consequentialist welfare and conservation outcomes

The increasing consideration of animal welfare considerations in conservation (Bradshaw and Bateson 2000; Bruskotter et al. 2017; Dubois and Fraser 2013; Fraser 2010; UFAW 2010), has led to discussion over different philosophical approaches to integrating welfare and conservation (e.g. Wallach et al. 2018, Hampton et al., 2018). A compassionate approach aims to safeguard biological diversity while retaining a commitment to treating individual animals with respect and concern for their well-being (Wallach et al., 2018). A compassionate approach aims to minimise harm from direct actions undertaken for conservation such as de-horning rhino (Wallach et al. 2018). A consequentialist approach to conservation considers the direct intended impacts of an action on welfare, as well as the indirect impacts that may result from a particular policy or management action. For example, if a legal trade does lead to increased poaching of rhino, the increased harm to individual rhinos would not have been the intent of the policy but a consequence of a policy action. The framework presented here, and highlighted through our sensitivity analysis, can guide deliberations among decision-makers on the potential for legalising trade to optimise both animal welfare and conservation outcomes.

4.2. Limitations of analysis

Poaching levels are dependent on many factors (Crookes 2017; Di Minin et al. 2015; Holden and McDonald-Madden 2017; Kennaugh 2015; Koen et al. 2016), some of which were not integrated into this study. Therefore, a weakness of this study lies in the fact that it does not model the socioeconomic factors that could influence the outcome of a legal trade of rhino horn. Additionally, we assumed poaching levels under a trade ban reflect historical data, despite the possibility that poaching may increase or decline in the future, in part due to simultaneous interventions such as increased enforcement capacity and efficiency and marketing campaigns to reduce rhino horn demand (Critchlow et al. 2017; Holden et al., 2018; Verissimo and Wan 2018). The study only assessed the welfare implications of poaching and legal-dehorning on wild white rhinos; consequently, the results of this study do not reflect either conservation scenario in total, as all species of rhinos (including those outside South Africa) and both wild (free-living) and privately owned/ranched rhinos are exposed to poaching. In addition, this study only evaluated the welfare implications imposed on target rhinos and not on the offspring or group members of poached or legally-dehorned individuals and hence does not evaluate potential indirect implications to occur to the population.

We only considered animal welfare in this paper which occurs when an animal is alive and aware of its environment and internal state (Phillips 2009). Alternatively, the value of an animal's life versus death may be considered a rights-based issue (i.e. its right to life). Hence, only suffering is considered here and not the value of each affected rhino that dies in comparison to one that survives under each conservation scenario. Despite these limitations, this study presents a framework to evaluate the welfare implications of a continued horn trade ban versus a potential legal trade.

Finally, we focussed on wild individuals in our assessment due to the multitude of differing factors that can affect an individual's welfare when under captive conditions. For example, stocking densities and ratios, proximity to and degrees of contact with humans, presence or absence of food/water/shelter, likely affect a rhino's welfare and would all vary between these situations. Hence, such variability and differences would need to be considered in combination with the number of rhinos exposed to these conditions in future studies that include individuals kept for intensive ranching or breeding purposes.

5. Conclusions

Our study provides a framework to evaluate animal welfare considerations under a potential legal trade in horn versus a continued trade ban. Such a framework is of increased policy relevance in light of China's recent announcement that it intends to legalise the trade in rhino horn, a policy change which was subsequently postponed (Cheung et al. 2018b). Furthermore, the framework presented here can be used as a basis to evaluate welfare outcomes in research and policy debates over trade and sustainable use of other taxa such as lion (Bauer et al. 2015) and elephant (Bennett 2015).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2019.05.004.

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