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Expert Judgments Regarding Risks Associated with Salmon Aquaculture Practices in British Columbia

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ABSTRACT Making sound decisions about managing ecological risks necessarily involves relying on judgments by technical specialists informed by the best available scientific evidence. Yet, organizing those judgments in ways to assess the relative risks of different components of a technology, and considering priorities in managing those risks, is a difficult and under-explored aspect of environmental management. In this study, we elicited the judgments of scientists associated with the salmon aquaculture industry in British Columbia in order to learn their expert viewpoints of potential risks. This paper presents survey results regarding structured judgments provided by scientists engaged in studies associated with aquaculture or preserving wild stocks of Pacific salmon species. There were statistically significant differences regarding judgments of the risks of various current aquaculture practices on wild salmon stocks. It was possible to rank the means of scientific judgment scores to prioritize these risks. Differences in rankings were location and context specific.

KEY WORDS: Ecological risk, expert judgments, aquaculture, decision-making, risk assessment

1. Introduction

Global salmon aquaculture production has grown rapidly since 1980, and has become an increasingly important source of high-valued seafood supplies (FAO, 2003). This rapid growth has also raised concerns and, at

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times, controversy over several aspects of salmon aquaculture; these concerns include the local and regional ecological impacts (as well as the socioeconomic impacts) of the in-shore saltwater net-pen technology for rearing salmon (Naylor *et al.*, 2000).

When assessing the consequences of a relatively new and rapidly-evolving technology such as salmon aquaculture, understanding the scientific information base relevant to its impacts is crucial. It is also important to understand how experienced scientists interpret that information and then assess the impacts of the technology (and its component activities) as they understand them. Understanding how experts judge the relative risks of specific practices within the overall salmon aquaculture production process could be particularly valuable in helping to set future research or regulatory priorities for that industry.

The objective of this paper is to characterize the relative ecological risks of specific activities and practices within the process of rearing salmon in net pens in coastal waters of British Columbia. This characterization relies on the expressed judgments of a sample of technical experts with science backgrounds knowledgeable about salmon aquaculture and its impacts. Ecological risks were considered in terms of potential impacts on three ecosystem components: *local effects on wild salmon, local effects on species other than salmon, and regional effects on wild salmon*. We also examine these experts confidence in their knowledge for these judgments and the potential influence of their employment on these judgments.

Section 2 of the paper outlines the rationale for and experience with reliance on expert judgments as a basis for risk assessment and risk-ranking activities. While most of the efforts to use expert judgments for risk assessment in the past have focused on eliciting probabilities for specific uncertain events (Morgan and Henrion, 1990), here we develop and apply methods drawing on the experience with risk-ranking or priority setting across a wide range of hazards (Finkel and Golding, 1996) to consider the relative risks of a number of practices within salmon aquaculture production. Hence, a secondary objective of this work was to develop and apply an approach to judging the relative risks of an array of discrete activities or technologies within an overall production process. Section 3 discusses methods for this study, including the characteristics of the participants, the survey design and nature of the questions asked. Section 4 presents the results of the survey, while Section 5 provides discussion, caveats and implications of the study.

Concepts Regarding the Role of Expert Judgments as a Basis for Risk Assessment

The judgments of technically-trained experts have always been an essential source of information in assessing the risks of technologies (Slovic, 1987; Keeney and von Winterfeldt, 1991). Yet, until the last few decades, those assessments have been largely implicit, as part of the broader process of designing technologies and managing their impacts. With the emergence of risk analysis as a quantitative analytical framework to characterize uncertainties within societal choices about technologies (McDaniels and Small, 2003), there has been increasing attention to making these implicit judgments more explicit.

Expert judgments are fundamental to many aspects of the risk analysis process: to help select the objectives of analysis, in thinking through and selecting the structure of models, in judging which data are relevant and how they will be used, among others. One relatively recent use of expert judgments is to characterize parameter uncertainties with probability distributions that are elicited by an analyst from a technical expert in a detailed interview, using all available data and models to inform the judgments (Spetzler and von Holstein, 1975). This approach was originally developed within decision analysis as a practical application of a subjectivist view of probability (Raiffa, 1968). Morgan and Henrion (1990) and MacNamee and Celona (1990) provide reviews of the conceptual and practical concerns in using this approach, as well as examples of materials prepared to help structure these assessments. Recent published examples of probabilities assessed from experts include work on uncertainties regarding the consequences of explosions in nuclear containment facilities (Keeney and von Winterfeldt, 1991), probabilities of different aspects of climate change (Morgan and Keith, 1995), probabilities for exposure assessments (Walker *et al.*, 2003) probabilities regarding resource management issues (Cleaves, 1994; McDaniels, 1995), probabilities regarding adverse health effects from sulfur air pollution (Morgan *et al.*, 2002), and several others. In sum, expert judgments elicited for specific, well-defined variables have become a legitimate and increasingly important source of synthesis perspectives that serve as data for analysis. While these assessments are only occasionally a sufficient substitute for primary data collection, they are frequently complementary to more direct research efforts.

The need for informed judgments from scientists and other technical specialists becomes even more pronounced when attempting to make comparisons and set priorities over a wide range of potential hazards or risk management decision contexts. This kind of risk assessment task has become more important as regulatory bodies seek guidance as to the most significant sources of risk among the many hazards they regulate (Finkel and Golding, 1996). The need to make strategic level assessments over a wide range of potential hazards necessarily means that a greater reliance on judgments is needed, in the absence of detailed, location-specific data. Yet the methods for eliciting probabilities from experts discussed above are generally too detailed and specific in their focus to be applicable for these kinds of broader comparative assessments. Hence new, relatively less demanding methods for eliciting judgments from interested stakeholders have been developed and tested over the last decade, as a basis for stakeholder involvement in risk ranking activities (Morgan *et al.*, 2002).

Here we develop and apply an approach for use by experienced specialists with scientific understanding of salmon aquaculture, its component processes and its impacts. The approach is informed by the concepts and applied experience with probability elicitation (e.g., Morgan and Henrion, 1990), by the methods for assessing risk perceptions of a wide range of technologies from laypeople with psychometric techniques (Slovic, 1987; 2000), and by the experience with risk ranking efforts, again primarily with laypeople. We need a method that is workable, sensible, and balances the specificity normally sought by experts with the need to make broad comparative assessments over a variety of aspects of the salmon farming process. Criteria used to design the method, and details of the survey process and instruments, are discussed in the next section.

Methods

Participants

Aside from the methodological guidance on eliciting probabilities noted above, there are no standardized protocols for selection of experts, or design of survey instruments for eliciting judgments from them. We recruited participants with a "snowball" sampling technique; we began by inviting noted natural scientists with expertise in key aspects of salmon aquaculture in British Columbia to participate in this assessment. We also sought their suggestions for other potential participants, and so forth. In addition, we also sought participants through presentations about this survey at scientific conferences or workshops regarding salmon aquaculture. The final tally of participants in this study stands at 50 scientists actively engaged in (or providing support to) research related to salmon aquaculture or its impacts, or who require an understanding of the science base associated with aquaculture in their employment. Responses were kept anonymous, with participants asked to provide information only regarding gender, primary scientific discipline to which they associate themselves and approximate number of years experience relevant to aquaculture. Of these scientific experts, 38 were men and 11 were women and one respondent preferred not to have their gender identified. These respondents included 20 employees of federal or provincial government and 30 individuals, academics or employees in the private sector. Four participants were students currently engaged in fisheries or aquaculture-related graduate studies at Canadian universities. The disciplines represented included fisheries biologists, environmental chemists, toxicologists, veterinarians, marine ecologists, fish physiologists, and habitat ecologists. Two experts declined participation in the survey but provided comments regarding their decisions not to complete the questionnaire. Surveys were conducted in the form of 29 personal interviews or via electronic submission.[1] Table 1 describes the participants of the study

[1] The basic results were similar between the two groups of respondents to the survey in personal interviews or electronic format.

Table 1. Participant profile

	Participants by Sector					
	Government (Federal)	Government (Provincial/State)	Consultants	Industry	Academia	Students
Women	2	0	2	3	2	2
Men	10	8	6	9	3	2
Average years experience	24.4	15	20.5	12.8	28.7	3.8

and the average number of years of professional experience and training related to aquaculture.

Questionnaire Development

A key first step in designing such a survey is to ensure that the framing of the judgment tasks generally reflects how the participants think about the issues at hand. It is also important that the judgments required are clearly defined and well-understood by the participants. First, a set of definitions was developed to ensure a consistent understanding of the concepts and practices addressed in the survey questionnaire. Appendix A provides some examples of key definitions, which were part of the information provided to participants. Next, a comprehensive literature review was conducted to identify activities, events or processes within salmon aquaculture that are potential sources or pathways for ecological risks associated with the overall process. This preliminary list was grouped according to potential biophysical, ecological or chemical interactions. The set of potential activities or practices was reviewed with an advisory group of three scientists from academia, government and the private sector. This group helped ensure that there were no omissions or falsely identified sources of risk prior to the survey pre-test. This list was also compared to risks reported in media to confirm the selected issues of concern represented the risks that were the most frequently described in both realms of discourse.

The scales and items represented in the survey questions were then selected to address a meaningful scope of concerns in sufficient depth without excessive time commitment on the part of respondents to complete the survey. A series of influence diagrams were constructed to map different dimensions of concern within the scientific community regarding the potential risks to health or survival of wild salmon stocks. Figure 1 illustrates an example of the influence diagrams used for narrowing the scope of the three contexts selected for the questionnaire questions.

Three assessment contexts were chosen based on this initial consultation with qualified experts. The first assessment context focused on local impacts

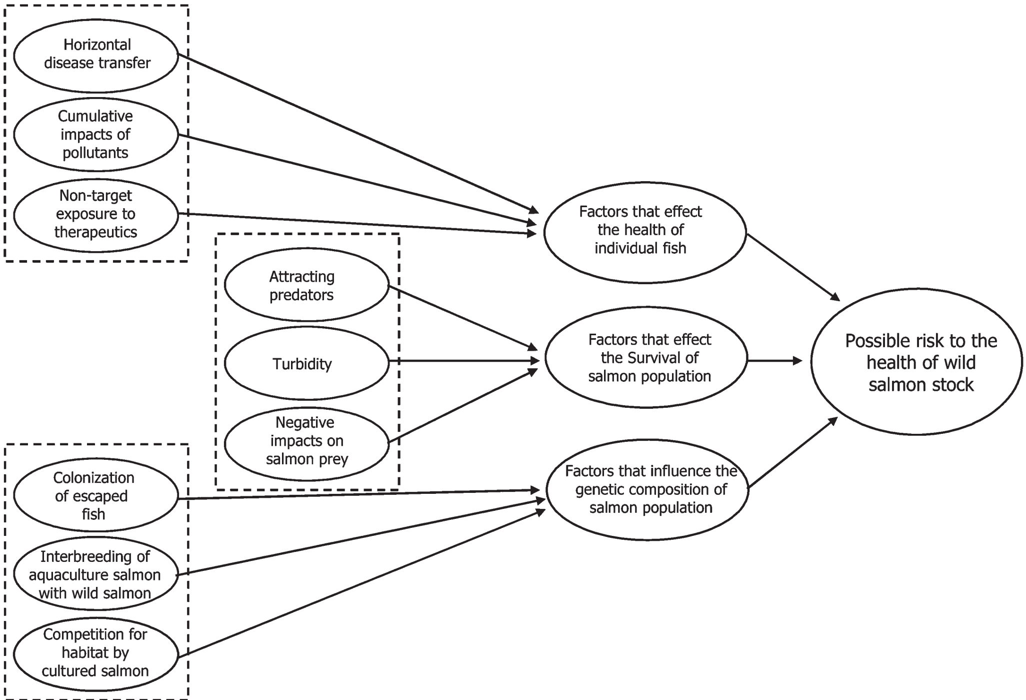

Figure 1. Influence diagram. Arrows indicate trends in contributors that could impact various scales of influence of selected risks. Triads of influences grouped by dotted lines indicate groups of risk contributors that impact individuals and populations.

on wild salmon stocks within 30m of open cultured salmon fish pens. This definition of "local" was based on the zone of impact described in provincial government documents relating to aquaculture (BC Environmental Assessment Office, 1997). The second context requested judgments of potential local impacts on organisms other than salmonids within 30 m of open cultured salmon fish pens. These organisms include, but are not limited to, other fish species, birds, large mammals, crustaceans, mollusks, invertebrates, zooplankton, phytoplankton and bacteria. The third context asked for judgments about regional impacts on wild salmon stocks where regional was defined as the whole British Columbia coastal zone considered greater than 1 km from fish pens.[2] Respondents were asked to provide

[2] The original pre-test survey questionnaire asked experts to provide judgments for zones of influence less than 30 m from net pens, between 30 m and 1 km of net pens and greater than 1 km. Experts suggested that 'local' impacts would be best described by less than 30 m from net pens and 'distant' impacts would be described by greater than 1km from net pens. It was thus decided to limit expert judgments to local and distant zones of influence rather than include an intermediary transition zone which would add a greater degree of complexity to the assessments.

judgments based on current aquaculture regulations, technology and practices in British Columbia, and addressed possible impacts occurring within the next five years. Table 2 summarizes the risks selected for the survey questionnaire in the three chosen contexts.

The table shows that each context examined in the survey questionnaire involved between eight to twelve activities, events or processes that could occur in salmon aquaculture production. The questions for each one of these activities, events or processes were in turn divided into six sub-questions, which asked respondents to rate their judgment based on seven-point scales which are frequently used in judgment elicitation contexts (e.g. Slovic, 1995). These sub-questions can be viewed as comprising two major parts (Figure 2). One part consisted of the elements of a judgment-based risk assessment, in that it asked for judgments about the likelihood of the activity or event occurring, the likelihood of adverse consequences if the event occurred, and the potential severity of those consequences. The second part consisted of a series of sub-questions intended to clarify participant views on how well the issues are understood by science, their own knowledge of the issue, and their confidence in their judgments.

The final question of the survey asked for the expert's prediction of whether their assessment of the risks outlined would change if the current production levels were to double.

The questionnaire was pre-tested with nine scientific experts from government to ensure the questions made sense to the participants and also ensure that the selected risks were described in a clear and appropriate manner consistent with the objectives of the study. Suggestions from the pre-test participants were used to improve the comprehensiveness and clarity of the language and presentation of the survey questionnaire. Results of the pre-test were not included in the results presented here.

Research Questions Guiding the Questionnaire Design

One specific research question that guided both the design (and data analysis discussed later) was to determine whether there were statistically significant differences in the mean views of the participants regarding the potential activities, events or processes that may create risks in the three contexts described earlier. In other words, are some of the activities or events clearly seen to be more risky than others, on average? Another research question was to examine if the ratings of uncertainty and variability among the expert judgments were consistent with their judgments of collective scientific knowledge of the risks. A third question guiding the design was to determine whether experts perceived a difference between the risk consequences and their severity at local and regional scales. A fourth guiding question was to compare expert judgments of risks to wild salmon health with the expert judgments of effects on other ecosystem species at the local scale. Finally, because other researchers had clearly demonstrated that different assumptions, conceptions and values underlie different expert views within disciplines about chemical

Table 2. Possible risks of current aquaculture practices

Local Effects on Wild Salmon (less than 30m from netpens)
If wild salmon consumed waste feed from cultured salmon, would this pose a risk to wild salmon health?
If wild salmon consumed waste feces from cultured salmon, would this pose a risk to wild salmon health?
Is there a risk to wild salmon health from exposure to therapeutants administered to cultured salmon?
Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?
Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?
Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?
Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?
Local Effects on Other Ecosystem Species (less than 30m from netpens)
Would consumption of waste feed/feces by species other than salmon, pose a risk to these organisms health?
Is there a risk to other organisms health from exposure to therapeutants administered to cultured salmon?
Could changes in local water quality near netpens of cultured salmon be a potential risk to other organism's health?
Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to other organism's health?
Would the spread of disease from confined fish to wild salmon pose a risk to other organism's health?
If populations of benthic species changed near salmon netpens, would this pose a risk to organisms other than salmonids?
If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to organisms other than salmonids?
Does presence of predators near netpens pose a risk to the health of organisms other than salmonids?
Could occupational exposure to chemicals used in aquaculture husbandry pose a risk to human health?
Regional Effects on Wild Salmon (greater than 30m from netpens)
Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?
Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?
Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?
Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?
If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to wild salmon health?
If cultured salmon escaped from netpens, would competition for food or habitat pose a risk to wild salmon health?
If cultured salmon escaped from netpens, would changes in genetic composition of salmonids pose a risk to wild salmon health?

Is there a risk to wild salmon health from *exposure to the therapeutants* administered to cultured salmon?

Likelihood of event	Highly unlikely (10% chance or lower)				very likely (90% chance or greater)		
What is the chance of the trigger event for this to occur?	1	2	3	4	5	6	7
Likelihood of consequence	Highly unlikely (10% chance or lower)				very likely (90% chance or greater)		
Given that the event occurs, what is the chance that the consequence would impair the health of wild salmon?	1	2	3	4	5	6	7
Severity	Minimal (little impact on wild stock)				catastrophic (potential to collapse wild stock)		
If this impact occurred, how severe could it be?	1	2	3	4	5	6	7
Scientific Understanding	Poorly understood				well understood		
How well do you think this issue is understood by science and the relevant scientific communities?	1	2	3	4	5	6	7
Your Knowledge	Not very knowledgeable				highly knowledgeable		
What is your self assessment of **your** scientific knowledge about this issue?	1	2	3	4	5	6	7
Your Certainty	Not certain at all				highly certain		
How certain are you **personally** about the judgments you have provided in this question?	1	2	3	4	5	6	7

Figure 2. Example survey question

risks (Kraus *et al.*, 1992), we were interested in seeing if there were differences in risk judgments depending on the employment of the participants.

Results

Assessing the Range of Expert Judgments

Descriptive statistics for the survey results are presented in Appendix B. Overall, the results indicate that current aquaculture practices posed some risk to the health of wild salmon stocks and the health of local ecosystem species other than salmonids. All respondents indicated that the events or activities, termed 'risk items' that serve as the triggering events in the survey questionnaire could occur, with the lowest mean of the likelihood of triggering events being 2.12 on the seven-point scale. Confidence intervals of the means calculated for each component of the questions were relatively broad, indicating that there was considerable uncertainty and variability in views reflected in the judgments of the experts.

Statistical Methods Used to Analyse Expert Judgment Data

In order to construct a consistent ranking scheme to describe the data, two indices were created using the means of scores derived from the seven point scale. These two indices formed part of the quantitative basis for ranking of the judgments. The first one is termed the 'riskiness index', **R**. The riskiness R_{ij} of any risk item i for one of the three assessment contexts j is calculated:

$$R_{ij} = L(E_{ij}) \cdot L(C_{ij}|E_{ij}) \cdot (S_{ij}|C_{ij}, E_{ij}),$$

where $L(E_{ij})$ is the likelihood of the triggering event (e.g. 3.40 in Question 1 in Appendix B); $L(C_{ij} \mid E_{ij})$ is the likelihood of the event causing adverse consequences from risk item i in assessment context j given the triggering event has occurred (e.g. 2.42 in Question 1 in Appendix B); and S_{ij} is the severity of the adverse consequences from risk item i in assessment context j, conditional on the triggering event ij having occurred and adverse consequences from ij having also occurred (e.g. 2.14 in Question 1 in Appendix B) Given the seven point scale from which mean scores were calculated, the minimum possible value of R for any i is 1 while the maximum possible R for any i is 343 (7·7·7).

The second index is termed the 'uncertainty index', **U**. The uncertainty U_{ij} associated with judgments regarding any risk item i and its consequences in assessment context, j, is calculated as a product of three terms:

$$U_{ij} = SK_{ij} \cdot PK_{ij} \cdot PC_{ij},$$

where SK refers to judged scientific knowledge regarding risk item i in an assessment context j, PK refers to personal knowledge of i in j, and PC refers to personal confidence regarding judgments concerned with i in j. The extrema of the uncertainty indices were the same as those for the riskiness indices (minimum=1; maximum=343)

Using the statistical package SPSS version 11.5, a repeated measures analysis of variance (ANOVA) was conducted for the individual components of each question and the riskiness and uncertainty indices. The means for individual responses and for calculated indices were compared using the

Tukey HSD analyses of variance technique. The Mann-Whitney U test was used to rank responses and paired T-tests were used to compare the means of the ratings.

Discussion

Prioritizing the Identified Risks

Table 3 compares how respondents ranked the potential risks for all three assessment contexts based on the calculated riskiness index, **R**. There are statistically significant differences among the expert judgments of potential risks to wild salmon stocks from the set of activities and events, based on comparison of the means of the riskiness indices, using the Mann-Whitney U test. For example, the potential risk of disease spread from confined salmon to wild salmon or other ecosystem species appeared within the top four risks in all three contexts. The ranking of the riskiness index was the highest for effects on wild salmon health at both the local and regional scales.

Table 4 describes the ranking of the activities and events for each context, using the uncertainty index, **U** calculated from the expert judgments of the potential risks. Experts identified changes in local water quality to be among the top three potential risks to both wild salmon stocks and other ecosystem species but they judged the likelihood of the consequence being a risk and the severity of the impact to be less for wild salmon than for other ecosystem organisms (riskiness index for wild salmon at the local scale=31.2; riskiness index for other ecosystem species at the local scale=89.6). A similar result was observed for the potential risk associated with exposure to therapeutants that experts ranked within the top four risks to both wild salmon and other ecosystem species at the local scale (riskiness index for wild salmon at the local scale=24.6; riskiness index for other ecosystem species at the local scale=71.3). The knowledge associated with changes in water quality at the local scale was also characterized by the highest uncertainty index for both effects on wild salmon stock and on other ecosystem species (uncertainty index for wild salmon=101.4; uncertainty index for other ecosystem species=100.8).

The correlation between the calculated riskiness and uncertainty indices for each of the questions is illustrated in Figure 3. The spread of disease from confined fish to wild salmon was identified as an important risk for which experts believed uncertainty in the scientific knowledge was comparably high for both the local and regional contexts. Some events, such as extended periods of artificial lighting, were suggested to pose less risk to wild salmon than to other ecosystem species at the local scale although uncertainty indices for both groups indicated similar trends in gaps in scientific knowledge. Changes in local water quality were cited as important risks to both wild salmon and other ecosystem species for which uncertainty in scientific understanding is high.

Table 3. Risks of current aquaculture practices ranked by 'riskiness index'

Local Effects on Wild Salmon (less than 30m from netpens)	*Riskiness Index*
1. Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?	95.5
2. Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?	52.4
3. Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?	31.2
4. Is there a risk to wild salmon health from exposure to therapeutants administered to cultured salmon?	24.6
5. If wild salmon consumed waste feces from cultured salmon, would this pose a risk to wild salmon health?	18.6
6. If wild salmon consumed waste feed from cultured salmon, would this pose a risk to wild salmon health?	17.6
7. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?	16.4
Local Effects on Other Ecosystem Species (less than 30m from netpens)	
1. Could changes in local water quality near netpens of cultured salmon be a potential risk to other organism's health?	89.6
2. If populations of benthic species changed near salmon netpens, would this pose a risk to organisms other than salmonids?	80.2
3. Is there a risk to other organisms health from exposure to therapeutants administered to cultured salmon?	71.3
4. Would the spread of disease from confined fish to wild salmon pose a risk to other organism's health?	65.9
5. Would consumption of waste feed/feces by species other than salmon, pose a risk to these organisms health?	65.6
6. Does presence of predators near netpens pose a risk to the health of organisms other than salmonids?	57.0
7. Could occupational exposure to chemicals used in aquaculture husbandry pose a risk to human health?	52.2
8. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to other organism's health?	49.0
9. If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to organisms other than salmonids?	43.4
Regional Effects on Wild Salmon (greater than 30m from netpens)	
1. Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?	69.6
2. If cultured salmon escaped from netpens, would changes in genetic composition of salmonids pose a risk to wild salmon health?	51.3
3. If cultured salmon escaped from netpens, would competition for food or habitat pose a risk to wild salmon health?	50.7
4. Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?	36.2

Table 3. (*Continued*)

Local Effects on Wild Salmon (less than 30m from netpens)	*Riskiness Index*
5. Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?	24.2
6. If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to wild salmon health?	19.6
7. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?	12.8

Table 4. Uncertainty associated with risks of current aquaculture practices ranked by 'uncertainty index'

Local Effects on Wild Salmon (less than 30m from netpens)	*Uncertainty Index*
1. Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?	101.4
2. Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?	91.9
3. If wild salmon consumed waste feed from cultured salmon, would this pose a risk to wild salmon health?	77.7
4. Is there a risk to wild salmon health from exposure to therapeutants administered to cultured salmon?	67.9
5. Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?	67.2
6. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?	58.9
7. If wild salmon consumed waste feces from cultured salmon, would this pose a risk to wild salmon health?	55.3
Local Effects on Other Ecosystem Species (less than 30m from netpens)	
1. Could changes in local water quality near netpens of cultured salmon be a potential risk to other organism's health?	100.8
2. Is there a risk to other organisms health from exposure to therapeutants administered to cultured salmon?	79.2
3. If populations of benthic species changed near salmon netpens, would this pose a risk to organisms other than salmonids?	79.2
4. Would consumption of waste feed/feces by species other than salmon, pose a risk to these organisms health?	77.0
5. Could occupational exposure to chemicals used in aquaculture husbandry pose a risk to human health?	71.9
6. Does presence of predators near netpens pose a risk to the health of organisms other than salmonids?	55.8

Table 4. (*Continued*)

Local Effects on Wild Salmon (less than 30m from netpens)	*Uncertainty Index*
7. Would the spread of disease from confined fish to wild salmon pose a risk to other organism's health?	55.1
8. If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to organisms other than salmonids?	54.2
9. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to other organism's health?	49.0
Regional Effects on Wild Salmon (greater than 30m from netpens)	
1. If cultured salmon escaped from netpens, would competition for food or habitat pose a risk to wild salmon health?	101.6
2. If cultured salmon escaped from netpens, would changes in genetic composition of salmonids pose a risk to wild salmon health?	89.9
3. Could changes in local water quality near netpens of cultured salmon be a potential risk to wild salmon health?	77.9
4. Would the spread of disease from confined fish to wild salmon pose a risk to wild salmon health?	65.1
5. Do cumulative effects of existing pollutants and contaminants from aquaculture facilities pose an additional risk to wild salmon health?	65.1
6. If populations of phytoplankton or zooplankton species changed near salmon netpens, would this pose a risk to wild salmon health?	60.8
7. Do extended periods of artificial lighting of netpens of cultured salmon pose a risk to wild salmon health?	56.9

Comparing Potential Risks Between Local and Regional Scales

Because coastal zone decisions regarding impacts of salmon aquaculture on wild salmon stocks must consider risk differences between scales, experts were asked to provide judgments about risks within 30 m of confined netpens as well as risks considered for a greater geographic area of coast. Expert judgments of potential risks to wild salmon stock were compared using paired T-tests of the individual means for the six measures included in each question. The difference between the means of the judgment ratings of likelihood of spread of disease occurring and likelihood that this would have an impact on wild health between the local scale were significantly higher than at the regional scale ($p=0.05$). However, there was no significant difference between judgments of severity of the impact of potential disease transfer. For judgments of both changes in water quality near to netpen sites and of their cumulative effects with contaminants from other pollution sources, likelihood of event, likelihood of a risk consequence and the severity of impacts were statistically significantly higher at the local scale than at the regional scale ($p=0.05$).

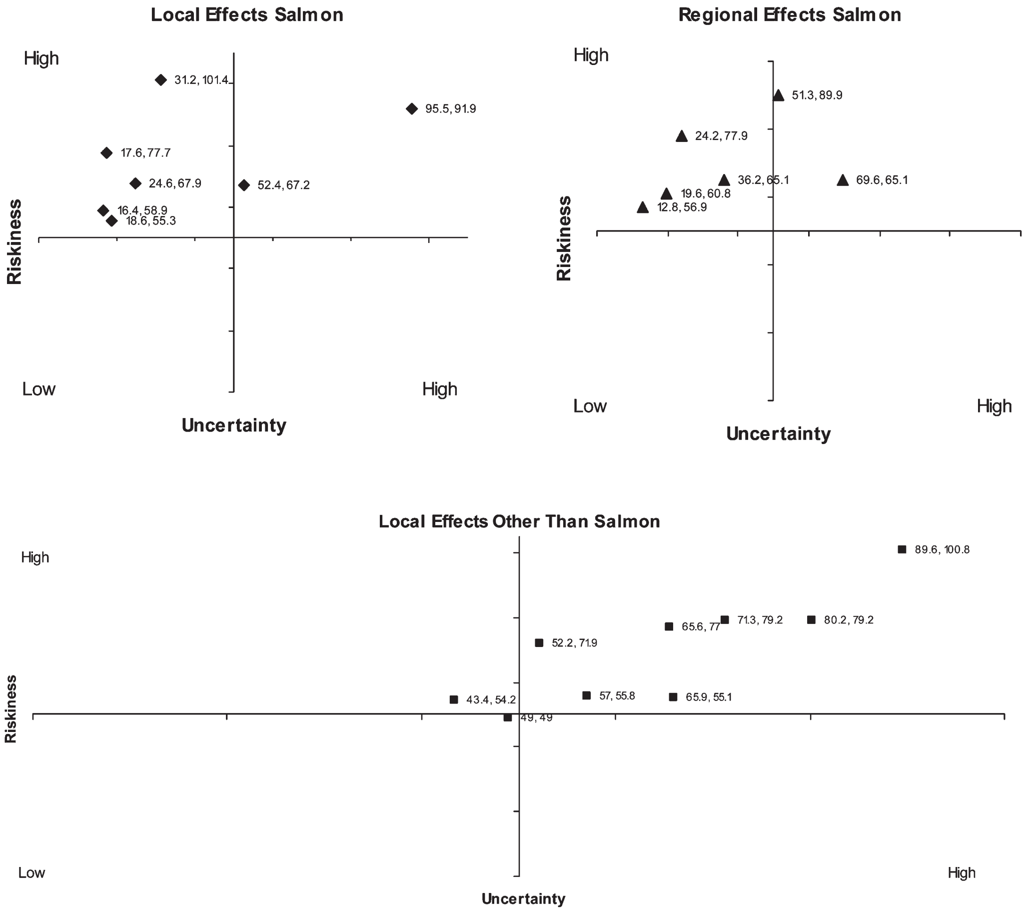

Figure 3. Correlation between riskiness and uncertainty

Comparing Individual Assessment of Knowledge with Collective Scientific Knowledge

One of the research questions of this study was to determine whether there was a discernable difference between the perceived collective scientific knowledge and the individual assessment of expert knowledge of particular risks. Despite there being no statistically significant difference between the means of expert judgments of collective scientific knowledge and individual knowledge, comparison of frequency histograms defined different distributions of responses. Some examples of frequency histograms for risks that experts consistently ranked highly are illustrated in Appendix C. This distribution of responses illustrates differences in values and assumptions among scientists upon which individual risk judgments are based.

Comparing Expert Judgments Between Sectors

Previous research (Kraus *et al.*, 1992) demonstrated a divergence between basic concepts, assumptions and interpretations among scientists working in industry, government and academia. Using decision theory, Giere (1988) modeled scientific judgments by accounting for scientists interests as one of the parameters in the decision matrix. The present study compared judgments about potential risks of current aquaculture practices made by scientists working in government with those scientists who did not work for government.

The sample of experts was divided into two primary sectors. Scientists who were affiliated with provincial, federal or state government from Canada, the United States or Chile were included in the group defined as "government" (n=20). All other non-government experts who were associated with private industry, consulting or academia from Canada, the United States or Chile comprised the other category (n=30). Pair-wise T-tests of the means of the riskiness index, averaged over all risks in each context revealed that government experts judged riskiness to be statistically significantly higher than non-government experts ($p=0.05$). However, the same statistical comparison made for the means of the uncertainty indices over all risks in each scenario demonstrated the opposite trend: uncertainty index was statistically significantly higher for other non-government experts. Table 5 summarizes the comparison between sectors of riskiness and uncertainty indices. Hence, government employees perceived the risks as higher, and the uncertainties lower, than did their counterparts who work in industry, consulting or academia, on average.

Comments from Respondents

A number of experts provided detailed comments about the questionnaire. Some respondents suggested that there had been insufficient research done on several of the identified risks for experts to allow valid judgments. Other experts provided comments which contradicted these points by noting that perfect information is never achievable and thus risk management decisions must be made using the best available scientific evidence. Some experts expressed concern that some risks were not addressed, such as the physical

Table 5. Sector comparison of participants

	Individual Judgment Parameter						
	Riskiness	Uncertainty	Event	Consequence	Severity	Understanding	Knowledge
Government	74.2	76.7	4.3	3.7	3.4	3.8	3.5
Others	62.2	105.5	3.7	3.2	3.0	4.4	4.2

effects of salmon in netpens consuming the wild salmon that stray into their pens. We discussed these comments with technical experts who felt that omission of this risk did not bring the other results into question. Two experts declined participation in this study; they justified their choice by commenting that some questions were too general and did not allow for answers to take into account the complexities of quantitative risk assessment. We discussed these concerns with them, and pointed out the purpose here was a comparison across several sources of risk, not a detailed quantitative assessment of any one risk.

Survey respondents indicated that some questions could have better addressed the difference between salmon "health" and salmon survival. This observation was most frequent for the question that dealt with extended photoperiods due to artificial lighting of salmon netpens. Some experts identified the health benefit for both wild salmon that may be near netpens and other organisms when prey items benefited from extended period of localized light, while other experts identified the predation potential on salmon (both wild and contained) as increasing risk of lethality not health impact. Other experts said the likelihood of wild salmon changing their natural diurnal cycle and preferentially traveling near lighted netpens at night was very low.

Some experts expressed concern that better known risk pathways were overemphasized in the survey questionnaire to the exclusion of less researched issues. One such example was the possible impact of fouling organisms on netpens on other ecosystem species suspended in the water column. The impacts on water quality of the use of anti-fouling paints was specifically identified as a competing risk to presence of excessive numbers of fouling organisms altering local plankton community structure. Although the protocol used in this study to record how different experts view potential risks associated with current aquaculture practices was designed to include the widest possible range of risks as identified in the literature, many experts could conceive of other potential contributing risks that were not explicitly stated in the questionnaire.

The intent of the survey was described as a means of gaining a broad overview of the views of different experts on the relative riskiness of a range of events or practices associated with aquaculture but some experts interpreted it as representing a risk assessment of selected trigger events. Every attempt was made in the construction of the survey questions to balance sufficient specificity with the need to cover a broad range of trigger events and possible consequences of current aquaculture practices. Some experts described the events included in the question as being too specific while other experts felt that the questions were too general to properly characterize any given risk.

Encouraging comments about the survey design were provided by many participants who thought it was a worthwhile way to characterize the relative risks of various aspects of the salmon aquaculture production process. While being explicit about judgments can sometimes be awkward for technical experts, the participants generally indicated the structure and content of the survey was sensible and thought provoking.

Implications of Survey Findings

While this paper is largely focused on methods, the findings presented here should be of direct relevance in two contexts. First, they should be helpful in setting priorities for new research regarding salmon aquaculture. Second, the results should be helpful in calibrating and understanding uncertainties embedded within assessments of the impacts of aquaculture facilities and operating practices. Both are discussed below.

A major reason for collecting expert judgments from scientists regarding any risk is to help set priorities for future research to address situations which involve the greatest knowledge gaps and the highest potential impacts. In Canada, salmon aquaculture on the British Columbia coast has received considerable attention in both the scientific community and the general public for several years. On-going research seeks to provide a sound scientific basis for decisions that foster sustainable human and ecosystem health.

In this study, the spread of disease spread between confined and wild salmon was identified as an important potential risk to salmon and other ecosystem species that required further research. To that end, several new studies to investigate impacts and transfer of sea lice, viral hemorrhagic septicemia and infectious hematopoietic virus have been conducted in Canada and in Europe over the last three years (CDFO, 2006). Changes to water quality near netpens were also identified by most scientists as a potential risk common to salmon and ecosystem health. New studies regarding water quality impacts in the marine environment are an important focus of many research groups worldwide with emphasis appearing to be placed on combined effects of pollutants on ecosystems rather than single source dependant impacts.

Results of the survey suggest that collective scientific knowledge regarding risks associated with salmon aquaculture share similar uncertainties with many environmental concerns. Scientific experts stressed the importance of situating judgments related to risks in broader ecological contexts and pointed towards integrating assessments of impacts with issues such as climate change, isolated environmental events and emerging pollutants in shaping policy decisions.

Finally, the degree to which scientists in the survey have differing levels of confidence about their knowledge, and the understanding of science about the impacts of aquaculture generally, should indicate contexts in which impacts of aquaculture facilities or practices involve greater uncertainties. These uncertainties in turn should suggest policy measures that reflect this uncertainty, and the need to manage these risks in effective ways.

Conclusion

This study demonstrated that wide variability exists among the judgments of members of only the scientific community when asked about specific risks linked to salmon aquaculture processes. The opinions of scientific experts did not appear to be more certain than the collective scientific knowledge about specific risks (based on the comparison of the scientific understanding and the uncertainty indices). Scientific judgments about potential risks and associated uncertainty varied between sectors. Identified risks do not appear to have the same impact on wild salmon health as other ecosystem species at the local scale - experts judged the potential risk to other ecosystem species higher than for wild salmon. Some risks were judged as having similar impacts at the local and the regional scales although the severity of some of these risks was assessed as being greater in the area immediately surrounding confined netpens of salmon farms.

Based on our evaluation of the judgments for this study, scientific experts suggested that the highest priority among the areas in which more knowledge is needed is the spread of disease between farmed and wild stock of salmon is the potential risk at the local and the regional scale. Risks associated with changes in water quality near to netpens and the cumulative effects of pollutants from aquaculture and other sources are also important issues where further research is needed. Scientific experts surveyed in this study identified risks associated with escaped farmed salmon as requiring further research before coastal zone risk management decisions can be made.

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References

British Columbia Environmental Assessment Office (1997) *Salmon Aquaculture Review*. Available at http://www.eao.gov.bc.ca/project/aquaculture/salmon/report/final (accessed 5 June 2002).

Canadian Department of Fisheries and Oceans (2006) http://www.pac.dfo-mpo.gc.ca/sci/aqua/AQ/aqupdate_e.htm (accessed 18 May 2006).

Cleaves, D. A. (1994) Assessing uncertainty in expert judgments about natural resources, *US Department of Agriculture General Technical Report*, so-1-10.

Ellis, D. W. (1996) *Net Loss – The Salmon Netcage Industry in British Columbia*, Report prepared for The David Suzuki Foundation, Vancouver, BC, Canada.

Finkel, A. and Golding, D. (1996) *Worst Things First? The Debate Over Risk-based National Environmental Policies* (Washington, DC: Resources for the Future).

Food and Agricultural Organization of the United Nations (2003) Fisheries Department Statistical Database., Retrieved from FISHSTAT Plus universal software for fishery statistical time series: Aquaculture Production and Values Datasets.

Giere, R. (1988) *Explaining Science: A Cognitive Approach* (Chicago, IL: University of Chicago Press).

Keeney, R. and von Winterfeldt, D. (1989) On the uses of expert judgment on complex technical problems, *IEEE Transactions on Engineering Management*, 36, pp. 83–86.

Keeney, R. and von Winterfeldt, D. (1991) Eliciting probabilities from experts in complex technical problems, *IEEE Transactions on Engineering Management*, 38, pp. 191–201.

Keeney, R. L. (1992) *Value-Focused Thinking – A Path to Creative Decision-making* (Cambridge, MA: Harvard University Press).

Kraus, N., Malmofors, T. and Slovic, P. (1992) Intuitive toxicology: expert and lay judgments of chemical risks, *Risk Analysis*, 12, pp. 215–232.

Kuhn, T. (1962) *The Structure of Scientific Revolutions* (Chicago, IL: University of Chicago Press).

Longino, H. (1990) *Science as Social Knowledge: Values & Objectivity in Scientific Inquiry* (Princeton, NJ: Princeton University Press).

MacNamee, P. and Celona, J. (1990) *Decision Analysis with Supertree*, 2nd edn (California: The Scientific Press).

McDaniels, T. L. and Small, M. (Eds) (2003) *Risk Analysis & Society – An Interdisciplinary Characterization of the Field* (Cambridge, UK: Cambridge University Press).

McDaniels, T. L. (2000) Creating and using objectives for ecological risk assessment and management, *Environmental Science & Policy*, 3, pp. 299–304.

McDaniels, T. L., Gregory, R. S. and Fields, D. (1999) Democratizing risk management: successful public involvement in local water management decisions, *Risk Analysis*, 19, pp. 497–510.

McDaniels, T. L. (1995) Using judgment in resource management: A multiple objective analysis of fisheries management decisions, *Operations Research*, 43, pp. 415–426.

Morgan, M. G., Florig, H., DeKay, M. and Fischbeck, P. (2000) Categorizing risks for risk ranking, *Risk Analysis*, 20, pp. 49–58.

Morgan, M. G., Fischhoff, B., Bostrom, A. and Atman, C. (2002) *Risk Communication – A Mental Models Approach* (Cambridge, UK: Cambridge University Press).

Morgan, M. G. and Henrion, M. (1990) *Uncertainty – A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Cambridge, UK: Cambridge University Press).

Morgan, M. G. and Keith, D. W. (1995) Subjective judgments by climate experts, *Environmental Science & Technology*, 29, pp. A468–A476.

Naylor, R. L., Goldburg, R., Primavera, J. H., Kautsky, N., Beveridge, M. C. M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. and Troell, M. (2000) Effect of aquaculture on world fish supplies, *Nature*, 405, pp. 1017–1024.

Raiffa, H. (1968) *Decision Analysis* (Reading, MA: Addison-Wesley Publishing).

Slovic, P. (1987) Perception of risk, *Science*, 123, pp. 280–285.

Slovic, P. (2000) *Risk Perception* (Cambridge, UK: Cambridge University Press).

Spetzler, C. S. and von Holstein, C-A. S. (1975) Probability encoding in decision analysis, *Management Science*, 22(3), pp. 340–358.

Walker, K. D., Evans, J. S. and MacIntosh, D. (2001) Use of expert judgment in exposure assessment part 1. Characterization of personal exposure to benzene, *J. Exposure Anal. Environ. Epidemiol*, 11, pp. 308–322.

Walker, K. D., Catalano, P., Hammitt, J. K. and Evans, J. S. (2003) Use of expert judgment in exposure assessment part 2. Calibration of experts judgments about personal exposures to benzene, *J. Exposure Anal. Environ. Epidemiol*, 13, pp. 1–16.

Appendix A: Definitions Used for Survey Questions

Aquaculture – Breeding, rearing and growing fish or other marine organisms for consumption by humans.

Benefit – Something that has a positive effect on the overall health or well-being of an organism.

Closed Marine Netpen – A closed contained system for holding cultured salmon populations in a marine based environment. Not terrestrial closed systems

Certainty – For the purposes of this study, certainty refers to your confidence in your judgments regarding likelihood and severity provided in a given question.

Contaminant – A foreign substance (chemical or biological) that is found in concentrations above natural background levels and has been scientifically demonstrated to have an adverse effect on organisms present in marine, aquatic, atmospheric or benthic ecosystems.

Cultured Salmon – Members of the species *Onchorhyncus* and *Salmo salar* held in confined netpens.

Cumulative Effects – The combined additive, antagonistic or synergistic effects that result from the chemical and physical interaction of two or more contaminant sources.

Ecosystem – The environmental system composed of all biological, ecological, chemical and physical processes that supports life.

Effect – Any change to the normal function of life processes of metabolism, growth, immunocompetence, reproduction in any ecosystem organism. For the purposes of discussing risk these effects are taken as adverse effects.

Event – Actions that result from naturally occurring phenomena, human activities or the use of current technology practices.

Hazard – Any natural or anthropogenic event that may cause adverse effects on the overall health and well-being of organisms.

Health – The soundness, state of well-being and vigor of organisms free of defect or disease.

Impact on Health – Any change that causes mortality to organisms, reproductive impairment or reduction in growth rate that is different in statistically significantly terms from historical evidence of the survival and growth of natural control populations of these organisms.

Interaction – Changes in natural ecosystem equilibrium that may not be observable from normal conditions without the presence of a confined netpen.

Knowledge – For the purposes of this study, knowledge refers to your knowledge about the likelihood and degree of severity of a possible risk occurring.

Likelihood – The chance that a particular event could occur given the conditions outlined.

Local Context– The region less than 30m surrounding any confined netpen facility.

Non-native Species – Any exotic species of fish or organism which is not naturally found in British Columbia ecosystems.

Open Marine Netpen – A marine net enclosure with ambient flow through sea water above an unprotected benthic layer.

Predator – Any member of the next trophic level above any species that uses these species as food source.

Regional – The entire coastal zone of the province of British Columbia – anywhere greater than three km from any confined population of salmonids.

Risk – The uncertain potential for any harm to the health or well-being of organisms.

Severity – If the occurrence of a particular event is likely, how severe would be the consequences.

Therapeutic – A natural or manmade chemical used to prevent or treat conditions that compromise the overall health or well-being of salmonids.

Turbidity – Presence of particulate matter in the water column that reduces Secchi depth to any value different from local natural levels.

Wild Salmon – All members of the species *Oncorhynchus kisutch, Oncorhynchus keta, Oncorhynchus nerka, Oncorhynchus gorbuschka, Oncorhynchus tshawytscha or Oncorhynchus mykiss* native to the British Columbia coastal zone.

Appendix B: Summary of Statistics for Survey Questions

Question 1	Consumed waste feed from cultured salmon					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.40	2.42	2.14	4.10	4.10	4.62
Std. Dev.	1.95	1.63	1.44	1.74	1.69	1.58
Confidence Interval	0.56	0.47	0.42	0.50	0.49	0.46
Question 2	Consumed waste feces from cultured salmon					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	2.22	3.04	2.76	3.56	3.70	4.20
Std. Dev.	1.39	1.52	1.38	1.72	1.83	1.84
Confidence Interval	0.40	0.44	0.40	0.50	0.53	0.53
Question 3	Exposure to the therapeutics					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.36	2.78	2.63	3.96	3.98	4.31
Std. Dev.	1.68	1.59	1.54	1.78	1.61	1.67
Confidence Interval	0.48	0.46	0.45	0.52	0.46	0.49
Question 4	Changes in local water quality					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.66	2.94	2.90	4.74	4.42	4.84

Std. Dev.	2.08	1.82	1.67	1.48	1.57	1.49
Confidence Interval	0.60	0.53	0.49	0.43	0.45	0.43
Question 5	Cumulative effect from these existing sources and contaminants from aquaculture facilities					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.96	3.80	3.48	3.80	3.98	4.44
Std. Dev.	1.93	1.76	1.64	1.64	1.44	1.53
Confidence Interval	0.56	0.51	0.47	0.47	0.41	0.44
Question 6	Extended periods of artificial lighting					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.25	2.37	2.13	4.00	3.52	4.18
Std. Dev.	2.04	1.69	1.41	1.55	1.73	1.74
Confidence Interval	0.60	0.49	0.42	0.45	0.50	0.51
Question 7	Spread of disease from confined fish					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.44	5.00	4.30	4.46	4.22	4.88
Std. Dev.	1.95	1.84	1.94	1.43	1.54	1.32
Confidence Interval	0.56	0.53	0.56	0.41	0.45	0.38
Question 8	Consumed waste feed or feces from cultured salmon					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	5.36	3.56	3.44	4.08	4.00	4.72
Std. Dev.	1.86	1.88	1.64	1.52	1.48	1.36
Confidence Interval	0.54	0.54	0.47	0.44	0.43	0.39
Question 9	Exposure of therapeutics (antibiotics and vaccines)					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.78	4.10	3.63	4.26	4.06	4.58
Std. Dev.	1.89	1.95	1.90	1.48	1.60	1.54
Confidence Interval	0.55	0.57	0.55	0.43	0.46	0.44
Question 10	Changes in local water quality					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.84	4.65	3.98	4.67	4.48	4.82
Std. Dev.	1.75	1.96	1.70	1.41	1.50	1.38
Confidence Interval	0.51	0.57	0.50	0.41	0.44	0.40
Question 11	Occupational exposure					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.13	3.52	3.60	4.69	3.76	4.08
Std. Dev.	1.93	1.70	1.69	1.62	1.80	1.77
Confidence Interval	0.57	0.50	0.50	0.47	0.52	0.52
Question 12	Extended periods of artificial lighting					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.75	3.56	2.90	3.77	3.27	3.98
Std. Dev.	1.86	1.60	1.42	1.68	1.72	1.73
Confidence Interval	0.55	0.47	0.42	0.49	0.50	0.51

Question 13	Disease be spread from confined salmon					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.02	4.20	3.90	3.84	3.50	4.10
Std. Dev.	1.83	1.85	1.98	1.49	1.72	1.64
Confidence Interval	0.53	0.54	0.57	0.43	0.50	0.47
Question 14	Populations of benthic species changed					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	5.38	4.14	3.60	4.52	4.08	4.29
Std. Dev.	1.44	1.88	1.87	1.58	1.82	1.70
Confidence Interval	0.42	0.54	0.54	0.46	0.52	0.50
Question 15	Changes to phytoplankton/zooplankton populations					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.10	3.48	3.04	3.94	3.44	4.00
Std. Dev.	1.82	1.89	1.65	1.43	1.61	1.63
Confidence Interval	0.53	0.54	0.48	0.41	0.46	0.47
Question 16	Presence of predators					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.84	3.54	3.33	3.96	3.49	4.04
Std. Dev.	1.79	1.68	1.56	1.59	1.61	1.53
Confidence Interval	0.52	0.49	0.46	0.46	0.47	0.45
Question 17	Changes in water quality					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	2.76	3.06	2.86	4.24	4.10	4.48
Std. Dev.	1.89	2.04	1.96	1.71	1.47	1.55
Confidence Interval	0.55	0.59	0.57	0.49	0.43	0.45
Question 18	Cumulative effect of pollutants					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.55	3.24	3.14	4.00	3.82	4.26
Std. Dev.	1.94	1.89	1.93	1.74	1.62	1.75
Confidence Interval	0.57	0.55	0.56	0.50	0.47	0.50
Question 19	Extended periods of localized artificial lighting					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	2.69	2.22	2.14	3.84	3.51	4.22
Std. Dev.	1.84	1.34	1.41	1.70	1.70	1.76
Confidence Interval	0.54	0.39	0.41	0.50	0.50	0.51
Question 20	Transfer of disease					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.72	4.10	4.56	3.96	3.86	4.26
Std. Dev.	2.06	2.12	2.01	1.50	1.55	1.55
Confidence Interval	0.60	0.61	0.59	0.44	0.45	0.45
Question 21	Competition for food or habitat					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.72	3.17	3.39	4.62	4.49	4.90
Std. Dev.	2.31	2.17	2.10	1.54	1.62	1.61
Confidence Interval	0.67	0.69	0.61	0.44	0.47	0.46

Question 22	Changes to phytoplankton/zooplankton populations					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.26	2.50	2.41	4.16	3.63	4.02
Std. Dev.	1.84	1.52	1.51	1.45	1.58	1.55
Confidence Interval	0.53	0.44	0.44	0.42	0.46	0.45
Question 23	Changes in genetic composition					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	3.98	3.45	3.73	4.65	4.22	4.57
Std. Dev.	2.11	2.06	2.02	1.60	1.70	1.68
Confidence Interval	0.61	0.60	0.59	0.47	0.50	0.49
Question 24	Would your answers to the questions above change if production levels of cultured salmon species were to double?					
	L(E)	**L(C/E)**	**S**	**SK**	**PK**	**PC**
Mean	4.04	N/A	3.38	4.13	4.02	4.26
Std. Dev.	2.19	N/A	1.83	1.54	1.36	1.47
Confidence Interval	0.65	N/A	0.56	0.46	0.41	0.44

Appendix C: Frequency Histograms of Some Key Risks