Oraby, T., Tyshenko, M. G., Darshan, S., Westphal, M., Croteau, M., Aspinall, W., ... Cashman, N. (2016). Using expert judgments to improve chronic wasting disease risk management in Canada. *Journal of Toxicology and Environmental Health, Part A: Current Issues*, *79*(16-17), 713-728. https://doi.org/10.1080/15287394.2016.1174005

Peer reviewed version

Link to published version (if available):
10.1080/15287394.2016.1174005

Link to publication record in Explore Bristol Research
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Taylor & Francis at . Please refer to any applicable terms of use of the publisher.

USING EXPERT JUDGMENTS TO IMPROVE CHRONIC WASTING DISEASE RISK MANAGEMENT IN CANADA

Tamer Oraby[1,*], Michael G.Tyshenko[2], Margit Westphal[2], Shalu Darshan[2], Maxine C. Croteau[2], Willy Aspinall[3,8], Susie Elsaadany[4], Neil Cashman[5], Daniel Krewski[2,6,7]

[1]Department of Mathematics, University of Texas-Pan American, Edinburg, Texas, USA78539
[2]McLaughlin Centre for Population Health Risk Assessment, Institute of Population Health
[3]Aspinall and Associates, Cleveland House, High Street, Tisbury UK SP3 6HF
[4]Blood Safety Surveillance and Health Care Acquired Infections Division, Centre for Infectious Disease Prevention and Control, Public Health Agency of Canada, Ottawa, Ontario,Canada K1A 0L2
[5]Brain Research Centre, University of British Columbia, Vancouver, BC, Canada V6T 2B5
[6]Department of Epidemiology and Community Medicine, Faculty of Medicine, University of Ottawa, Ottawa, Canada
[7]Risk Sciences International, Ottawa, Canada. KIP 5N5
[8]School of Earth Sciences and Cabot Institute, University of Bristol, Bristol, UK BS8 1RJ

*Corresponding author

Running head: Expert Opinion about CWD Risk Management in Canada

ABSTRACT

Chronic wasting disease (CWD) is a neurodegenerative, protein misfolding disease affecting cervids in North America in epidemic proportions. While the existence of CWD has been known for more than 40 years, risk management efforts to date have been unable to curtail the spread of this condition. An expert elicitation exercise was carried out in May 2011 to obtain the views of international experts on both the aetiology of CWD and on possible CWD risk management strategies. This paper presents the results of the following three components of the elicitation exercise: expert views of the most likely scenarios for the evolution of the CWD among cervid populations in Canada, ranking analyses of the importance of direct and indirect transmission routes, and rating analyses of the CWD control measures in farmed and wild cervids. The

implications of these findings for the development of CWD risk management strategies are explored in a Canadian context.

INTRODUCTION

Chronic Wasting Disease in North America

Chronic wasting disease (CWD) is a fatal neurological disease affecting both captive and free-ranging cervids in North America. CWD belongs to the family of transmissible spongiform encephalopathy (TSE) diseases encompassing scrapie in sheep, bovine spongiform encephalopathy (BSE) in cattle, transmissible mink encephalopathy (TME) in mink, and Creutzfeldt - Jakob disease (CJD) in humans. Symptoms of CWD are physical wasting, increased thirst and urination, excessive salivation, difficulty swallowing, trouble walking, drooping of ears, and changes in behaviour (Gilch et al., 2011).

Chronic wasting disease was first detected in 1967 in a captive mule deer at a research facility in Fort Collins, Colorado, U.S.A. Subsequent cases were detected in other cervid species and in other locations: in 1979, another mule deer and a black-tailed deer were diagnosed with CWD at a research facility in the state of Wyoming. CWD was first classified as a prion disease by Williams and Young (1980), thirteen years after its discovery. The year 1981 marked the first time CWD was detected in the wild in an elk in Colorado. Subsequently, two wild mule deer with CWD were discovered in Colorado and Wyoming in 1985. CWD has continued to spread geographically, with the number of reported cases increasing over time.

The first case of CWD in Canada was confirmed in 1978 after a mule deer, that had been imported into Canada from the United States four years earlier, was euthanized at the Toronto Zoo (Dube et al., 2006).The first indigenous CWD case was discovered in a farmed elk in Saskatchewan in 1996. Farmed elk exported from the US into Canada in the late 1980s are believed to be responsible for the entry of CWD into Canada (Kahn et al., 2004). The first case of CWD in the wild in Saskatchewan (reported in the year 2000) was a mule deer; the first wild elk case in the same Province was detected in 2008. In 2005, CWD was diagnosed in a wild moose in Colorado.

CWD has spread geographically, reaching both farmed and wild cervids in other locations in the US (11 and 21 states, respectively) and Canada (the provinces of Alberta and Saskatchewan) (Chronic Wasting Disease Alliance, 2011a). Among 125farmed elk exported from Canada to South Korea in 1994 and 1997, one animal was diagnosed with CWD in 2001 (Kahn et al., 2004;Sohn et al., 2002). A second case of CWD was detected in South Korea in 2004 (Kim et al., 2005). A total of 68 infected herds have been identified in Canada from 1996 to April 2013 (Canadian Food Inspection Agency, 2013). One case of CWD appeared recently in a moose in Alberta[1].

CWD in Different Cervid Species

CWD has appeared in multiple species of cervids, including white-tailed deer (*Odocoileus virginianus*), black-tailed deer (*Odocoileus columbianus*), mule deer (*Odocoileushemionus*), Rocky Mountain elk (*Cervus elaphus nelsoni*), and Shira's moose (*Alces alces shirasi*) (Gilch et al., 2011; Sigurdson, 2008). Although red deer (*Cervus elaphus*) are experimentally susceptible to CWD (Balachandran et al., 2010), there are no reported naturally infected CWD cases. Fallow deer (*Dama dama*) seem to be resistant to CWD transmission environmentally and directly from mule deer (Rhyan et al., 2011); however, they can contract the disease following intracerebral inoculation with elk or white-tailed deer CWD infected brain homogenate (Hamir et al., 2011). Eurasian reindeer (*Rangifer tarandus tarandus*) have demonstrated susceptibility when orally inoculated with white-tailed deer's brain tissue (Mitchell et al., 2012).Alaska caribou (*Rangifer tarandus granti*) have sufficient genetic similarity to the other cervids that it is reasonable to suspect they are a susceptible species (Happ et al., 2007): the experts polled in the present elicitation believe that the likelihood that CWD could occur in caribou within the next 50 years is non-negligible (Aspinall, 2011).

To date, there is insufficient evidence to establish that CWD can transmit to other (non-cervid) animal species (Gould et al., 2003) or to humans (Gilch et al., 2011;Sandberg et al., 2010); nonetheless, several investigators have advocated a precautionary policy with regard to CWD risk management (Angers et al., 2006;Belay et al., 2004;Hamir et al., 2006;Hamir et al., 2007), in part because of its long incubation period, which ranges from 15 to 23 months in mule deer and from 12 to 34 months in elk. The time from infection with the CWD agent to the expression of clinical signs of the disease can also vary among animals of the same species depending on the genotype (Fox et al., 2006;Kahn et al., 2004;Wilson et al., 2009).

Routes of Transmission

The possible modes and routes of transmission of CWD, and their relative efficiency and importance, have been the subject of intensive investigation (Angers et al., 2009;Daus et al., 2011;Denkers et al., 2010;Denkers et al., 2011;Di Guardo and Marruchella, 2010;Haley et al., 2009b;Haley et al., 2011;Hamir et al., 2011;Mathiason et al., 2009;Smith et al., 2011;Tamguney et al., 2009;Wiggins, 2009). The CWD agent is normally found in the brain, spinal cord, and neurons(Williams and Young, 1980), as well as in saliva and urine (Haley et al., 2009b;Mathiason et al., 2006), blood (Mathiason et al., 2006), feces (Safar et al., 2008;Tamguney et al., 2009), and skeletal muscle (Angers et al., 2006;Daus et al., 2011). The CWD agent can be also found in the antler velvet of elk (Angers et al., 2009). CWD infected mule deer excrete prions in feces very early in the incubation period of the disease, with the cumulative amount of the CWD agent in feces equal to the amount of prion mass in the brain at the end of the incubation period (Tamguney et al., 2009).

Oral inoculation of saliva and urine in transgenic Tg(CerPrP) mice expressing normal cervid prion protein resulted in infection with a prolonged subclinical stage of the disease (Haley et al., 2009a;Haley et al., 2009b). Deer exposed to the CWD agent from urine and feces through oral inoculation have also become infected (Haley et al., 2009a). Moreover, nasal exposure to CWD via aerosol and intranasal inoculation has shown to be efficient in transmitting the disease to Tg(CerPrP) mice with long incubation periods (Denkers et al., 2010).

Chronic wasting disease can be transmitted directly between deer, through the environment (including through soil) (Miller et al., 2004), or vertically (from mother to offspring) (Mathiason et al., 2010). The CWD agent can be shed in to the environment through cervid excreta and through decaying cervid carcasses. Pre-clinical CWD infected deer can transmit the disease to other deer (Mathiason et al., 2009;Safar et al., 2008). The CWD agent persists in soil for lengthy periods of time, creating an environmental reservoir for the disease (Johnson et al., 2006;Saunders et al., 2012;Smith et al., 2011).

Adsorption of prions and replication efficiency of CWD prion in the environment depends on soil type (Saunders et al., 2011b;Saunders et al., 2011c). The persistence of the CWD agent in soil may impose a long-term risk of environmental transmission. Prion binding to the soil mineral, montmorillonite (Mte), increases the titre of CWD agent infectivity 680-fold, as compared to unbound prion (Johnson et al., 2007). Enzymatic treatment of the soil at regular environmental conditions is effective in reducing environmental contamination with the CWD agent by 4 to 6 orders of magnitude (Saunders et al., 2011a), depending on soil type. The CWD agent can be also found in water at very low titres in regions where CWD is endemic (Nichols et al., 2009).

In (Argue et al., 2007), it was found that shared equipment, breeding herd and forage in feeders are the most important risk factors for within farm transmission. The time from the introduction of infected cervid till the depopulation of the herd would also increase the risk of transmission. Hence changing cervid-farming protocols might be a good control measure of CWD spread on farms. Selective culling in free-ranging cervids, on the other hand, has been found to be effective in some cases to reduce the spread of CWD in the wild (Joly et al., 2006).

Management of CWD in the Provinces of Canada

Surveillance. Mandatory surveillance in Alberta of CWD was initiated in August 2002, following six years of voluntary submission of cervid tissue samples to Provincial government authorities. It was later updated in 2011 to support the access of Albertan cervids industry to external markets. Current regulations require cervid (elk and deer) farmers to submit cervid heads for testing to the Alberta Agriculture and Rural Development (ARD) laboratory in Edmonton. Animals eligible for submission include dead, euthanized, and slaughtered cervids one year of age or older (Alberta Agriculture and Rural Development, 2011). Farmers and producers also are required to report suspected CWD cases to district veterinarians at the Canadian Food Inspection Agency (CFIA). Hunters are encouraged to submit wild deer heads to the ARD laboratory. As of September 2004, Alberta permitted the importation of live cervids from other provinces in Canada and the US under certain regulations designed to mitigate the risk of CWD.

In Saskatchewan, mandatory CWD surveillance began on December 31, 2001. Prior to that date, CWD surveillance had been conducted passively since 1997 (Canadian Cooperative Wildlife Health Centre, 2011a). Surveillance depends on hunter head submission for testing.

Control Measures. Although CWD control measures in Canada differ among provinces, all ten provinces currently have captive and wild cervids testing regulations (Chronic Wasting Disease Alliance, 2011b). In Alberta, Provincial regulations allow elk, white-tailed deer, mule deer and moose farming. Farmers require an annual permit, and animals must have official identification. All animal movements and inventory are reported by farmers, audited by the Province, and recorded in a provincial database for tracking purposes. Import protocols are in place to decrease the risk of importing CWD or other disease carriers.

In Saskatchewan, a permit is required for cervid importation. Sika, red deer, and elk/red deer hybrid ranching is prohibited, although other types of cervid ranching are permitted.

In British Columbia, a prohibition against importation of live cervids has been in place since the 1980's, and the Ministry of Agriculture and Lands controls intra-provincial animal movements. Manitoba prohibits importation of native and exotic cervids, and has bans in place on the possession of any product that contains cervid urine, feces, saliva, or scent glands. As of April 2001, it is mandatory for Quebec farmers to obtain a certificate of CWD clearance for all farmed cervids imported into the Province. In June 2001, another import protocol was introduced under which importers must acquire provincial authorization before importing cervids. Procedures for identification and traceability of cervids have been in place in Quebec since February 2009.

METHODS

CWD Expert Elicitation

Expert elicitation is a well-known method used in the fields of risk science, health science, and engineering to address knowledge gaps in cases where scientific data or evidence is sparse, missing, or unobtainable. Expert opinions are not data subject to usual methods of statistical inference; rather, expert opinions provide useful information on uncertain issues that might be the best possible information that can be obtained at the time they are elicited (Meyer and Booker, 2001).

Members of our research team have previously carried out expert elicitation exercises for other transmissible spongiform encephalopathies (TSEs), including bovine spongiform encephalopathy (BSE) and variant Creutzfeldt-Jakob disease (vCJD) (Tyshenko et al., 2011;Tyshenko et al., 2012). The experts involved in these exercises provided their opinions about different factors affecting the risk of BSE and vCJD, thereby strengthening the basis for BSE and vCJD risk assessment in areas where scientific data is lacking.

In the present exercise, the opinions of fourteen international experts on CWD were elicited to obtain information on the following four issues: 1) uncertainty associated with 13 parameters pertaining to the latency and spread of CWD; 2) possible future scenarios for the course of the epidemic in Canada; 3) ranking of the likely effectiveness of possible CWD control measures in farmed and wild cervids; and 4) ranking of the efficiency of intra-species transmission via direct or environmental routes based on the method of paired comparisons as described below. The experts were chosen both for their expertise of CWD in particular and in prion diseases in general.

In the first exercise, the experts' opinions were elicited and aggregated according to Cooke's classical model (Cooke, 1991). During the meeting, the experts were administered a set of 10 seed questions whose answers can be found in the literature. Following this calibration exercise, the experts responded to 13 target questions to which the answers are unknown. For each seed and target question, the expert gave his/her best judgment for the quantity in question in the form of median (the 50th percentile value) and 90% credible range (the 5th and 95th percentiles of their range of plausible values). By doing so, the experts stated their subjective belief that the correct answer has equal likelihood of being on either side of his or her median evaluation and only a 10% likelihood of being outside the credible range. In Cooke's method, expert opinion about the target question is weighted according to his or her performance on the seed questions, taking into account both statistical accuracy and uncertainty informativeness of the responses to the seed questions. An important consequence of this performance- based weighting is that the opinions of experts who perform better on the seed questions will be given greater weight when interpreting expert responses to the target questions. An explanation of the methods used in this type of expert elicitation exercise is provided by Aspinall (2011) (and see also Appendix 1 in Tyshenko et al., 2011).

The weights were used to determine collective weighted opinions in the scenario analysis and the rating exercises. Since most of the equally weighted opinions are somewhat non-informative, the weights measured according to the classical method of Cooke (1991) are preferred, reflecting robust enumeration from the collective knowledge of the experts. Although the paired comparisons exercises are not weighted (see below), but each expert opinion is tested for internal consistency and filtered out if found to be inconsistent. The present expert elicitation involves three separate exercises in which expert opinion about the factors affecting CWD risk and risk management among farmed and wild cervids in Canada has been obtained. Our overarching goal is to apply the results of this expert elicitation to evaluate the potential effectiveness of current and possibly enhanced CWD control measures in Canada. An important aspect of this exercise will be to obtain the experts' views on the efficiency of direct and environmental routes of disease transmission.

CWD Foresight Scenario Analysis

The first component of the elicitation exercise was a foresight scenario analysis (SA) of the future course on CWD epidemic in Canada. After presenting the current measures implemented to control the spread of CWD in Canada, the experts were asked to assign probabilities that add up to 100% to each of the mutually exclusive scenarios.

- **Foresight Scenario Analysis Question 1 (SA1):** Consider the following scenarios for the evolution of the CWD epidemic in Canada, assuming current efforts to manage CWD are maintained.

Scenario 1: Current efforts to manage CWD will result in the virtual eradication of CWD in Canada.

Scenario 2: Current efforts to manage CWD will result in the eventual extinction of cervids in Canada.

Scenario 3: Current efforts to manage CWD will result in CWD remaining endemic in Canada for decades.

The experts were also asked to offer their opinion on the impact enhancing current control measures through the following question.

- **Foresight Scenario Analysis Question 2 (SA2):** Consider the following scenarios for the evolution of the CWD epidemic in Canada, assuming enhanced efforts to manage CWD are implemented.

Scenario 1: Enhanced efforts to manage CWD will result in the virtual eradication of CWD in Canada.

Scenario 2: Even with enhanced efforts to manage CWD, the disease will lead to the eventual extinction of cervids in Canada.

Scenario 3: Even with enhanced efforts to manage CWD, the prevalence and /or geographic distribution will increase and the disease will remain endemic in Canada for decades.

Scenario 4: With enhanced efforts to manage CWD, prevalence and/or geographic distribution of CWD can be notably reduced.

In each exercise, probabilities of scenario i were aggregated to find the pooled probability $\bar{P}_i$ according to the formula

$$\bar{P}_i = \frac{\sum_{e=1}^{E} w_e P_i(e)}{\sum_{e=1}^{E} w_e}, \qquad (1)$$

where $P_i(e)$ is the subjective probability of expert e for scenario i and w_e is the weight assigned to that expert based on the seed questions. An unweighted analysis can be obtained from this same formula simply by assigning when $w_e = 1$ for all$e$. Variability in expert opinion can be gauged by the weighted standard deviation

$$\sigma_i = \sqrt{\frac{\sum_{e=1}^{E} w_e}{(\sum_{e=1}^{E} w_e)^2 - \sum_{e=1}^{E} {w_e}^2} \sum_{e=1}^{E} w_e (P_i(e) - \bar{P}_i)^2} \qquad (2)$$

of the probabilities to the various scenarios assigned by individual experts.

Paired Comparisons of CWD Transmission Routes

In order to understand the experts' opinion about the disease management, we first sought to understand their beliefs about the relative efficiency of CWD transmission routes in both a direct and environmental context. These opinions were also interpreted in light of the current state of knowledge about CWD and cervid behaviour. To address this issue, we conducted the following two paired comparison exercises (only 12 of the 14 experts participated in these exercises, with the remaining 2 experts declining because of a lack of familiarity with the method of paired comparisons).

- **Paired Comparison 1 (PC1):** Using the method of paired comparisons, rank the following possible sources of CWD prion infection with respect to their efficiency in intra-species transmission of CWD under normal conditions: saliva, blood, feces, semen, urine, milk, aerosol, nasal discharge, and sores and minor cuts.
- **Paired Comparison 2 (PC2):** Rank the following environmental sources of CWD prions with respect to their efficiency in intra-species transmission of CWD under normal conditions: urine deposits in soil, feces deposits in soil, running water, standing water pool (small pond), decaying carcasses, shared bedding, scavengers, winter feeding, and hunter baiting.

Experts were asked to complete the upper triangle of a matrix, called the preference matrix, stating their opinion about the relative efficiency (or importance or effect) of each pair of items. For example, if the expert perceived the row item was more efficient than the column item, then he/she inserted a greater than sign (>); a less than sign (<) was used to denote less efficiency, and an equals sing (=) used to indicate equal efficiency. Each expert evaluated 36-

paired comparisons per exercise. In making these comparisons, an expert might demonstrate inconsistency in his or her choices by indicating, for instance, that item 1 is more efficient then item 2, item 2 is more efficient then item 3, but then asserting item 3 is more efficient then item 1. This inconsistent set of choices is called a 'circular triad', and violates the principle of transitivity. How many of these circular triads render the expert's opinion non-meaningful can be determined using a statistical test for inconsistency (Kendall, 1975;Macutkiewicz, 2008): an appropriate chi-square test applied to each expert's preference matrix for **PC1** and for **PC2** was thus carried out to test if the expert's opinion is inconsistent; in which case the expert's opinion was filtered out. A measure of consistency between zero and one was also calculated (Macutkiewicz, 2008): the closer the measure of consistency to one the more consistent the expert's opinion is.

Another statistical test along with a corresponding measure of concordance was used to measure the degree of agreement within the group of experts about the efficiencies of the different items in **PC1** and **PC2**, (Macutkiewicz, 2008). If the test of agreement is not significant, then the 12 opinions are not concordant. The closer the measure of agreement is to unity, the better the agreement within the pool of experts about the efficiencies of the routes of transmission. The tests of inconsistency and agreement as well as the measures are implemented in the software package UNIBALANCE[1] (Delft University, 2012).

There are three methods available to aggregate the 12 preference matrices to form one pooled opinion of the relative efficiency of the routes of transmission: the Bradley-Terry

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[1]Software available from: http://dutiosc.twi.tudelft.nl/~risk/.

method (Bradley and Terry, 1952), the Thurstone method (Thurstone, 1959), and probabilistic inversion method (Macutkiewicz, 2008). We prefer the last method, as it involves no assumptions about the random utility function (comprising from a deterministic component and random error component) assigned to each item. There are two numerical algorithms implemented in the software UNIBALANCE to carry out the probabilistic inversion: Iterative Proportional Fitting (IPF) and Parameter Fitting for Uncertain Models (PARFUM). In analyzing **PC1** and **PC2**, we performed all these methods to ensure a complete evaluation of the expert elicitation results for these two items.

Rating of CWD Control Measures:

In the final part of the expert elicitation exercise, experts were asked to rate the efficiency of different control measures in the farm and wild setting on the following five-point Likert scale: 1=not at all effective, 2=minimally effective, 3=moderately effective, 4=very effective, and 5=extremely effective. Before the experts gave their opinions, they discussed and revised both sets of proposed control measures, to reflect their collective views about which measures should be reasonably considered for use in practice. The two elicitation questions relating to the effectiveness of CWD management practices are given below.

- **Rating Analysis of CWD Control Options 1 (RA1):** How effective are each of the following methods for the control of CWD in wild cervids?
    - A. Target herd reduction (80%)
    - B. Target herd depopulation (100%)
    - C. Baiting ban

D. Transport ban on live animals

E. Feeding ban (winter)

F. Double fencing

G. Stray farmed cervids (stopping)

H. Development of vaccine

I. Diagnostic test, with selective culling

J. Use of natural predators, such as coyotes

K. Natural barriers (mountain ranges)

L. Communication strategies (hunter and aboriginal groups)

M. Increased hunting opportunities

N. Carcass disposal

O. Transport ban of carcasses

- **Rating Analysis of CWD Control Options 2 (RA2):** How effective are each of the following methods for the control of CWD in farmed cervids?

A. Farm depopulation (100%) and repopulation

B. Live export restriction

C. Live import restrictions

D. Herd inspection (compliance)

E. Farm certification

F. Double fencing

G. Fencing standards (height)

H. Vaccine development

I. Diagnostic antemortem test availability

J. Stray wild cervids (protocol)

K. Cervid identification and traceability programs

L. Restrictions on transport of live animals

M. Restrictions on transport of animal parts

N. Development of effective decontamination procedure

The Friedman test is commonly used to test the ratings of judges assigned to different items (Conover, 1971). This test was used to determine if there were differences in experts' ratings of the set of control measures, with Tukey's multiple comparisons test used to determine which subgroups of experts had compatible opinions in a *post hoc* analysis (Betz et al., 2010). The weighted mean and standard deviation given in equations 1 and 2 was used to obtain a pooled rating across experts and a measure of variability in the experts' opinions. Both unequal and equal weightings were used to combine the expert ratings. Statistical analyses were performed using the statistical softwareR (R Development Core Team, 2008).

RESULTS

The five experts with the highest scores based on the seed questions accounted for more than 98% of the total performance-based weights, calculated according to the classical model method of Cooke. Consequently, the weighted analyses of the opinions of these five experts are an optimal representation (in asymptotically proper scoring rule terms (Cooke, 1991)) of the group view. However, for completeness, we present here both the weighted and unweighted/simple (based on equal weights) pooled opinions of all the experts that responded to each of the elicitation questions.

CWD Foresight Scenario Analysis:

The experts perceived that the current efforts would prove insufficient to eradicate CWD in Canada. Specifically, the experts estimated that there is an 85% chance that CWD will remain endemic in Canada under current measures (Figure 1). Even with enhanced control measures, the experts believe that CWD would not be eradicated, and that it would either spread geographically and stay endemic or remain at a low level (Figure 2).

Figure 1. Simple (Panel A) and weighted (Panel B) means and standard deviations of the probabilities assigned by the experts to the three scenarios in the SA1 exercise (the upper and lower limits are trimmed at zero and one, respectively). Scenario 1 proposes the future eradication of CWD in Canada under the current efforts; scenario 2 suggests that the Canadian herd of cervids will become extinct due to CWD; and scenario 3 reflects that CWD will remain endemic in Canada.

Figure 2. Simple (Panel A) and weighted (Panel B) means and standard deviations of the scenarios' probabilities for the SA2 exercise (the upper and lower limits are trimmed at zero and one, respectively). Scenario 1 proposes the future eradication of CWD in Canada under enhanced efforts; scenario 2 suggests that the Canadian herd of cervids will extinct under those efforts; scenario 3 reflects that CWD will remain endemic in Canada; and scenario 4 suggests that it will be endemic but relatively controlled.

Paired Comparison of CWD Transmission Routes:

Since all of the twelve tests of inconsistency in each of the two paired comparison exercises **PC1** and **PC2** were significant, none of the individual opinions was filtered out. The tests of concordance in both exercises were also significant, with the measure of agreement and concordance equal to 0.2 and 0.4 allowing, respectively, reflecting reasonable agreement among the experts on the most important routes of transmission (Aspinall, 2011). We note that expecting complete agreement among experts on such indefinite and uncertain issues is not realistic, so these measures should not be expected to be close to one.

The three methods of analysis of the paired comparison results produce the same rank ordering of the importance of the possible routes of CWD transmission (Figures 3 and 4). The experts considered saliva to be the most important animal-to-animal route of transmission (Figure 3). In another part of the elicitation exercise (Aspinall, 2011), the experts estimated that deer shed prions in saliva throughout 73% of the incubation period, which equates to approximately 13 months. Transmission via feces is thought to follow saliva in its efficiency for direct transmission of CWD. The experts also estimated that deer shed infectious CWD prions in feces for two-thirds of the incubation period, or approximately 12 months, (Aspinall, 2011). The experts gave almost identical weights to the importance of urine and nasal discharge, and semen was thought to be the least important form of direct transmission in comparison with the other nine routes.

Figure 3. Ordered scores and 95% confidence intervals, for nine direct transmission routes, calculated using the Bradley-Terry method (Panel A) and the Thurstone method (Panel B), and scores and standard deviations calculated using the UNIBALANCE probabilistic inversion method (Panel C).

Within the physical environment, the experts believed that decaying carcasses were the most important source of indirect transmission, exceeding feces deposited in soil, winter feeding, shared bedding, urine deposited in the soil, and hunter baiting. The experts believed that both still (small pond) and running water were the least efficient methods of CWD environmental transmission. Scavengers were not considered to be of material concern as a transmission route when compared to the other possible routes.

Figure 4. Ordered scores and 95% confidence intervals, for nine environmental transmission routes, calculated Bradley-Terry method (Panel A) and Thurstone method (Panel B), and scores and standard deviations using the UNIBALANCE probabilistic inversion method (Panel C).

Rating of CWD Control Measures:

Overall, the experts thought that the development of an effective vaccine would be the best way to control CWD in both wild and farmed cervids (see Figures 5, 6, 7, and 8), although there was some disagreement in this regard, as reflected by the individual opinions of the experts. Antemortem diagnostic testing and 100% target herd depopulationalso represent effective methods of CWD control in the experts' opinion.

However, the development of effective decontamination procedures for cervids farms is seen as being more important than depopulation, which is a costly management option for the farmer. A diagnostic antemortem test, if available, however, may be more effective on farms than in the wild due to the difficulties in testing wild populations. Vaccination in the wild poses similar challenges. The experts indicated that natural barriers could act to slow down the geographical spread of CWD in the wild. Other common control measures used for CWD in wild cervids such as winter feeding bans, hunter baiting bans, carcass disposal, and increased hunting opportunities were not considered effective. Double fencing of farms received an intermediate rating, with fair group agreement in both the simple and weighted expressions of pooled opinion.

Figure 5. Simple (Panel A) and weighted (Panel B) averages, standard deviations (on top) and box plots (on bottom) of Likert ratings for the fifteen control measures of CWD in the wild cervids. The letters in the box plot correspond to the proposed control measures in exercise RA1 and are in descending order according to their medians.

Friedman's test revealed significant differences among the ratings in **RA1** ($p<0.03$) and **RA2** ($p<0.005$).*Post-hoc* analyses demonstrated consistent differences between the items at both extremes of the ordered items. For example, in **RA1**, there is a significant difference between H (development of vaccine) and L (communication strategies), H and M (increasing hunting opportunities), B (100% target herd depopulation) and L, and D (transport ban on live animals) and M. However, there were no significant differences between adjacent ordered items.

Figure 6. Simple (Panel A) and weighted (Panel B) averages, standard deviations (on top) and box plots (on bottom) of the ratings for the fourteen control measures of CWD in the farmed cervids. The letters in the box plot correspond to the proposed control measures in exercise RA2 and are in descending order according to their medians.

DISCUSSION

In October 2005, *National Chronic Wasting Disease Control Strategy* was released by the Canadian Cooperative Wildlife Health Centre. The purpose of the plan was to establish a coordinated national policy and a disease response plan within an achievable CWD management framework. The ultimate objective of the strategy is the eradication of CWD. If eradication is not possible, the strategy seeks to achieve the tightest possible control of CWD in Canada in the future (Canadian Cooperative Wildlife Health Centre, 2013).

Since the inception of the national strategy, experts have met both formally and informally to share knowledge and discuss how to best manage the CWD epidemic in Canada. In 2011, the CWD national strategy document was revised and updated to incorporate new scientific evidence and surveillance data. Goal 3 of the strategy is, "a planned management and response program", which seeks to develop an integrated strategy to deal with current and new occurrences of CWD in Canada (Canadian Cooperative Wildlife Health Centre, 2013). To achieve this goal, experts will need to review current developments in prion science as well as the available surveillance data to synthesize appropriate CWD management options. The evidence needed to make appropriate risk management decisions is often incomplete, requiring the use of expert opinion as a proxy until such evidence becomes available. The results of the three expert elicitation exercises reported in this article complement the current body of evidence, and will serve to inform the development of specific CWD control strategies.

The experts who took part in this exercise were chosen for their knowledge of prion diseases and CWD based on their contributions to the peer reviewed scientific literature and through referrals by other experts consulted during the expert selection process. Selection of CWD experts was similar to the previous expert elicitation exercises performed for bovine spongiform encephalopathy (BSE) (Tyshenko et al., 2011; Tyshenko et al., 2012).The invited experts were either Canadian scientists and/or knowledgeable of the state of CWD in Canada.

The management of CWD in farmed cervids is complicated by on-farm environmental transmission of the CWD disease agent, likely through various environmental exposure routes (including saliva, urine, shared bedding, and feces) and social behaviour patterns (directly) among domestic cervids. The detection of CWD in wild cervids near infected farmed cervids in Saskatchewan suggests that environmental transmission of the CWD disease agent may occur between wild and captive cervids. Indeed, it was initially thought that CWD epidemic, in free-ranging North American wildlife, is geographically limited and slowly expanding in its natural rate; however, investigations revealed market-driven movements of infected farmed elk and deer is the main driver of CWD geographic spread(Miller and Williams, 2004). The persistence of the CWD agent in the environment requires that risk management interventions consider both wild and farmed cervids.

With respect to farmed cervids, the results of the present expert elicitation exercises show that the experts believed that the development of effective decontamination procedures would be very important in controlling CWD in Canada. Other interventions, including 100% farm depopulation, animal traceability and farm certifications were also considered relevant to controlling transmission of the CWD agent. Other measures, such as restrictions on transport of animal parts, herd inspections, fencing standards for height, and double fencing, were believed to be less effective in controlling CWD in domestic cervids. Initial risk management actions adopted by the CFIA for farmed cervids, including CWD confirmation by immunohistochemistry (including testing of all herd mates), trackback investigations, farm quarantines and entire farm depopulation to prevent further disease spread, are consistent with the views of our experts.

The relative importance of direct transmission versus environmental transmission in the spread CWD has been the subject of a long-standing debate. When the experts were asked to give their answers about that matter, the pooled weighted opinion was that they are almost equally important, with a slight preference for environmental contamination as the most important route (Aspinall, 2011). At the same time, the pooled weighted credible interval was found to be very wide, from environmental contamination being 100 times more important than social contact to social contact being 12 times more important than environmental transmission (Aspinall, 2011), entailing a high level of uncertainty in the experts' beliefs about this question. The equally weighted pooled opinions of the experts, which does not take into account the performance of the experts on the seed questions, suggests that direct transmission is only 25% more important than environmental transmission (Aspinall, 2011).

The management of CWD in free-ranging (wild) cervids, is confounded by environmental and cervid social factors that promote CWD transmission. Epidemiological and surveillance reports on wild cervids from the US and Canada show a slow but consistent spread of the disease geographically over time (Gilch et al., 2011;Kahn et al., 2004;Miller and Williams, 2004). This elicitation indicates that the experts believed that current efforts to control CWD will prove insufficient to eradicate CWD in Canada, and that the disease will remain endemic (Almberget al., 2011). As a result, CWD management efforts are focused on surveillance to help control the disease. The experts believed that targeted herd depopulation, natural barriers, live animal transport bans, double fencing, reducing stray farmed cervids, and carcass disposal are likely to be the most effective options for controlling CWD. Even though targeted herd depopulation was ranked highly by the experts as a risk management option, previous work by Conner et al. (2007)–based on a meti-BACI approach to evaluate the effectiveness of attempts to reduce CWD prevalence through intensive localized culling of mule deer –suggests such interventions may be less efficacious than expected. Other less effective management measures for reducing CWD in wild cervids, as judged by the experts, included: the increased use of natural predators (natural herd culls), winter feeding bans, baiting bans, transport bans of carcasses, increased hunter culling, and increased communication with hunters. The pairwise comparisons of CWD risk management options made by the experts, the ranking of transmission factors, and the use of foresight scenario analyses are important for analysing CWD risk management options for wild and farmed cervids. The results of the expert pairwise comparison and ratings of control measures reported herein revealed that different control options for farmed versus wild cervids may be expected to yield the best results within the context of an integrated risk management plan for CWD.

Chronic wasting disease spreads at a slower rate geographically over time among farms than in the wild, especially in the last decade. That may be due to the possibility of containing the spread of the disease to other farms by complete depopulation and closure of farms and traceability of cervids (Argue et al., 2007). The experts found that effective decontamination, vaccine development, ante-mortem diagnostic test, 100% farm depopulation, cervid identification and traceability programs are the most important control measure for the spread of CWD within and between farms. Indeed, the odds are of CWD transmission are higher when an infected elk dies for a suspected CWD on farm or exhibited clinical signs than when it was destroyed before showing clinical signs (Argue et al., 2007). The odds increased also with the increase of time from the introduction of the CWD infected elk and the herd depopulation (Argue et al., 2007).A highly sensitive ante-mortem test would then decrease the risk of CWD spread especially if it could detect infection in the early stages of the disease.

The risk management options that ranked highly by the experts, including vaccination, antemortem testing (Monello, 2013), and decontamination, remain to be fully developed (VerCauteren, 2004). Nonetheless, the experts believed that vaccine development represents one of the most promising approaches to addressing the challenge of CWD in both farmed and wild cervids. Although vaccination on farms would be a viable and easily implemented measure, traditional vaccination in the wild would be problematic, as the inoculation of entire herds would be a labour-intensive and expensive undertaking. Although an effective vaccine against CWD is currently unavailable, recent research into oral prion vaccines shows great promise as a potential risk management option for TSEs such as CWD (Goñi et al., 2005;Goñi et al., 2008). Vaccination of farmed cervids alone is not likely to be sufficient as CWD in wild cervids, if left unchecked, can serve as a reservoir that can spillback to farmed cervids unless vaccination continues for many decades or a more rigorous fencing policy is put in place.

Policies aimed at reducing the presence of the infectious CWD agent in the environment (including carcass disposal and CWD positive farm depopulation), reducing deer densities (targeted culling), and reduced movement of cervids in critical areas (through the use of fencing, double fencing, or natural barriers) were considered to be effective control measures, and were ranked highly by experts for both wild and farmed cervids.

Deliberations by experts seeking to reach consensus can be biased or influenced by experts who are more assertive or appear more certain about their judgements. This, in turn, can lead to side-lining of other opinions that may possess greater value for consensus decision-making where uncertainty is large and difficult to quantify precisely. At the very least the use of a more formal and structured expert judgment elicitation, like the one conducted here, can be used to provide transparent methodological rules to the process of decision-making under uncertainty. The method effectively treats expert judgments as scientific data in a formal decision process that can be statistically quantified. Testing to calibrate and score expert judgments, along with tests for inconsistency, are used to differentially weight individual's answers within a group, helping to reduce uncertainty and bias.

The results of expert elicitation exercises such as the one described here can be used to help decide which routes of transmission are likely to be most important, and need to be included in mathematical models of CWD disease management. CWD risk modeling results can incorporate expert opinion about the likely effects of specific interventions aimed at farmed and wild cervid populations to help determine the most effective control measures for each group. The formalized use of expert opinion can help to achieve the goals set out in the

National Chronic Wasting Disease Control Strategy (Canadian Cooperative Wildlife Health Centre, 2013).

New research evidence and ongoing surveillance requires an iterative approach for CWD risk management policy development. The expert elicitation method used here is amenable to re-elicitation as more information becomes available. Future consultation with experts using formalized exercises can be used to refine present CWD management policies, and to help determine the optimal mix of CWD risk management options for farmed and wild cervids.

ACKNOWLEDGEMENTS

This work was supported by a grant from PrioNet Canada, a Canadian Network of Centres of Excellence on prion diseases. D. Krewski was the Natural Sciences and Engineering Research Council of Canada Chair in Risk Science at the University of Ottawa.

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(Figures for: Oraby et al., Using Expert Judgments to Improve Chronic Wasting Disease Risk Management in Canada)

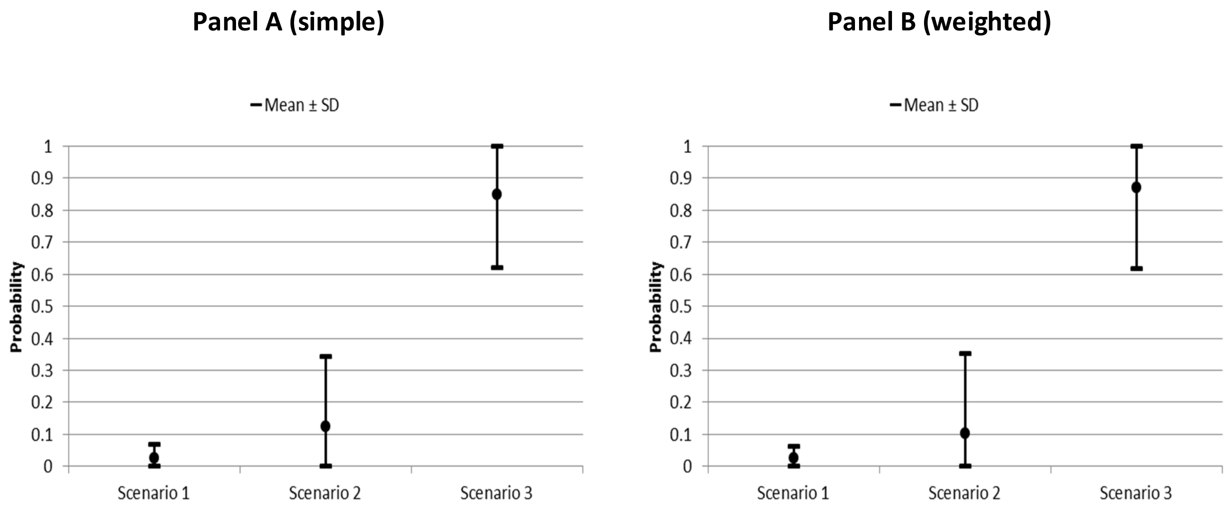

FIGURE 1. Simple (Panel A) and weighted (Panel B) means and standard deviations of the probabilities assigned by the experts to the three scenarios in the SA1 exercise(the upper and lower limits are trimmed at zero and one, respectively). Scenario 1 proposes the future eradication of CWD in Canada under the current efforts; scenario 2 suggests that the Canadian herd of cervids will become extinct due to CWD; and scenario 3 reflects that CWD will remain endemic in Canada.

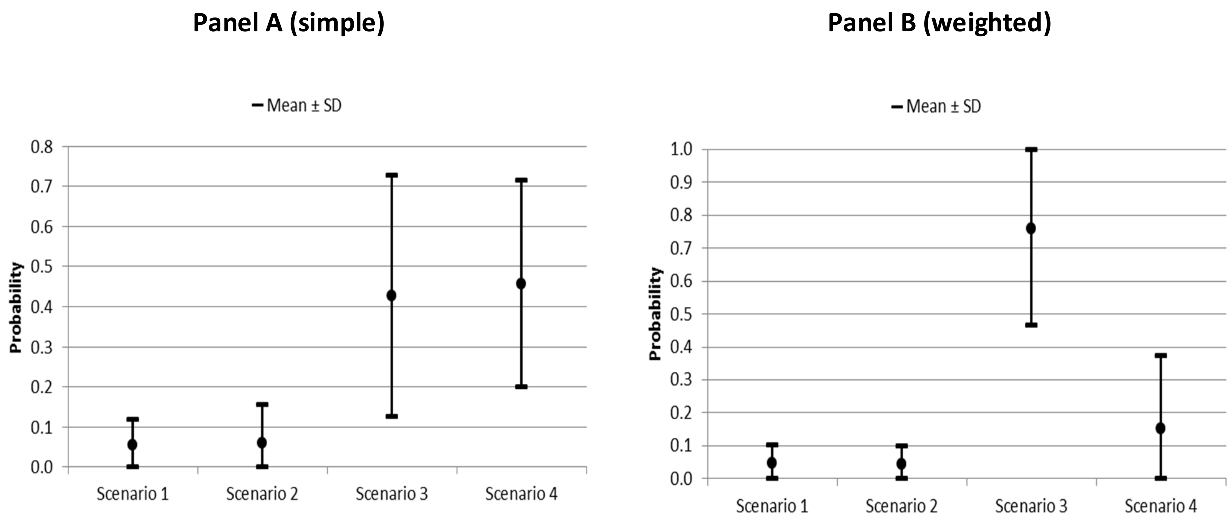

FIGURE 2. Simple (Panel A) and weighted (Panel B) means and standard deviations of the scenarios' probabilities for the SA2 exercise (the upper and lower limits are trimmed at zero and one, respectively). Scenario 1 proposes the future eradication of CWD in Canada under enhanced efforts; scenario 2 suggests that the Canadian herd of cervids will extinct under those efforts; scenario 3 reflects that CWD will remain endemic in Canada; and scenario 4 suggests that it will be endemic but relatively controlled.

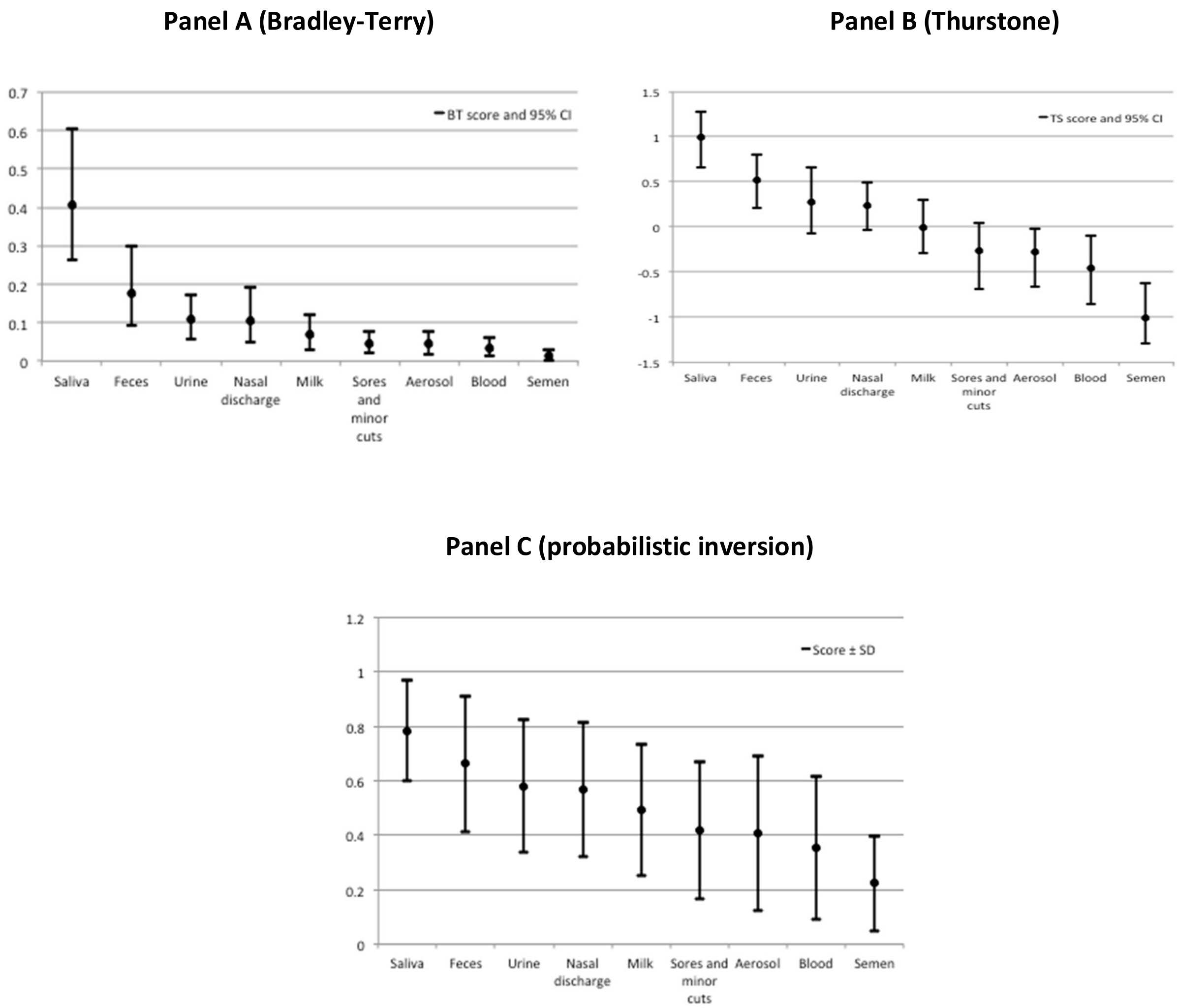

FIGURE 3. Ordered scores and 95% confidence intervals, for nine direct transmission routes, calculated using the Bradley-Terry method (Panel A) and the Thurstone method (Panel B), and scores and standard deviations calculated using the UNIBALANCE probabilistic inversion method (Panel C).

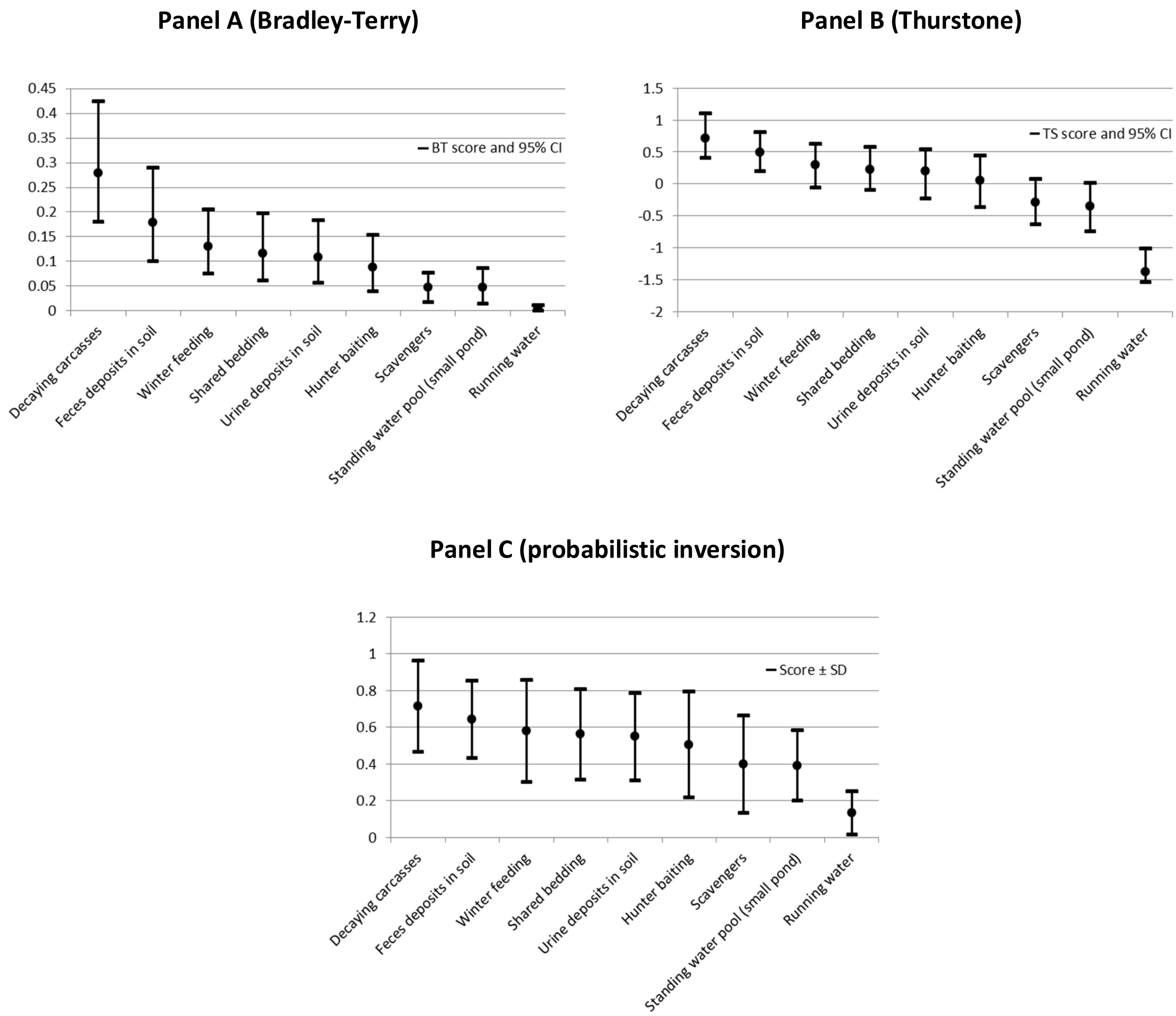

FIGURE 4. Ordered scores and 95% confidence intervals, for nine environmental transmission routes, calculated Bradley-Terry method (Panel A) and Thurstone method (Panel B), and scores and standard deviations using the UNIBALANCE probabilistic inversion method (Panel C).

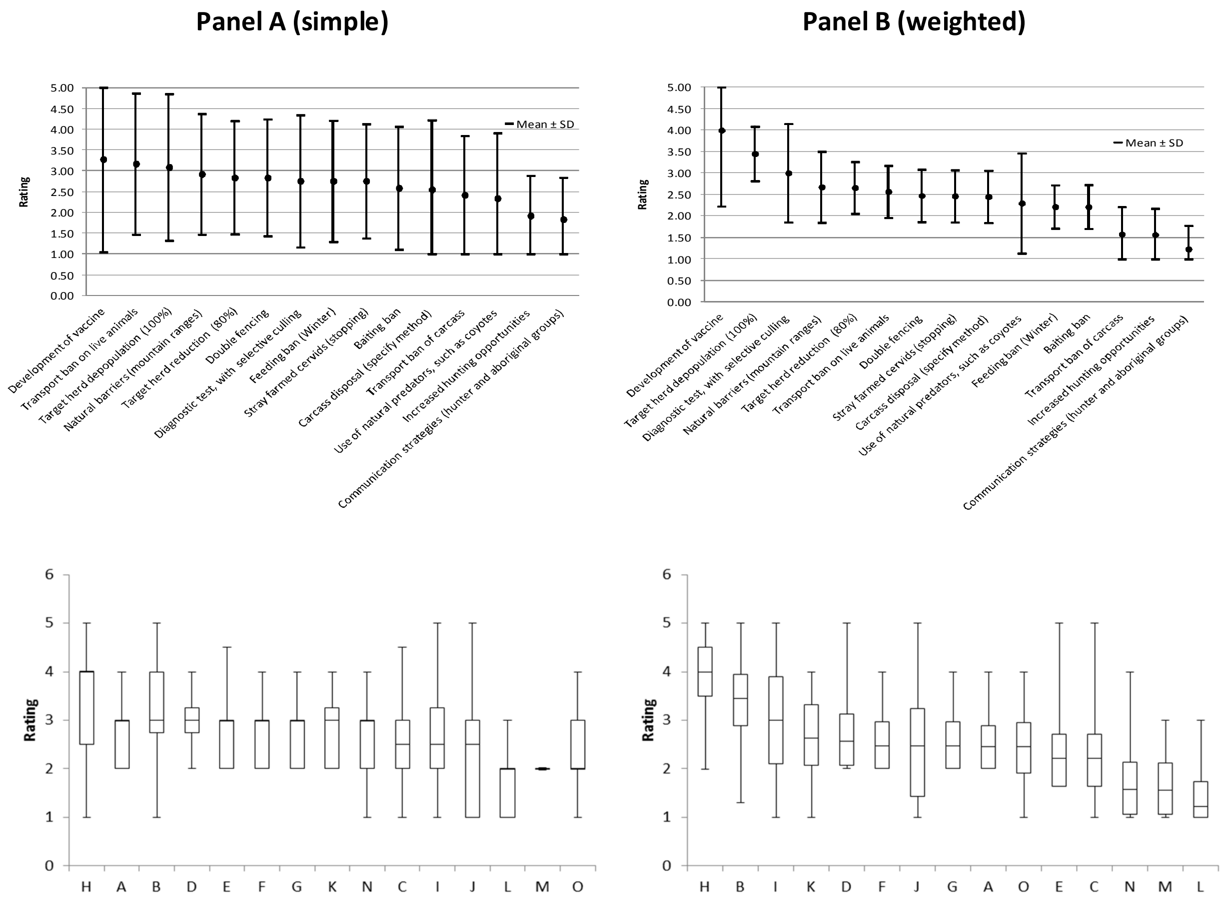

FIGURE 5. Simple (Panel A) and weighted (Panel B) averages, standard deviations (on top) and box plots (on bottom) of Likert ratings for the fifteen control measures of CWD in the wild cervids. The letters in the box plot correspond to the proposed control measures in exercise RA1 and are in descending order according to their medians.

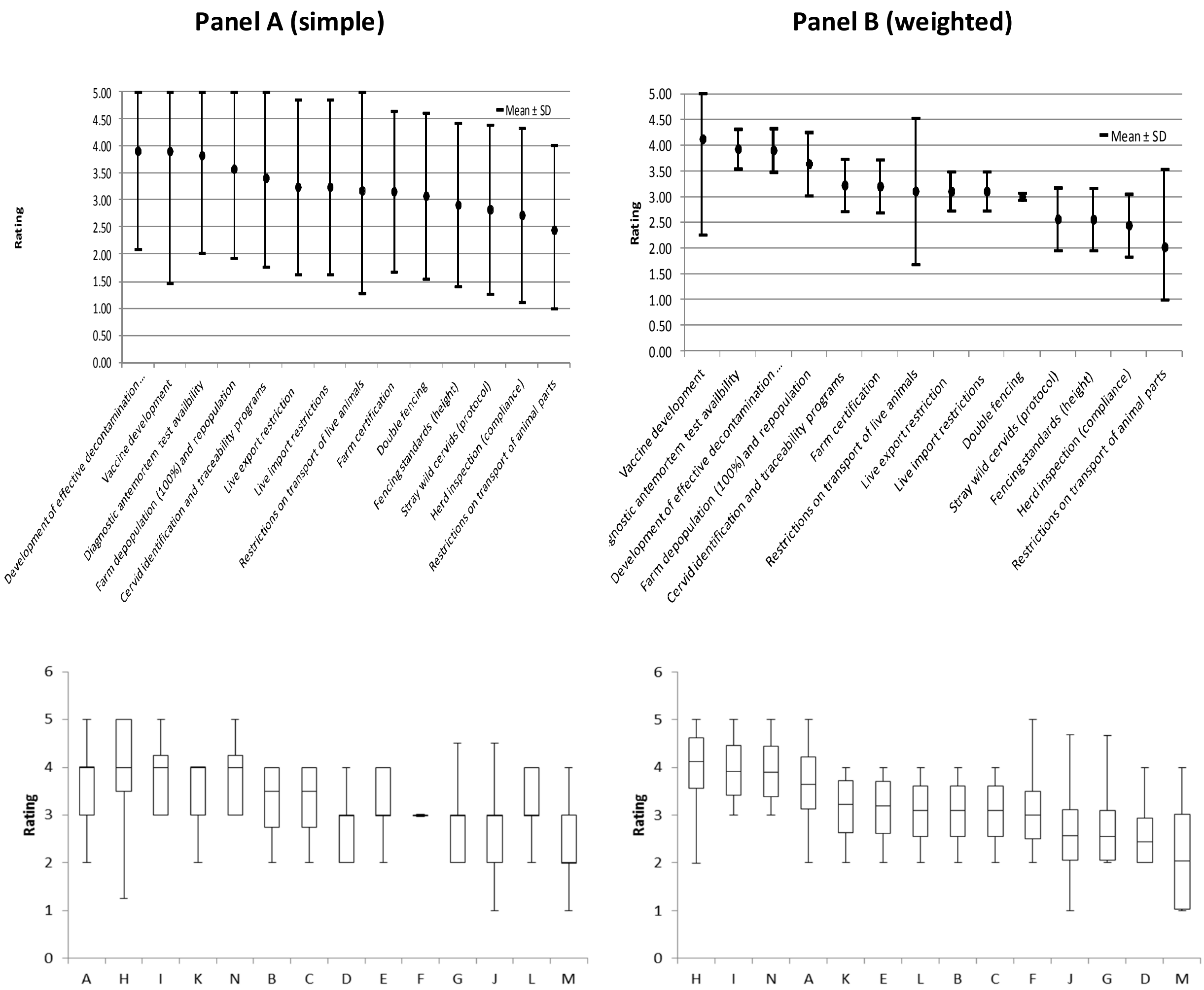

FIGURE 6. Simple (Panel A) and weighted (Panel B) averages, standard deviations (on top) and box plots (on bottom) of the ratings for the fourteen control measures of CWD in the farmed cervids. The letters in the box plot correspond to the proposed control measures in exercise RA2 and are in descending order according to their medians.