Proceedings of a Workshop to Develop Methodologies for Conducting Research on the Effects of Seismic Exploration on the Canadian East Coast Fishery, Halifax, Nova Scotia, 7-8 September 2000

by

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EXECUTIVE SUMMARY

Studies of the effects of seismic exploration on East Coast fisheries may be conducted within the next few years. Some studies required to fill gaps in present knowledge will be relatively simple and inexpensive and others will be costly, complex, and of relatively long duration. These studies must build on what has been learned about the conduct of successful field studies in other countries. Each study design must address specific questions related to effects of seismic exploration, be scientifically defensible, and be accepted by interested stakeholders.

In spring 2000, the Environmental Studies Research Fund (ESRF) awarded a contract to LGL Limited to conduct a workshop designed to develop methods to study the effects of seismic exploration on the Canadian east coast fishery and set priorities for research. The workshop was held on 7 and 8 September 2000 in Halifax, Nova Scotia, Canada. Forty-six people attended the workshop. Experts in relevant fields attended and made presentations that described state-of the-art technologies in fisheries/seismic research. Experts and their field of expertise included:

Laurie Wiglle, Western Geophysical Inc. (what is seismic exploration, how and why is it done),
Charles Malme, (underwater acoustics, nature and propagation of seismic noise),
Dr. Arthur Popper, University of Maryland (how fish hear, damage to hearing organs in fish),
Robert McCauley, Curtin University, Australia (effects of seismic on fish behaviour and hearing organs),
Dr. Egil Ona, Institute of Marine Research, Bergen, Norway (studies of effects of seismic exploration on catch of groundfish and eggs and larvae),
Captain Ernest Syme, National Sea Products (catch reduction in a real-life fisheries situation in the presence of an operating seismic vessel),
Dr. John R. Skalski, University of Washington (effects of seismic on catch of California rockfish; statistical considerations in study design),
Dr. John Richardson, LGL Limited, King City, Ontario (studies of the effects of seismic on bowhead whales; effort needed to show unequivocal results), and
Dr. Trevor Kenchington, Gadus Associates, Nova Scotia (issues relevant to seismic and east coast fish & fisheries).

Other participants included:

Fishermen or representatives of fisheries organizations - 9
Canadian government scientists (DFO) - 8
Nova Scotia government (fish marketing) - 1
Canadian regulatory agency personnel - 3
U.S. government regulatory agency personnel - 1
Oil and gas company personnel - 3
Consultants/technical personnel - 10
Project team - 6

Day One of the workshop began with presentations by experts in several fields. The presentations included talks on the importance of hearing and the acoustic environment to fish, effects of seismic on hearing in fish, results of field experiments on behaviour of fish, and a cautionary account of research into seismic impacts on bowhead whales. These accounts summarized what was known about effects of seismic sounds on fish and fisheries and identified related issues in Atlantic Canada.

There was general agreement among participants that seismic surveys can markedly reduce catch of some groundfish species. There was recognition that existence of these effects on some groundfish species does not need to be proven again, but that some related work needs to be done to confirm effects on Canadian East Coast species. Some questions about the nature of effects remain, especially those related to duration of effects and distance to which effects can be expected.

After the invited experts made their presentations, workshop participants discussed issues and questions to be addressed by the proposed research, and designed a set of research programs that should be given priority. The programs were

1. Small experimental studies of fish;
2. Small experimental studies of shellfish;
3. Studies of behavioural responses to seismic noise; and
4. Effects of seismic noise on catchability of fish.

The results of a Norwegian risk assessment of the effects of seismic noise on eggs and larvae of fish showed that effects were indistinguishable from natural variability (Booman 1996; Seatre and Ona 1996). The workshop participants concurred that studies of seismic effects on fish eggs and larvae were of low priority and were not considered further.

On Day Two, the workshop participants distributed themselves into smaller breakout sessions, each of which addressed one of the research topics, and designed research programs to investigate them. Topics 1 and 2 were merged into one session. After sessions had met for 2.5 hours, participants were redistributed such that some remained with their original session to provide continuity and others went to different sessions to facilitate the flow of ideas among breakout groups.

Following the breakout sessions, session leaders presented results of their group's deliberations. The workshop participants discussed the results, and an attempt was made to set priorities for research and to discuss programs within the context of the agreed-upon topics.

Research Priorities and Recommendations

The workshop participants discussed priorities for future research. The following studies were deemed to be of worthy of consideration because they would provide key information about effects of seismic noise on valuable fisheries resources or were of great concern to stakeholders. Priorities for research were set by the study team based on the apparent priorities expressed by the majority of participants.

(1) The highest priority for Nova Scotia was considered to be studies of seismic effects on shellfish, especially crab and lobster, because nothing is known about their reactions to seismic noise, anecdotal information implies that there may be effects, and the fishery for them is very valuable. Studies would begin with laboratory experiments and experiments with cages in the nearshore environment. If the animals were found to react to seismic

sounds, then experiments would progress to small-scale catch studies and then to the kind of full-scale catch studies described in Point 4, below. The cost of laboratory experiments, cage experiments and small scale catch studies for crab, lobster, and scallop, and limited studies of invertebrate larvae was estimated to be about $500,000 to $700,000 if all experiments were done.

The study group recommends that first priority be given to measurement of the behavioural reactions of crabs to seismic sounds in the laboratory and in small cages. The tests should be done in a graduated manner. The tests would be done as a series where Test 1 would determine whether crabs in the laboratory react in any way to typical seismic noise, other low frequency sounds, and vibrations and, if so, Test 2 would determine whether crabs in cages respond to typical received levels on the bottom and the duration and nature of such a response. If crabs were found to respond to seismic sounds, then experiments would proceed to Test 3, designed to determine if seismic sounds caused reduction in catch in a small-scale study. If seismic sounds caused a reduction in catchability, then full-scale field studies of effects of seismic noise on catch rates would be of very high priority, and a study such as that designed for cod in Point 4, below, should be done.

The cost of setting up and running each experiment would be relatively high, and there would be economies of scale if two or more species could be tested at once or sequentially. The cost of laboratory and cage trials on all four invertebrate species would be about $250,000 if done sequentially or if more than one species were tested at once. The study group would recommend that crab and lobster be tested first, at a cost of about $150,000. The initial laboratory tests on crab and lobster could be done for a relatively low cost (about $25,000 to $50,000, depending on the sophistication of the acoustic component). The initial tests would go a long way to answering the basic question of whether they react to seismic noise.

A small-scale field trial on one species would cost about $100,000 and would require some in-kind support and co-operation from fishermen. A full-scale study of effects of seismic noise on catch rates of crab would cost somewhat less than the one proposed for cod (see Point 4, below), about $500,000.

(2) An *ad hoc* study of effects of seismic noise on catch rate when cod fishing and seismic are scheduled for the same area was also of very high priority. There was a great deal of support for a limited kind of catch study that would show whether catch was affected on the Canadian East Coast as it was in Norwegian waters. The study would be conducted on an opportunistic basis when a seismic vessel and fish vessel were working in close proximity. The study should be designed with valid replication and so that efficiency is maximized (reducing the need for additional replicates) and sources of criticism are minimized. The cost may be about $50,000 plus. There may need to be compensation of the fishing vessel, as it would not normally fish in an area where it is not catching fish.

(3) The group felt that studies of valuable pelagic species were warranted, but conceded that such studies may be impossible to conduct because of large variability in the distribution and catch of these species. Anatomical studies of swordfish and tuna hearing structures should be conducted to yield information on their hearing abilities and provide some information on their susceptibility to seismic sounds. The cost would be about $15,000. In addition, a pilot study of variability in catch rates of large pelagic species should be undertaken to determine if catch studies are feasible. The study would be a statistical

analysis of existing data on catch of swordfish and tuna. The cost would be less than $25,000. This kind of study should also be undertaken for other species prior to any field studies. Results could be used to enhance statistical power of the experiments. These studies would yield valuable results for minimal expenditure, and so are highly recommended.

(4) Field studies on the duration and extent on effects on catch of cod in area 3Ps and redfish on the slope were deemed to be of very high priority. These studies would take up where the Norwegian studies left off and concentrate on the distance at which effects occur and how long they last. Studies on catchability of cod like the Norwegian studies could not be conducted on St. Pierre Bank in area 3Ps because the area of high cod abundance is too small. Such studies could be conducted on redfish. The study should be done with a real seismic boat and fishing vessel. The cost would be $700,000 to $1,000,000, approximately the cost of the Norwegian study. The California rockfish study cost $700,000. This type of study is of lower priority that the first three on the list. Seismic exploration reduces fish catches. This experiment is designed to address the questions, "How long do effects last?" and, "How far do they extend?" The study group does not feel that the study warrants a high priority because of the high cost and relatively high probability of obtaining poor or equivocal results (compared to other studies recommended here).

(5) Laboratory-based and small-scale experimental studies of behavioural and sub-lethal effects of seismic noise on fish were also deemed worthy of consideration. In the laboratory and in cages in nearshore waters, fish would be exposed to seismic sounds, and changes in behaviour would be monitored. Fish would then be examined for physical effects on hearing organs and changes in biochemistry that indicate stress. The studies recommended here would cost $250,000 to $500,000. Because set-up costs and costs of running the experiments (airgun source, acoustic measurements, cage maintenance) would be high, it would not be economical to run experiments on just one species or on one species at a time. This study would have low priority. It has been done in other areas, and the general results could be applied to the East Coast. The study group recommends a scaled back version of this study that addresses effects on only a four or five species that include cod, herring, flatfish and silver hake. Emphasis should be on behavioural reactions and examinations for evidence of damage organs and tissues associated with hearing. The Australian study cost about $200,000 to $250,000 and examined about 12 species. However, it was done at a university with some low-cost labour and considerable support. Cage experiments on four species could cost about $100,000 and the necropsies about $15,000. However, the study group recommends that services of Dr. Arthur Popper, or someone recommended by him, be retained to train a qualified East Coast scientist in methods of examining organs and tissues associated with fish hearing for damage. The scientist would bring some fish used in the experiment to Dr. Popper's (or alternate's) laboratory. Initial cost of the necropsies would be about $50,000 in the first (training year) and $15,000 in subsequent years. This scientist could also examine for damage in hearing organs and tissues in fish collected during other experiments.

(6) A behavioural study of effects on spawning was deemed of importance to resource managers. This study would use radio-tagged fish, bottom mounted arrays of receivers (for tags), boats with receivers (for tags), and echosounders to study the behaviour of spawning fish exposed to seismic sounds. The cost would be about $2,500,000. Because of the prohibitive cost, this study would be given very low priority. If the necessary

information were collected and made available (see below), potential effects could be mitigated by avoiding spawning areas at sensitive times.

Other studies briefly discussed at the workshop were as follows:

1. A GIS study that used existing data to map fish spawning locations should be done. It was agreed that this study was part of DFO's mandate and should not be funded by ESRF. The study group recommends that the study of effects on spawning fish not be done. If mitigation by avoiding spawning areas is to be implemented, then this GIS study needs to be done by DFO.
2. Stakeholder knowledge of the attributes of fish that would be helpful, and in some cases essential, for designing studies should be assembled.
3. An additional potential study discussed by the group was the effects of seismic exploration on spawning migrations of cod. This study could be done off northern Cape Breton.

Implementation

Priorities for research would be based on the priority assigned to the project and the availability of funds. Stakeholders should be consulted prior to soliciting proposals, especially if their co-operation is needed to conduct the work. Proposals then would be solicited from interested parties to conduct the work.

The study team strongly suggests that each proposal for research contain provision for a Scientific Review Board for the study. The Scientific Review Board (SRB) would be an independent entity that would ensure the scientific integrity of the work and would enhance acceptance of results. The board would consist of six or seven members that included, as a minimum, a statistician, underwater acoustician, an expert on the species in question, one or two stakeholders representing the species in question, a scientist who has conducted similar research and representatives of industry. The offshore petroleum boards' advisory teams and ESRF Management Board could serve as a basis for the SRB. The SRB would review proposals for research, make recommendations about how the study should proceed, and review reports. The SRB would meet after project award to evaluate the proposed methodology and make recommendations as to how to best proceed. It would meet after the field/laboratory work is complete to discuss analysis, and again when the draft report is finished. The final results of each study should be a 'publication-grade' document.

It would be desirable to co-ordinate research programs with those being done in other countries, or at least to keep each other informed of plans for current and future research. Researchers would receive details of planned studies, preliminary results, reports on effectiveness of methods, and observations. Cost-effectiveness would be achieved by preventing duplication of effort.

There are several entities that could fund these or related studies and/or provide in kind support such as vessels, laboratory facilities and experimental areas. These include the Environmental Studies Research Fund, the Canada-Nova Scotia and Newfoundland Offshore Petroleum Boards, Department of Fisheries and Oceans, the fishing industry and the offshore oil and gas industry. The Workshop will provide guidance to the Management Board to help prioritize research, which they may eventually recommend to the Ministers of DIAND and NRCan for funding through the levy process. Because some of the recommended studies require complex support and logistics, co-operation among some combination of agencies NGOs, universities, stakeholders and industry would be required.

SOMMAIRE

Des études concernant les effets de la prospection sismique sur les pêches dans les eaux atlantiques canadiennes sont envisagées pour les prochaines années. Ces études visent à combler les lacunes dans l'état actuel des connaissances en la matière. Certaines d'entre elles seront relativement simples et peu coûteuses, d'autres plus complexes, plus longues et plus onéreuses. La méthodologie devra être définie en tenant compte d'expériences similaires ailleurs dans le monde. Chaque étude devra avoir un objet bien défini, scientifiquement défendable et dont l'importance est reconnue par les intéressés.

Au printemps 2000, un contrat, financé à même le Fonds pour l'étude de l'environnement (FEE), a été attribué à la société LGL Limited pour organiser un atelier en vue de définir des méthodes adaptées à l'étude des effets de la prospection sismique sur les pêches dans les eaux atlantiques canadiennes, et d'établir les priorités de recherche en la matière. Cet atelier a eu lieu les 7 et 8 septembre 2000 à Halifax (Nouvelle-Écosse), au Canada. On y comptait quarante-six participants. Des spécialistes des divers domaines concernés y ont présenté les techniques de pointe employées en recherche dans ce domaine. On a pu ainsi entendre :

Laurie Wiglle, Western Geophysical Inc. (qu'est-ce que la prospection sismique, quelle en est l'utilité et quels en sont les procédés),
Charles Malme, (acoustique sous-marine, nature et propagation des ondes acoustiques d'origine sismique),
Dr. Arthur Popper, Université du Maryland (l'ouïe chez les poissons, les dommages causés par les ondes acoustiques d'origine sismique aux organes de l'ouïe des poissons),
Robert McCauley, Université Curtin, Australie (les effets de la prospection sismique sur le comportement et sur les organes de l'ouïe des poissons),
Dr. Egil Ona, Institut de recherche marine, Bergen, Norvège (études concernant les effets de la prospection sismique sur les prises de poissons de fond et sur les œufs et les larves),
Capitaine Ernest Syme, National Sea Products (réduction des prises de poissons dans des conditions réelles de pêche en présence d'un navire de prospection sismique),
Dr. John R. Skalski, Université de Washington (effets de la prospection sismique sur les prises de sébastes du Pacifique; considérations d'ordre statistique dans la définition des plans d'étude),
Dr. John Richardson, LGL Limited, King City, Ontario (études concernant les effets de la prospection sismique sur la baleine boréale; ce qu'il faut faire pour obtenir des résultats non équivoques), et
Dr. Trevor Kenchington, Gadus Associates, Nouvelle-Écosse (incidences de la prospection sismique sur les ressources halieutiques et les pêches dans les eaux territoriales de la Côte atlantique).

Parmi les autres participants figuraient :

9 pêcheurs/représentants d'organisations pour les pêches
8 scientifiques du gouvernement canadien (P&O)
1 représentant du gouvernement de la Nouvelle-Écosse (commercialisation du poisson)
3 représentants d'organismes canadiens de réglementation
1 représentant d'organisme américain de réglementation
3 représentants de l'industrie du gaz et du pétrole

10 consultants/spécialistes techniques
6 membres de l'équipe de projet

La première journée de l'atelier a commencé par les présentations des spécialistes sur divers sujets, notamment l'audition et l'importance de l'environnement acoustique chez les poissons, les effets de la prospection sismique sur l'ouïe des poissons, les résultats d'études *in situ* sur le comportement des poissons et un résumé critique, invitant à la prudence dans l'interprétation des résultats, des travaux de recherche concernant les effets de la prospection sismique sur la baleine boréale. Ces présentations résumaient l'état des connaissances sur les effets des ondes sonores provoquées par les explosions de la sismique sur les poissons et les pêches, et pointaient les problèmes de cette nature dans les eaux atlantiques canadiennes.

Les participants s'entendaient sur le fait que la prospection sismique peut réduire considérablement les prises de certaines espèces de poissons de fond. Ils reconnaissaient que la preuve de cette incidence n'est plus à faire en ce qui concerne certaines espèces, mais qu'il y aurait lieu de vérifier si elle se confirme pour ce qui est des espèces fréquentant les eaux de la Côte atlantique canadienne. Il resterait notamment à déterminer jusqu'à quelle distance les effets des explosions se font sentir et quelle est la durée de ces effets.

Après les présentations des spécialistes invités, les participants ont discuté des problèmes sur lesquels devrait porter la recherche et des questions auxquelles elle devrait chercher des réponses, puis ils ont dressé une liste de programmes de recherche à réaliser en priorité. Voici les résultats :

5. Expériences restreintes sur des poissons
6. Expériences restreintes sur des crustacés et coquillages
7. Effets des ondes acoustiques sismiques sur le comportement des poissons/crustacés et coquillages
8. Effets des ondes acoustiques sismiques sur les prises de poissons/crustacés et coquillages

Une étude norvégienne visant à évaluer les risques liés à la prospection sismique pour les œufs et les larves de poissons n'a pas permis de conclure à une quelconque incidence, au regard de la variabilité naturelle (Booman 1996; Seatre and Ona 1996). Ce sujet n'a pas été retenu au rang des priorités.

Le deuxième jour, les participants se sont répartis en petits groupes. Chacun des groupes discutait d'un des sujets de recherche proposés et établissait un programme de recherche. Les premier et deuxième sujets susmentionnés ont été considérés ensemble. Après deux heures et demie de discussion, il y a eu brassage des groupes : pour assurer la continuité tout en favorisant l'échange des idées, un noyau de chaque groupe original demeurait en place et des participants d'autres groupes venaient s'y joindre.

Les porte-parole des différents groupes ont ensuite présenté les résultats des discussions. Ces résultats ont fait l'objet d'une discussion générale où les participants ont considéré les programmes au vu des sujets retenus et ont tenté d'établir un ordre de priorité.

Priorités et recommandations en matière de recherche

Les participants ont discuté des priorités à accorder en matière de recherche. Ils s'entendaient sur l'importance des études ci-dessous, puisqu'elles permettraient de recueillir des données cruciales concernant les effets des ondes sonores sismiques sur les ressources halieutiques ou qu'elles touchaient des sujets de préoccupation pour les intéressés. L'ordre de priorité de ces études a été établi par le groupe d'étude, d'après les avis exprimés par la majorité des participants.

(7) Pour la Nouvelle-Écosse, l'effet des ondes sonores sismiques sur les crustacés et coquillages, en particulier sur le crabe et le homard, vient en tête de liste, puisqu'on ne possède aucune donnée scientifique sur les réactions de ces espèces aux ondes sonores sismiques, sinon des données isolées qui indiqueraient qu'elles n'y sont pas insensibles, et que ces espèces sont très importantes pour l'industrie des pêches de cette province. On commencerait par des études en laboratoire, puis des études en cages dans les eaux du littoral. Dans l'éventualité où celles-ci révéleraient que les ondes sonores sismiques ont une incidence sur le comportement de ces espèces, on passerait à des études restreintes sur les prises, puis à des études en conditions réelles de pêche comme celle décrite au paragraphe 4 ci-après. Le coût de l'ensemble des études en laboratoire, des études en cages et des études restreintes sur les prises pour le crabe, le homard et le pétoncle et d'études restreintes sur les larves d'invertébrés est estimé à environ 500 000 $ à 700 000 $.

Le groupe d'étude recommande de procéder d'abord à l'étude en laboratoire et en cages de la réaction du crabe aux ondes acoustiques provoquées par la sismique. Les travaux devraient être réalisés par étapes. La première étape consisterait à déterminer en laboratoire si le crabe réagit aux ondes sonores typiquement produites par la sismique, à d'autres sons de basse fréquence et aux vibrations. Dans l'affirmative, on passerait à l'étude, en cages, de la réaction du crabe aux niveaux sonores auxquels il est typiquement exposé sur le fond marin, afin de qualifier cette réaction et d'en déterminer la durée. Dans un troisième temps, il s'agirait de procéder à une étude à petite échelle en vue de déterminer si la réaction de cette espèce aux ondes sonores d'origine sismique a une incidence sur les prises. Si cette dernière laissait croire à une réduction des prises, il y aurait alors lieu de procéder à une étude sur l'impact de la prospection sismique sur les prises de crabe dans les conditions réelles de pêche, comme celle prévue pour la morue au paragraphe 4 ci-après.

Le coût lié à la préparation et à la réalisation de chacune des études est relativement élevé, et il y aurait des économies d'échelle à réaliser en étudiant deux ou plusieurs espèces en même temps ou à la suite l'une de l'autre. En procédant de cette manière, les études en laboratoire et les études en cages pour les quatre groupes considérés pourraient être réalisées au coût d'environ 250 000 $. Le groupe d'étude recommande que le crabe et le homard soient étudiés en premier, ce qui représenterait une dépense d'environ 150 000 $. Les essais initiaux en laboratoire sur ces deux espèces pourraient se faire à coût assez modéré (de 25 000 $ à 50 000 $ environ, selon le perfectionnement technique de l'appareillage acoustique). Cette étape apporterait une première réponse à la question fondamentale, qui est de savoir si ces espèces sont affectées ou non par les ondes acoustiques qui accompagnent la prospection sismique.

Une étude restreinte sur les prises d'une des deux espèces coûterait environ 100 000 $ et nécessiterait la collaboration des pêcheurs et la mise à contribution de leur matériel. Le coût d'une étude sur l'effet des ondes sonores sismiques sur les prises de crabe dans les conditions réelles de pêche serait inférieur à celui de l'étude proposée pour la morue (voir paragraphe 4 ci-après), soit d'environ 500 000 $.

(8) Les participants ont aussi attaché une grande importance à une étude ponctuelle sur l'incidence des ondes sonores sur les prises de morue lorsque la pêche et la prospection sismique ont cours simultanément dans une zone donnée. Ils étaient très en faveur d'une étude restreinte *in situ* qui permettrait de déterminer si la prospection sismique a la même incidence sur les prises dans les eaux atlantiques canadiennes que dans les eaux norvégiennes. Cette étude se ferait à la faveur d'une occasion où un navire de prospection sismique opérerait à proximité d'un bateau de pêche. Le plan d'étude doit prévoir les duplications voulues pour assurer la validité des résultats et doit être conçu de manière à maximiser l'efficacité des travaux (éviter d'avoir à répéter des opérations) et à donner le moins de prise possible à la critique. Le coût serait de l'ordre de 50 000 $, peut-être plus. Il peut s'avérer nécessaire de dédommager l'exploitant du bateau de pêche, car normalement celui-ci ne resterait pas à pêcher dans une zone où il ne prend pas de poissons.

(9) Les participants étaient d'avis que des études sur les espèces pélagiques de grande valeur commerciale seraient utiles, mais ils reconnaissaient qu'elles ne sont peut-être pas réalisables du fait de l'importante variabilité de la répartition et des prises de ces espèces. L'anatomie des organes de l'ouïe de l'espadon et du thon devrait être étudiée afin de recueillir des données sur l'audition de ces espèces et leur sensibilité aux ondes acoustiques produites par la sismique. Ces travaux coûteraient environ 15 000 $. Il y aurait aussi lieu de faire une étude préalable sur la variabilité des prises d'espèces pélagiques de grande taille, à titre d'étude de faisabilité. Il s'agirait d'une analyse statistique des données existantes sur les prises d'espadons et de thons, dont le coût ne dépasserait pas les 25 000 $. Les études *in situ* sur d'autres espèces devraient toutes être précédées de ce genre d'analyse statistique, dont les résultats peuvent servir à appuyer ceux de l'étude *in situ*. Ces analyses préalables sont fortement recommandées, car elles donnent des résultats utiles en retour d'un très faible investissement.

(10) Les participants attachaient une très haute importance aux études *in situ* sur la portée et la durée de l'incidence des ondes acoustiques produites par la sismique sur les prises de morue dans la zone 3Ps et les prises de sébastes dans la zone du talus continental. L'investigation prendrait comme point de départ l'aboutissement des études norvégiennes et viserait plus particulièrement à définir jusqu'où se font sentir les effets des explosions provoquées et combien de temps durent ces effets. Des études sur les prises de morue de l'envergure de celle qui a été faite en Norvège ne peuvent pas se faire sur le Banc de St. Pierre dans la zone 3Ps puisque la zone où la morue y est abondante est trop restreinte. Par contre, ces études pourraient se faire sur les prises de sébastes. Elles seraient effectuées à bord d'un bateau de pêche opérant en présence d'un navire de prospection sismique. Le coût se situerait entre 700 000 $ et 1 000 000 $, soit les coûts respectifs de l'étude sur les sébastes du Pacifique et de l'étude norvégienne. Dans l'ordre des priorités, ces études venaient après les trois décrites précédemment. Il a déjà été établi que la prospection sismique réduit les prises de poissons. Il s'agirait maintenant de déterminer la durée de cet effet et le rayon dans lequel il se fait sentir. Le groupe d'étude n'accorde pas une priorité élevée aux travaux de recherche visant à répondre à ces questions, d'une part parce qu'ils seraient très coûteux et, d'autre part, parce que les résultats seraient fort probablement peu concluants comparativement à ceux auxquels on peut s'attendre d'autres études parmi celles qui sont recommandées.

(11) Les expériences en laboratoire et les expériences restreintes dans le milieu pour déterminer les effets de la prospection sismique sur le comportement et l'anatomie des poissons ont

aussi suscité de l'intérêt. Ces études consistent à exposer les poissons à des ondes sonores correspondant à celles provoquées par la prospection sismique, en laboratoire et dans des cages placées dans les eaux du littoral, puis à observer les changements dans leur comportement. Les poissons sont ensuite examinés afin de constater les dommages aux organes de l'ouïe et les changements biochimiques révélateurs de stress. Le coût de ces études se situerait entre 250 000 $ et 500 000 $. Comme le coût des installations requises et celui de la préparation et de la conduite des expériences sont élevés (canon à air, instruments de mesure acoustique, entretien des cages), il ne serait pas judicieux de limiter l'étude à une seule espèce, ou d'étudier une seule espèce à la fois. Ces études n'ont pas une priorité élevée. Il y en a déjà eu de semblables, et les résultats pourraient être appliqués par extrapolation aux conditions de la Côte atlantique. Le groupe d'étude recommande une version restreinte à quatre ou cinq espèces choisies parmi la morue, le hareng, les poissons plats et le merlu argenté. L'étude serait axée sur le comportement des poissons en réaction aux ondes acoustiques provoquées par la sismique et sur les dommages aux organes de l'ouïe et tissus associés. L'étude australienne, qui portait sur une douzaine d'espèces, a coûté aux alentours de 200 000 $ à 250 000 $. Mais il faut préciser qu'elle a été faite dans une université où elle a bénéficié d'une main-d'œuvre peu payée et d'un appui matériel considérable. Les études en cages pourraient coûter pour quatre espèces environ 100 000 $, et les nécropsies environ 15 000 $. Le groupe d'étude recommande de retenir les services du professeur Arthur Popper, ou d'un autre spécialiste recommandé par lui, pour former un scientifique de la Côte atlantique en matière d'examen des organes de l'ouïe des poissons. Cette personne apporterait au laboratoire du professeur Popper (ou d'un autre spécialiste) les poissons à examiner. Le coût des nécropsies serait d'environ 50 000 $ la première année (année de formation) puis de 15 000 $ les années suivantes. Le même scientifique pourrait s'occuper de ce genre d'examen lors d'autres expériences.

(12) Pour les gestionnaires des ressources, il serait important de connaître les effets de la prospection sismique sur le frai. L'étude de la réaction des poissons aux ondes sonores sismiques au moment du frai nécessiterait le radiomarquage de poissons, l'installation de batteries de récepteurs radio sur le fond, l'installation de récepteurs radio à bord de bateaux de pêche et l'emploi d'échosondeurs. Il faudrait consentir à une dépense de l'ordre de 2 500 000 $. Vu son coût prohibitif, cette étude est reléguée au bas de la liste de priorité. Si ces données étaient recueillies et publiées (voir ci-après), il serait possible de parer aux éventuels effets de la sismique sur le frai en évitant ces zones pendant la saison critique.

D'autres types d'études ont été envisagées, notamment :

4. Une étude SIG utilisant les données existantes pour dresser la carte des zones de frai. On s'entend pour dire que cette étude est du ressort de P&O et ne devrait pas être financée à même le FEE. Le groupe d'étude ne recommande pas de recherche sur les effets de la prospection sismique sur le frai. S'il est décidé d'atténuer les éventuels effets de la prospection sismique sur le frai en évitant ces zones pendant la période critique, l'étude SIG sera alors nécessaire.
5. Il faudrait que les connaissances que possèdent les intéressés sur les espèces considérées et qui peuvent être précieuses, voire nécessaires, pour la planification des projets de recherche soient rassemblées.

6. Une autre étude jugée digne d'intérêt concerne les effets de la prospection sismique sur les migrations de reproduction de la morue. Cette étude pourrait se faire au nord du cap Breton.

Réalisation

L'ordre de priorité des projets de recherche serait établi sur la base de l'importance accordée au sujet et de la disponibilité de fonds. Les intéressés devraient être consultés avant publication de l'appel de propositions, surtout si leur collaboration est nécessaire ou susceptible d'être sollicitée.

Le groupe d'étude recommande fortement que toutes les propositions de recherche prévoient un comité de révision scientifique (CRS). Ce comité doit constituer une entité indépendante, dont le rôle serait d'assurer la qualité scientifique des travaux et de cautionner la valeur scientifique des résultats. Il doit compter six ou sept membres, dont au moins un statisticien, un spécialiste en acoustique sous-marine, un spécialiste de l'espèce étudiée, un ou deux intéressés par l'espèce étudiée, un scientifique ayant déjà participé à des travaux de recherche dans le domaine et des représentants de l'industrie. Un certain nombre des membres du CRS pourraient être choisis parmi les équipes consultatives des offices des hydrocarbures extracôtiers et le conseil de gestion du FEE. Le CRS examinerait les propositions de recherche, ferait des recommandations quant à la marche à suivre et examinerait les rapports. Il se réunirait après l'attribution des contrats afin d'examiner la méthodologie proposée et de faire des recommandations sur la façon de procéder. Il se réunirait de nouveau après l'achèvement des travaux en laboratoire ou *in situ* pour discuter de l'analyse des données, et encore une fois après la présentation du rapport provisoire. Les résultats finals de chaque étude doivent être présentés sous forme de document publiable.

Il est souhaitable que les programmes de recherche soient coordonnés avec les travaux qui se font dans le même domaine ailleurs dans le monde, ou du moins que les équipes de recherche se tiennent mutuellement informées des études en cours ou prévues. Il s'agirait de communiquer aux autres chercheurs une description détaillée des études envisagées, les résultats préliminaires de la recherche, un rapport sur l'efficacité des méthodes utilisées et les observations pertinentes. On éviterait ainsi des doublements d'efforts coûteux.

Le financement de ces études, ou d'autres études connexes, ou un appui matériel sous forme de navires de prospection, bateaux de pêche, laboratoires et zones d'études, pourraient être assurés par diverses sources. On peut penser au Fond pour l'étude de l'environnement, à l'Office Canada-Nouvelle-Écosse et l'Office Canada-Terre-Neuve des hydrocarbures extracôtiers, au ministère des Pêches et des Océans, à l'industrie de la pêche et à l'industrie de l'exploitation pétrolière et gazière extracôtière. Les résultats de cet atelier guideront le Conseil de gestion dans l'établissement des priorités en matière de recherche, et celui-ci pourra faire les recommandations de financement qu'il juge opportunes auprès des ministres responsables de AINC et de RNCan. Comme certaines des études recommandées nécessitent des moyens et une organisation complexes, il faudra une coopération entre plusieurs organismes parmi les ONG, les universités, les intéressés et l'industrie.

Workshop to Develop Methodologies for Conducting Research on the Effects of Seismic Exploration on the Canadian East Coast Fishery

(Halifax, September 7-8, 2000)

The first part of this report contains a summary of the proceedings of the workshop. They are presented in chronological order so that the reader can follow the sequence of events and discussions that shaped the direction of the workshop and lead to the conclusions. The last part of the report is a synthesis of the results of the workshop and is meant to be used as a starting point by those designing and prioritizing studies. This is followed by recommendations for research priorities.

WORKSHOP DAY ONE

Background

The Canada Nova Scotia Offshore Petroleum Board (CNSOPB) regulates oil and gas exploration and development activities off Nova Scotia and is mandated to ensure that activities comply with the Canada Nova Scotia Offshore Petroleum Resources Accord Implementation Act, offshore oil and gas regulations and guidelines and Board policies. The Canada Newfoundland Offshore Petroleum Board (CNOPB) performs the same function for activities in Newfoundland waters. In 1998, LGL Limited produced an Environmental Assessment (EA) of the effects of offshore seismic exploration on the marine resources of the Scotian Shelf for the oil and gas industry, for submission to the CNSOPB (Davis et al. 1998). The EA contained a review of the effects of seismic operations on fish behaviour and fisheries. There is consensus among studies, cited in this report, that seismic exploration does have an effect on fish behaviour and catchability. However, several deficiencies were noted in the available data. Specifically:

- several studies produced conflicting results about the extent, kinds and duration of effects,
- most studies did not address long-term effects, including habituation,
- only two studies followed the behaviour of individual schools of fish, and
- with the exception of the California studies of seismic and rockfish, investigators did not measure received noise levels; thus, it was not possible to determine received sound levels associated with reductions in catchability (e.g., the dose-response relationship).

In addition, studies have not been conducted off the East Coast of Canada where the fish community and oceanographic conditions are quite different from those in areas where studies have been conducted. Over the next few years, the Environmental Studies Research Fund (ESRF; funded by the oil and gas industry) will support studies of the effects of seismic exploration on East Coast fisheries to fill some of the knowledge gaps. In spring 2000, the ESRF decided to fund a workshop, described in this report, to develop methods to study the effects of seismic exploration on the east coast fishery. LGL Limited and Griffiths Muecke Associates were selected to organize and conduct the workshop, which was held on 7 and 8 September 2000 in Halifax, Nova Scotia, Canada.

Goals and Objectives

The oil and gas industry is actively pursuing exploration and development on the Canadian East Coast. There is a concern that the loud noises associated with seismic exploration could alter the behaviour or movements of shellfish and finfish in a way that reduces their catchability in the fishery.

The purpose of the workshop was to bring together experts in various disciplines, stakeholders, and industry personnel to develop methodologies and set priorities for field studies of the effects of seismic exploration on catchability of groundfish, and to a lesser extent, of the effects on pelagic species, fish eggs and larvae, and shellfish. A related objective was to maximize return on research effort.

Participants

The workshop contained a broad cross section of participants from stakeholder groups, industry personnel, regulatory personnel, local scientists, and international experts. A list of workshop participants is presented in Appendix C.

Invited Experts

The study team included invited international and local experts who had conducted studies of the effects of seismic on fish and fisheries or who had specialized knowledge that could be of use to the group. These experts made presentations during the first day of the workshop. This allowed participants to become familiar with the state of the art in the subject, as well as the issues and concerns on the east coast. Presenters and topics were:

- Laurie Wiglle, Western Geophysical, Inc. (what is seismic exploration, how and why is it done),
- Charles I. Malme, Hingham, MS (underwater acoustics; nature and propagation of seismic noise),
- Dr. Arthur Popper, University of Maryland (how fish hear, damage to hearing organs in fish),
- Rob McCauley, Curtin University, Australia (effects of seismic on fish behaviour and hearing organs),
- Dr. Egil Ona, Institute of Marine Research, Bergen, Norway (studies of effects of seismic on catch of groundfish and eggs and larvae),
- Captain Ernest Syme of National Sea Products (catch reduction in a real-life fisheries situation in the presence of an operating seismic vessel),
- Dr. John R. Skalski, University of Washington (effects of seismic on catch of California rockfish; statistical considerations in study design),
- Dr. John Richardson, LGL Limited, ON, Canada (studies of the effects of seismic on bowhead whales; effort needed to show unequivocal results), and
- Dr. Trevor Kenchington, Gadus Associates, NS, Canada (issues relevant to seismic and east coast fish & fisheries).

Stakeholders

Stakeholders who participated in the workshop included fishermen, representatives of the oil and gas industry, and the geophysical industry. They had an active role in the workshop and articulated their concerns and participated in the formulation of studies and setting priorities for research. Fishermen have knowledge of the vessels and gear types used in the fisheries and advised the group about fishing areas, target species for research, the feasibility of various sampling methods that could be used, commercial vessels, and much other useful information.

Formal Presentations

The invited experts made presentations to familiarize participants with the state-of-the-art in fish seismic/research and various aspects of the issues to be discussed. These presentations are summarized below.

Mr. Laurie Wiglle (Western Geophysical, Inc., Halifax, NS) presented an overview of the purpose, methodologies and operational locations of seismic exploration on the east coast.

Mr. Wiglle differentiated 2D (usually small vessel, single streamer running more widely-spaced source lines) and 3D (carefully-spaced source and receiver lines to characterize the local geology in greater detail). Seismic operations may use submerged ocean bottom receiver cables [OBC], or receivers in towed streamer cables.

Mr. Wiglle described specific configurations and operational methodologies (e.g., hydrophone streamer [up to 7.3 km in length; Western Geophysical uses solid cables rather than kerosene-filled; bi-vanes or doors to maintain streamer cable spacing; buoy systems], and energy source configurations [multiple underwater airgun sub-arrays; 2000 psi air pressure; 10 sec seismic pulse intervals]). Typically, two sound sources are used, which alternate in firing. [For recent, descriptive reviews of airguns and how they are employed in seismic operations see articles by Caldwell and Dragoset (2000) and Dragoset (2000).]

Mr. Wiglle showed a typical marine seismic array that incorporated eight 6400 m-long streamers spaced 700 m apart. Current seismic vessels can tow up to 10-12 streamer cables. The source vessels are limited to a turning rate of only 3 degrees per minute and could take 6 km or 2-3 hours to complete a turn. The distance from the bow of the source vessel to the end of the tail buoy behind the steamers can be 7 to 7.5 km. The area covered by the towed array during operations is slightly larger than the typical mapped area of the survey due to the large turning radius of the seismic source vessel.

Inter-vessel communication between seismic and fishing vessels is important, as are pre-survey consultations with local stakeholders, such as fishermen.

Mr. Charles I. Malme (Engineering and Scientific Services, Hingham, MA) presented an overview of the sounds produced by seismic arrays, and factors affecting sound transmission (including propagation modelling and measurements).

Mr. Malme reviewed seismic terminology (e.g., sound wavelength, sound level, sound level spectra [sound levels as a function of frequency], source level spectrum [sound level spectrum for a specific source, adjusted to a reference distance of 1 metre from the source], received level spectrum [sound level spectrum for a specific source minus the transmission loss as a function of frequency and range], airgun array sound directivity).

(See Appendix B for a list and the definitions of the acronyms used throughout this report.)

The pressure of a sound pulse diminishes with increasing distance from the source. Most of the loss in pressure is due to spreading. The diminishing of pressure with increasing distance from the source is spherical to a distance that is approximately equivalent to the water depth (Fig. 1). The loss in sound pressure resulting from spherical spreading is expressed as:

20 log R dB

Where *R* is the distance from the source (in m). When spherical spreading is occurring, the transmission loss is 6 dB with each doubling of the distance. That is to say, sound pressure decreases by one half with each doubling of the distance. At horizontal distances much greater than bottom depth *D*, sound propagates through a channel bounded by the bottom and the surface and spreading is often assumed to be approximately cylindrical, with loss in dB expressed as:

10 log R dB

When spreading is cylindrical, the spreading loss is 3 dB with each doubling of the distance, or one half that of spherical spreading. A simple model of acoustic spreading would use spherical spreading to distances equal to that of the bottom and then cylindrical spreading. At ranges intermediate between spherical and cylindrical spreading, loss is often assumed to be 15 log R dB. Which model of spreading to choose is not a simple matter of knowing the receiver or source depth, and receiver distance, as other factors can be important as well.

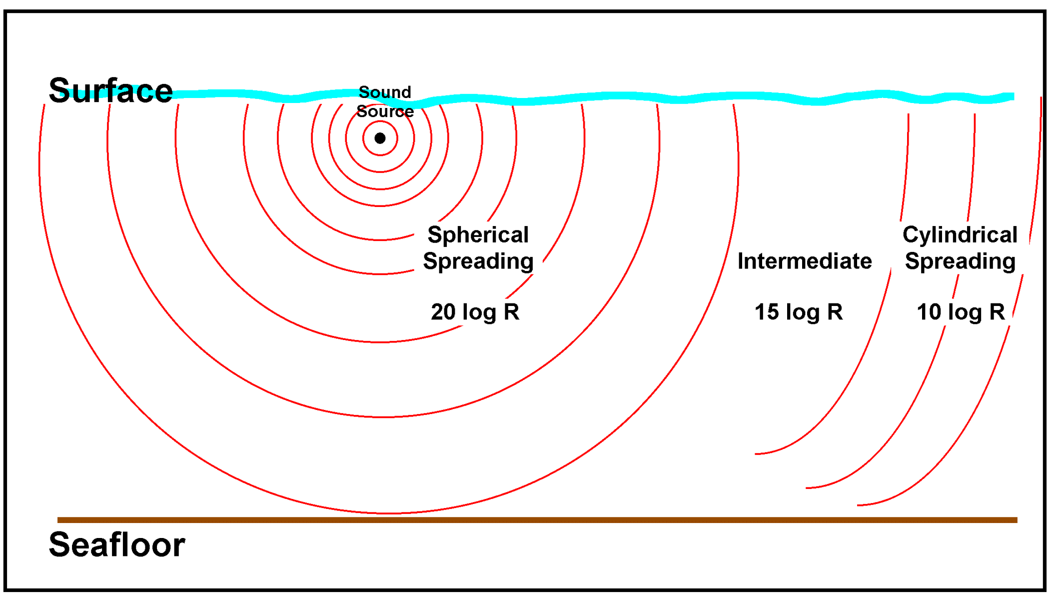

FIGURE 1. Schematic representation of acoustic spreading loss from a sound source as a function of distance and interaction with the seafloor (adapted from Davis *et al*. 1998). Note that distances are not drawn to scale.

In many cases, recorded and modelled spreading losses do not agree well with a simple spherical/ cylindrical spreading model. The estimation of spreading is complicated by many factors. These include reflections from the sea surface and sea floor bottom and sub-bottom layers, absorption in the sea floor and (at high frequencies) in the water itself, and differences in propagation (=transmission) for different sound frequencies within the impulse. Sound speed varies with water temperature, salinity, and pressure, and thus there can be reflection and/or refraction at water mass discontinuities such as the seasonal thermocline (Richardson *et al*. 1995). In deep water, sound speed often varies with depth in a way that causes sound waves to be channeled within the water mass, resulting in low propagation loss and good propagation over long distances. Sound propagation characteristics may change as sound travels from a source in shallow water (such as the Scotian Shelf) to a receiver in deeper water (such as the Gully). Received levels are generally lower just below the surface than deeper in the water column, especially for the lower frequency components. This is a result of "pressure release at the surface" and interference effects associated with reflections of sound from the surface. These and other factors complicate the estimation of transmission loss and necessitate the use of sophisticated models (e.g., Davis *et al*. 1998).

Mr. Malme reviewed sound transmission loss studies conducted near Sable Island (see also Davis *et al*. 1998). He noted that sound spreading is spherical out to a distance of about 10 km, and then intermediate between spherical and cylindrical and cylindrical beyond that. Dr. Malme recommended that development of an acoustic propagation loss model for any sound source, including seismic, must include spectrum analysis and knowledge of physical factors which affect sound transmission loss.

As a brief review, the following table lists estimated underwater sound levels at a distance of 1 m from their sources. The received levels at a range of 50 m would be about 34 dB lower (Richardson *et al*. 1995). The dominant frequencies are given in the table. Frequencies are higher for outboards than for somewhat larger boats.

Vessel Type	Frequency (Hz)	Source Sound Energy (dB re 1 microPascal at 1 m)	Notes
Twin diesel[a] (34 m vessel)	630	159	
Trawlers[a]	100, 160, 200, 250 1/3-octave	158	
Outboard drive[a] (7 m boat, 2 x 80 hp motors)	630	156	Same level at 400, 500, 630 & 800 Hz 1/3-octave
MV *Sequel* [b] (12 m vessel)	250 to 1000	151	Fishing boat, 7 knots
Zodiac[a] (5 m boat, 25 hp)	6300	152	Outboard engine

[a] Malme *et al*. (1989) [b] Greene (1985)

Dr. Arthur Popper (Department of Biology, University of Maryland) presented an overview of the hearing abilities of fish, and the effects of seismic sounds on fish.

Dr. Popper described the fish octavolateralis system (comprised of the ear and lateral line; these two receiver mechanisms have similar receptors, innervate closely related regions of the brain, and have some small overlap in frequency range of detection). It is probably not true that the fish ear evolved from lateral line.

The fish lateral line responds to water motion (low level dc and acoustic levels to several hundred Hz), and detects signals that arise within several body lengths of the fish). On the other hand, fish ears respond to sound (30 to over 1000 Hz), and can detect signals at greater distances.

Most fish we are concerned with probably do not hear very well (e.g. groundfish, Atlantic salmon) and hearing abilities may extend up to 800 Hz. However, herring and closely related species such as shad are exceptions. Dr. Popper described the fish sensory hair cell (a sensitive biological accelerometer). These cells, which are the same cells as found in the mammalian ear, are found in the fish lateral line and inner ear and are responsible for converting mechanical signals (acoustic or hydrodynamic) to signals compatible with the nervous system. The sensory hair cell can sense direction as well as the presence of a signal.

Dr. Popper described why sound is important to fish; it provides information about their environment and it is also used by many species for communication in reproduction, territoriality, and other behaviours. Sound is directional, relatively fast, is not impeded by light or objects, and travels considerable distances underwater. He stated that “Sound is critical to fish”.

Fish produce relatively low frequency sounds that are often pulsive but can be continuous.

Fish hearing varies by species. Audiograms show the best sensitivity of an animal (or threshold) at each frequency tested. These often have a “U”-shape similar to that of other vertebrates (Figure 2). Most marine fish have best hearing sensitivity in the 500-800 Hz frequency range (although Dr. Popper suggested that some deep-water fish might have even better hearing). Some clupeid species (e.g., Atlantic menhaden, American shad) can hear frequencies up to 200,000 Hz (ultrasound) and thus, may be able to detect the sounds produced by marine mammal predators (e.g., dolphins).

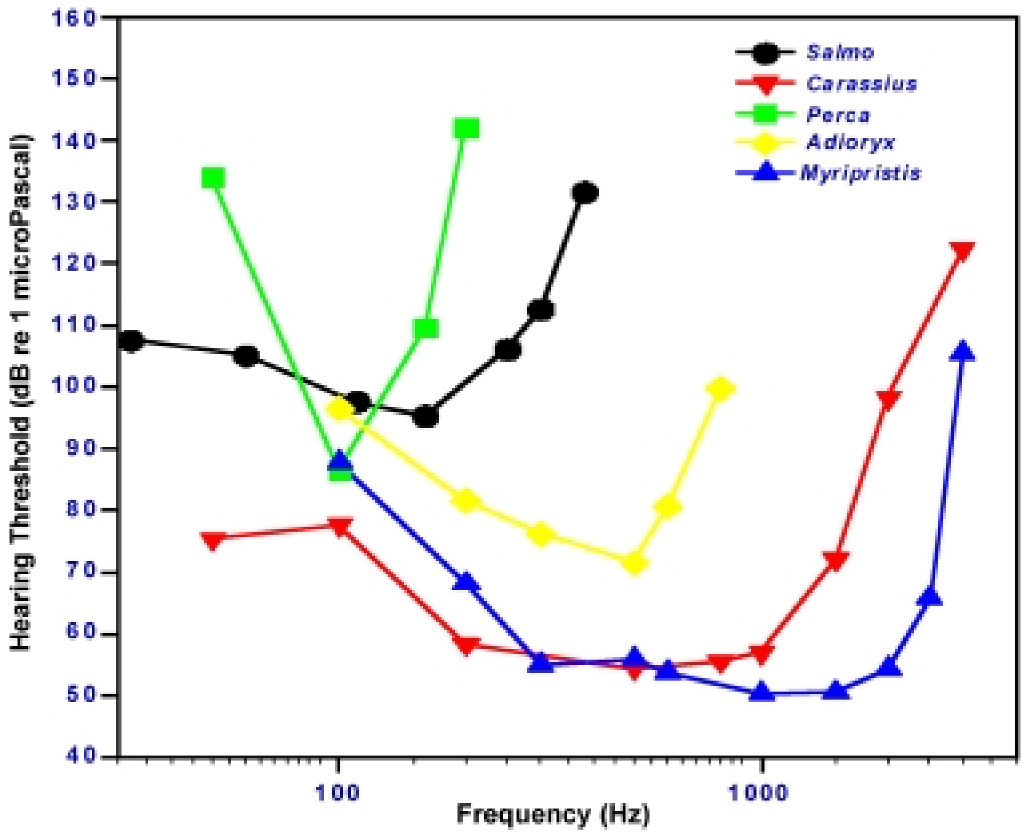

FIGURE 2. Hearing sensitivity of selected fish species (from data presented by Dr. Popper; *Salmo*= salmon; *Carassius* = goldfish; *Perca* = perch; Adioryx = *squirrelfish* and *Myripristis* = soldierfish).

Dr. Popper discussed the potential for anthropogenic masking of sounds received by fish by noting that background noise can interfere with fish hearing, and therefore affect fish behaviour if the animals are unable to detect normal environmental sounds, or communication sounds, that are important for survival.

Dr. Popper described the physical and physiological structure of fish ears and lateral lines. Since fish do not have an external ear they get direct stimulation from sound waves travelling through their bodies; and indirect stimulation when the swim bladder re-radiates sound (swim bladders can channel sounds of higher frequencies) (e.g., Popper 1983).

Brief exposure to high-energy sounds, or long-term exposure to lower-energy sounds, can both potentially cause hearing damage or behavioural effects (e.g., death, altered behaviour, physiological changes, damage to octavolateralis system). There is very little evidence regarding seismic effects on fish (e.g., Hastings et al. 1996), but this may be due more to the lack of (well-done) research as opposed to the lack of effects.

The work that has been done suggests that exposure to loud, long-duration sound could cause physical damage (e.g., Hastings et al. 1996). Unlike humans, there may be some regeneration of hearing capabilities in the damaged fish ear, at least for fish that have had hearing damage induced by drug exposure (Lombarte et al. 1993; Song et al. 1995). There is still a question that even if the sensory cells of the ear or lateral line regenerates, can the fish hear normally? Other questions include what seismic sound levels affect a species? Are there behavioural effects? What are the effects of seismic on different species? Does hearing regeneration occur?

There are few data for cod, and the experimental data on fish hearing damage that do exist are subject to many caveats. In addition, studies have not dealt with physiological effects that may result from stress rather than acute exposure damage.

Robert McCauley (Centre for Marine Science and Technology of Curtin University, Perth, Australia) presented an overview of experimental studies of the behavioural effects of seismic sounds on fish, sea turtles, squid and humpback whales (McCauley et al. in press)

Mr. McCauley's work (1) characterized the airgun's signal and sound source level, (2) analysed propagation (the seismic pulses did not propagate well except at low frequencies), (3) built an "exposure model" which required an understanding of the sea bottom and transmission loss characteristics, (4) documented humpback whale and sea turtle behavioural responses to the seismic pulses, (5) conducted controlled sea turtle, fish and squid (caged) trials, and (6) created a theoretical ear model.

For studies of the effects of a seismic source, McCauley's group studied a 2678 in^3 12-element airgun array with a receiver at 40 meters. During the ten cage exposure trials, a single airgun was towed past experimental underwater cages with subjects (such as fish, sea turtles and squid) which had been acclimated to the holding conditions. The subject animals' behaviour was videotaped and scored for position, swim speed and other patterns. These behavioural patterns and responses were correlated with the exposure distance and signal strength; e.g., a difference ratio [the proportion the number of video frames of fast swimming to the number of frames in which the fish was visible] was derived between exposed and non-disturbed measures of a variable such as swim speed.

Generally, fish swam faster and in tighter formation as the airgun approached (Fig. 3). Mr. McCauley's group also assessed cortisol hormone levels as a measure of stress response; they did not find significantly elevated stress levels at different intervals following the exposures. On examining the hearing organs at microscopic levels following airgun exposures (132-182 dB re 1 micro-Pascal), McCauley's group found surface pitting (perhaps due to some hair cell clumps being removed entirely), changes in the remaining hair cell orientation, and evidence of inflammatory repair response structures (hair-like filaments) on the macula (Fig. 4). The otoliths also appeared damaged in some cases.

Fish exposed a second time to the airgun sounds exhibited little or no behavioural response, and it was hypothesized that this might have been due to hearing damage. For example, at higher sound exposures, a model of the fish ear suggests that the displacement and oscillation of the otoliths in the fishes' ears may become great enough to cause mechanical damage.

Squid responded dramatically (based again on the difference-ratio alarm response) to airgun exposures (e.g., a strong flight response with ink release). McCauley described a study in the UK in which the catch of scallops declined after seismic surveys were conducted in the area; scientists hypothesized that the airgun sounds may have caused the scallops to swim up into the water column. The UK scientists further hypothesized that repeated exposures during the seismic programme may have exhausted the scallops and they were subsequently unable to swim up from the bottom in response to fishermen's "tickler chains" during the normal fishing process.

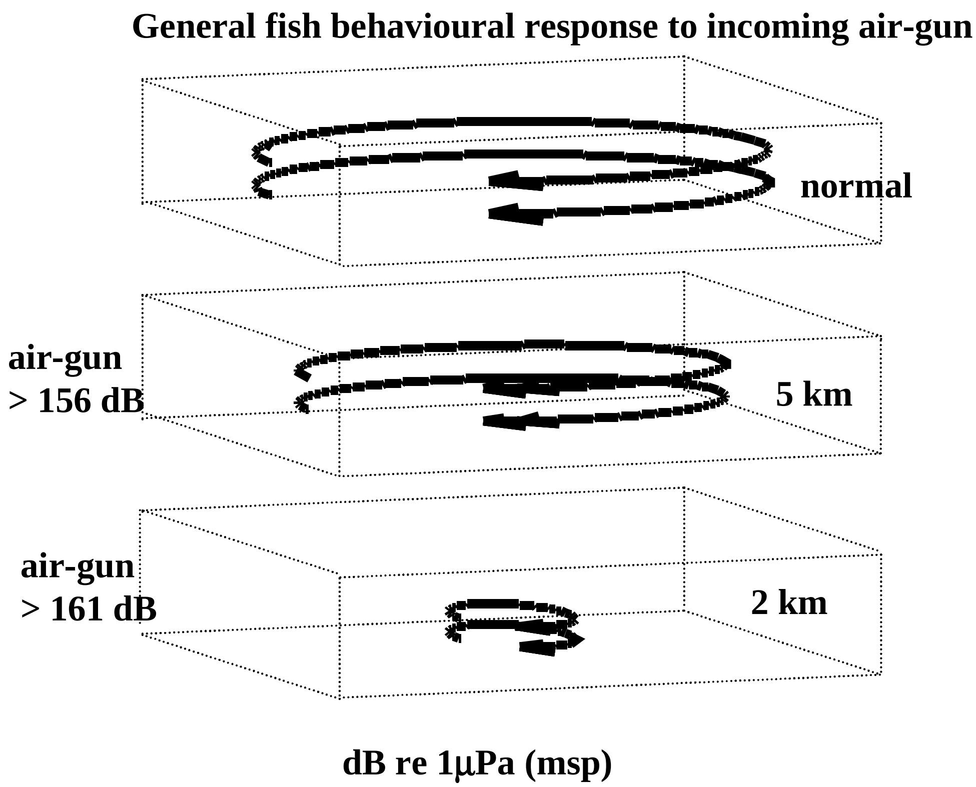

FIGURE 3. General fish behavioural response to an approaching airgun signal (as presented by Robert McCauley).

Mr. McCauley described an exposure modelling procedure (at what and how many points within a seismic grid would fish be exposed to sounds of sufficient loudness to reduce their availability to the fishery due to significant changes in their behaviour). Such modelling could provide a management tool if such modelling could be conducted before seismic was conducted.

Dr. Egil Ona (Institute of Marine Research, Bergen, Norway) presented an overview of effects of seismic sounds on fish catch, eggs and larvae.

The Norwegian coast has been the site of increasing numbers of seismic surveys (hundreds of thousands of line kilometres - often in important fishing areas). During this time, there have been several Norwegian studies on the impacts of seismic sounds on fish catch, eggs and larvae, sponsored by government and industry.

Dr. Ona provided a brief summary of Norwegian experiments and results on effects of seismic investigations on fisheries, conducted before 1992: these were contained in reports by Dalen and Raknes (1985), Dalen and Knudsen (1987), and Bjørke et al. (1991). Dr. Ona also described research since 1992 in greater detail.

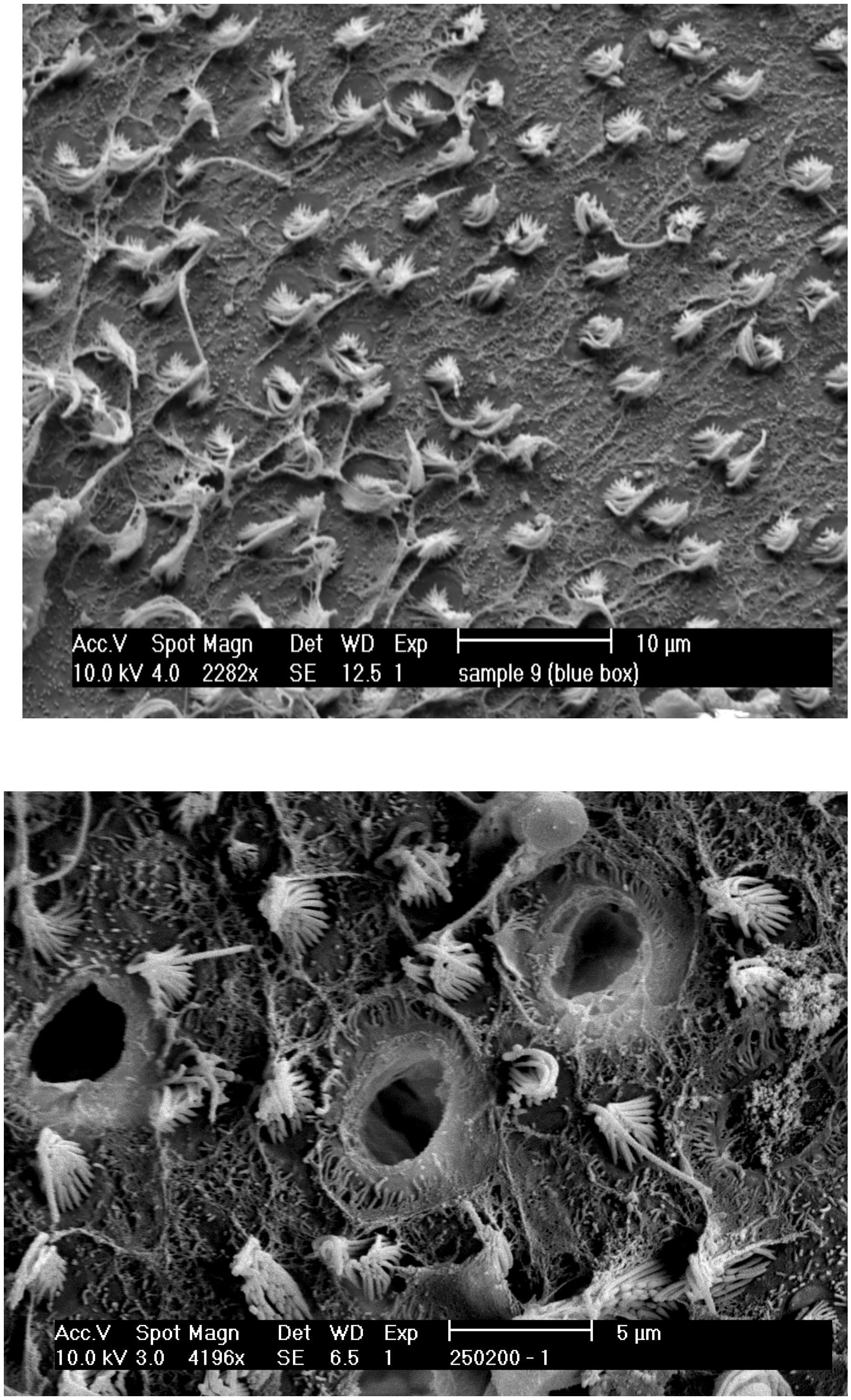

FIGURE 4. Macula (structure in a fish ear) before (above) and after exposure to airgun sounds (below). Damage to the hearing apparatus is evident as holes in the tissue where sound receptor structures are missing (as presented by Robert McCauley).

Løkkeborg and Soldal (1993) studied the influence of seismic exploration on cod (*Gadus morhua*) behaviour and catch rates by investigating data on reported conflicts between fishing and seismic operations derived from fishing vessel log books and seismic survey log books. The catch rates were reduced 55-85% for long line and trawl fisheries at distances up to 5-10 nautical miles. The bottom trawl catch results were variable.

Engås et al. (1993) studied the effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). In a three-week experimental trial (before [1 week], during [1 week], and after [1 week]), a full-scale, four-vessel investigation examined impacts of a seismic survey using a before-after study design in an experimental area (40 n.mi across). Fish density was assessed using survey and commercial bottom trawls, acoustic density profile measures, and long line catches. These surveys were conducted in survey grids prior to, during, and after a seismic vessel operated a full (82,000 cm^3=5,000 in^3) airgun array through the experimental area. Fish densities assessed using acoustic methods were different before (highest), during (much lower) and after (far lower) seismic shooting. In contrast, the longline data showed that the catch did not decline as rapidly and appeared to recover sooner. Large cod were believed to have moved out of the area within half a day after the onset of seismic activity (estimated to be a decline in biomass from 16,000 to 9,000 tonnes). While costly (more than $700,000 US$), they did find clear evidence that abundance and catch rates were reduced during seismic operations by 50-70% to distances up to 33 km (18 n.mi).

Booman et al. (1996) conducted a cage study of close-range exposure of fish, fish larvae and eggs to seismic sounds from an airgun cluster. Variables included distance to source (1-5 m) and depth of cage, with experimental and control subjects. Mortality and reduction in hatching success were not measurable beyond 2-3 meters distance from the airgun cluster. There was evidence of increased mortality in several groups, but only at ranges of less than 2 m.

Sætre and Ona (1996) undertook a worst-case risk analysis to estimate total mortality from one 3D seismic survey on a typical larval population near Norway. They used data from typical seismic areas and volume coverage, horizontal and vertical fish larval distribution, and estimated effective mortality radius. Results indicated that the maximum population mortality from one large 3D seismic survey would be only 0.45% (0.1 to 0.5%) of the fish larvae (0.18% of the total population per day). Since natural mortality is estimated to be 5-15%/day for eggs and larvae, or 1-3% for fish fry and 0-age group, the effects of seismic on fish larvae would be difficult to differentiate from natural mortality.

A report by Dalen et al. (1996) summarized the available knowledge on seismic and fisheries, and sought to give advice with respect to management practices. The main results of this study were that seismic investigations may be conducted safely in larval drift areas. Regulations now forbid seismic operations in Norwegian waters within 50 km of spawning areas and migration corridors during summer months when fish larvae and eggs are present.

Dr. Ona reviewed the regulatory structure for those companies applying for seismic permits (mainly dealing with issues of resource protection). Options include mitigation measures (e.g., the 50 km distance limit, timing of operations outside critical periods for fish, limiting operational duration) and outright bans.

Dr. Ona reiterated that there is still need for further research on the possible effects of seismic operations on different fish species. Such research might include:

(1) Effects on pelagic fish (e.g., avoidance experiments),

(2) Effects on sand lance eggs/larvae and adult fish in bottom sediment,

(3) Effects on small fish (e.g., do they have directional hearing?),

(4) Effects on fish species with no swim bladder,

(5) The efficacy of the present 50 km limit from the seismic source, and

(6) Development of seismic/fisheries interaction software-based management tools.

Management of seismic and fisheries interactions in Norway presently involves a series of governmental reviews that address issues of possible conflict (Fig. 5). All review levels must approve an application for seismic operation by a company before it can be initiated. If the seismic protocol has the potential to affect fisheries resources, the Institute of Marine Research can either undertake new research or, based on previous research, suggest changes in the timing or duration of the seismic operation so as to minimize potential impacts.

FIGURE 5. Management of seismic and fisheries interactions in Norway involves a series of governmental reviews that address issues of possible conflict (as presented by Dr. Ona).

Dr. John Skalski (School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington) presented an overview of statistical considerations in the design of studies of the effects of seismic sounds on fish; he used the California Rockfish Study as an example (Pearson et al. 1992; Skalski et al. 1992).

Dr. Skalski described a case study of the seismic effects on rockfish (*Sebastes*) in California in 1986. Based on cage studies, it determined that a 180 dB acoustical exposure level that was sufficient to elicit behavioural responses.

Dr. Skalski recommended conducting a preliminary study to yield better results and planning techniques (recommended spending 10% of a study's budget on a preliminary study). During their preliminary study, they established a standard unit of fishing effort (CPUE) to minimize sampling error; it yielded a coefficient of variation (CV) of 95.7%.

There are two kinds of statistical errors that researchers can make. They can make a finding of no effect when, in fact, there is an effect or they can find an effect where there is none (Type I and Type II errors). Statistical techniques have been developed to minimize the chance of making these two kinds of errors and to determine the numbers of samples needed to show a specified effect. Statistical power is a means to balance Type I and II errors. For their experiment, they selected alpha = 0.10, 1-beta = 0.84 and Δ = -50%. This turned out to require 20 control/mock emission trials and 20 emission trials to gain a power of 80% to detect a 50% difference in rockfish behaviour caused by seismic exposure.

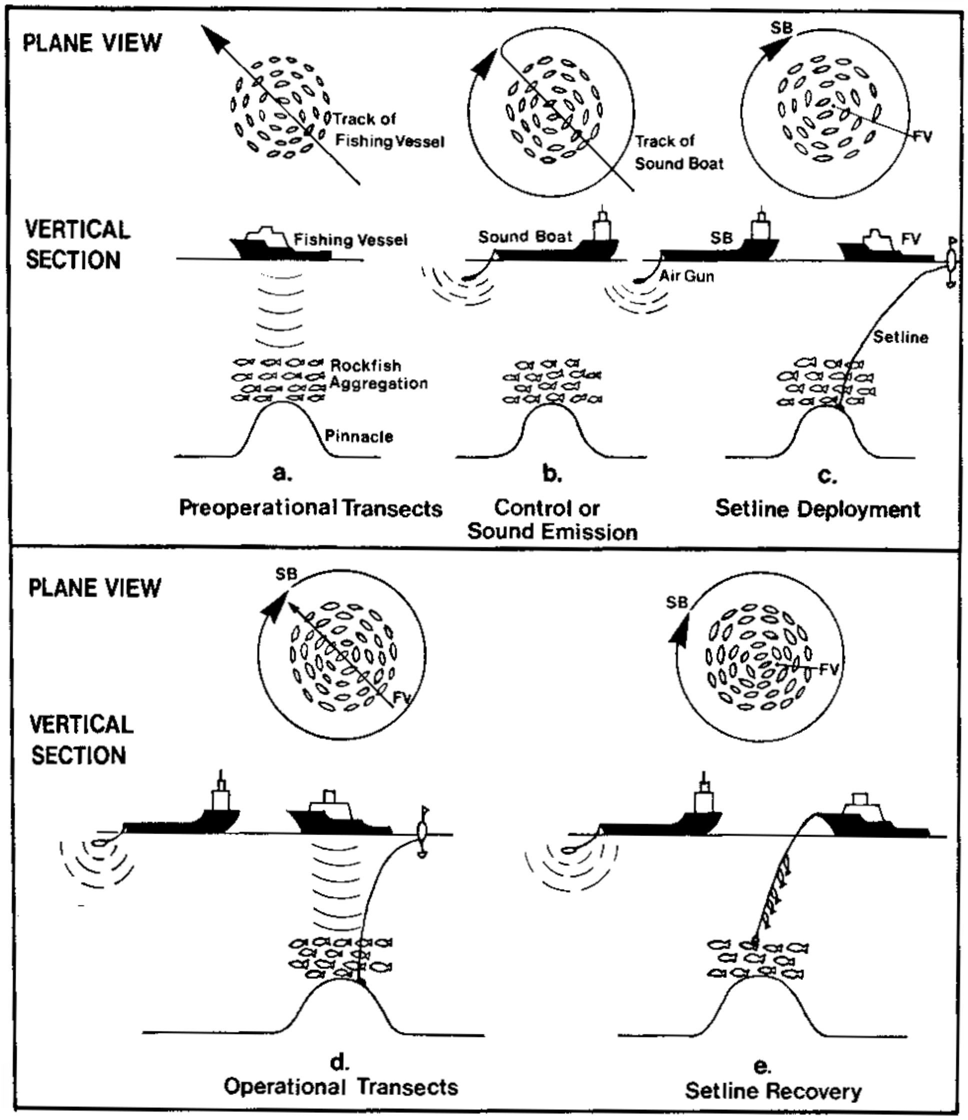

FIGURE 9. Fishing trial methodology to detect, characterize and collect California rockfish over experimental underwater rock pinnacles before and after exposure to seismic sounds (as presented by Dr. Skalski).

Dr. Skalski described the methodology used to detect, characterize and collect fish "aggregations" over experimental underwater rock pinnacles before and after exposure to seismic sounds (Fig. 9). Replication and randomization were integral to the design, with "blind" fishing trials (using a bubble source to eliminate visual cues to fishermen during control trials). Fishermen were "blind" to treatment choice to maintain integrity, objectivity and defensibility.

The study was designed so that pseudo-replication, lowered efficiency (e.g., the need for more trials to meet objectives) and sources of criticism were minimized. The design included measures of important co-variates such as water depth, species composition, and acoustic exposure levels.

There was a 52.4% reduction in CPUE overall (and 52.4-71.4% for individual species) with a loss in cash value of catches of 49.8%. The CI (-27.9% ≤ RC ≤ -76.9%) = 0.90. The rockfish that were studied aggregate at pinnacles and other features on the bottom. In responses to seismic sounds the fish aggregation flattens out. The height above bottom of these aggregations of fish were reduced during exposure ($P = 0.094$), although the horizontal size of the fish plumes did not change (although highly variable [CV = 270%] and therefore had low statistical power).

Dr. Skalski recommended that scientists keep the experimental design and analysis as simple as possible because it enhances believability and improves interpretation. A post experimental power calculation is mandatory if the experimental outcome indicates no effect is found (the hypothesis of no effect cannot be rejected). This test describes the power of the test to detect change. If the test had very low power to detect change then a finding of no effect could be made when, in fact, there was an effect.

Captain Ernest Syme (National Sea Products) described an interaction between fishing and seismic on St. Pierre Bank.

Captain Syme described an interaction between fishing and seismic exploration on St. Pierre Bank. His crew was fishing and catch ranged from 25,000 - 30,000 pounds per tow. When a seismic boat began operations, the catch dropped to several thousand pounds. Approximately one day later the catch rate appeared to have returned to pre-exposure levels. This occurred several times. Captain Syme also said that fish in the net were much more "lively" after exposure to seismic than they were normally. Despite seeing aggregations on their sounder, they could not catch these fish. Captain Syme suggested the fish may have had a heightened sensitivity to vessel and sonar noise after exposure to seismic sounds. (Fish are known to react to vessel and echosounder sounds [Misund 1997], but this does not usually prevent their capture).

Dr. W. John Richardson (LGL Ltd.) presented a description of previous studies to examine the effects of seismic exploration on marine mammals.

The subjects of these studies of seismic impacts have included gray whales (pre-1995 by Malme et al.), rorquals (UK monitoring studies by Stone), humpback whales (pre-1995 by Malme et al., western Australian study by McCauley [see above]) and bowhead whales (pre-1995 by Richardson et al. and Ljungblad et al.).

During initial studies of bowhead whales in the Beaufort Sea in the 1980's, the whales showed strong avoidance at 7.5 km distance (received levels may have been 160 dB), with reduced behavioural responses beyond this distance. These results were controversial at the time as the Inupiat hunters felt that the whales' normal migration route was "deflected" seaward as much as 35 miles before they reached a seismic operation area, and deflected as much as 30 miles when passing seismic vessels.

Monitoring programmes have since been designed to test the true magnitude of deflections from the migration route (avoidance) effects. These included vessel-based observers, directed aerial surveys, additional aerial surveys by Minerals Management Service (MMS) during their broad-range surveys of the Beaufort Sea, and acoustic recording methods (to characterize sounds exposure). The study went on for three years, during which LGL alone flew thousands of km of aerial surveys.

Based on the results of these recent surveys, plots of fall-migrating whale distributions relative to that of the seismic vessel showed a clear avoidance zone around the seismic source of approximately 20 km (unless the seismic sounds were blocked by intervening islands). Whales returned to the normal migration route within 12-24 hr following cessation of seismic operations. Received levels at this distance were 130 dB but were variable. Some bowhead whale avoidance was evident at 30 km where the received levels would be lower than 130 dB. Also, it is important to note that virtually all bowhead whales remained far outside the visual range of observers on the source vessels.

For fish studies of seismic effects, recommendations arising from the marine mammal research conducted to date could include:

- The effects of seismic operations might extend further than expected; thus, the survey design of seismic studies must be designed with sufficient scope to account for this,
- Natural biological conditions change over time and the possible effects of these changes must be accounted for in the study design and analyses,
- It is important to listen to stakeholder opinions and information (e.g., Traditional Ecological Knowledge), and
- Researchers must have adequate information on the received exposure levels (difficult given variable sound propagation).

Recently, researchers have used the ocean bottom hydrophone arrays to record and characterize the magnitude and propagation characteristics of seismic pulses. This method shows promise as an additional data source to supplement dedicated acoustic recordings.

Participants' Questions Following Presentations

Andrew Parker (C-NSOPB) stated that researchers should look at other areas of impact (not just CPUE for fish species alone); he mentioned crab, scallop, shrimp and other fisheries. **Denis Thomson** replied that the workshop agenda was not fixed and the purpose of the next part of the program was to set issues and priorities.

Norval Collins (CEF Consultants Limited) asked about the duration of the "after" effects in the Norwegian studies. **Dr. Ona** replied that this is still an area of interest and the duration of seismic effects on catchability is unknown.

Dr. Richardson asked **Dr. Popper** whether masking might be a problem for fish when the seismic duty cycle is so low. **Dr. Popper** replied that there have been no studies and this issue should be addressed; pulsive sounds could have TTS-type (Temporary Threshold Shift in hearing) effects subsequent to a string of exposures.

Dr. Ona suggested to **Dr. Richardson** that there are longer-term influences caused by multipath effects etc. such that the seismic exposure to a fish may be more or less continuous even though the primary seismic pulses may be discharged every 10 sec. Also, **Dr. Ona** stated that 130 dB may be the reaction levels for BOTH fish and whales. **Dr. Richardson** replied that peak levels might not be as important as signal duration considerations, and that the behavioural reactions of other whale species suggests that the 130 dB reaction thresholds for bowhead whales may not be the case for other species. **Dr. Richardson** also indicated that he felt that pulsed sources would not have as great an effect as continuous sources. **Dr. Popper** emphasized that more subtle effects might be just as important and result in behavioural responses at sound levels that might be lower than those that cause TTS or masking. **Dr. Popper** noted that communication is 'conscious sending of signals' and that there doesn't have to be a continuous signal to bother a fish (jackhammer analogy).

Brian Giroux (Scotia-Fundy Mobile Gear Fisherman's Association) queried whether an OBC (receivers on bottom rather than streamed behind boat) system would require an airgun array. **Dr. Richardson** replied that the airgun array is still towed whether the receivers are OBC or towed streamers.

Gerard Chidley (Fishing Captain**)** asked **Dr. Popper** about the development of ear bones in younger fish - do young fish have higher sensitivity, or different responses to acoustic stimuli than older individuals? **Dr. Popper** replied that older fish may have better hearing since their hearing system is better developed (although there are confounding factors, such as annual variability and reproductive season) - this needs to be studied. Ear bones occur in small fish but the swim bladder is smaller; one study he is currently conducting claims small fish do not hear as well as big fish. **Dr. Ona** noted that catch rates of older fish changed more than those for young fish when both were exposed to seismic. Functionally, the close proximity of the ears of smaller fish may affect their ability to localize (and therefore respond to) sounds. **Paul Fanning** (Fisheries and Oceans Canada) stated that small fish may be constrained in their responses by their size, relative to larger fish, and can't move as fast or as far.

Dave Taylor (D. G Taylor Inc.) brought up the issue of habituation in fish. **Dr. Popper** stated that data are limited, and suggested that some short-term habituation may occur. **Robert McCauley** concurred that there was some habituation, and smaller fish seemed "flightier". In his studies, there were classic 'startle' responses that dropped off after a few minutes. There can be two levels to the response and although they startle less after previous exposure, they may still leave the area of seismic operation.

Review of Fisheries Issues on the East Coast, and Results of a Pre-Workshop Stakeholder Survey of Seismic Effects on Fisheries

Dr. Trevor Kenchington (Gadus Associates) presented a review of fisheries issues on the east coast, and the results of a pre-workshop survey of stakeholders' concerns regarding the effects of seismic operations on fisheries. He reviewed important species, historical operations, principal fishing grounds, and fishing methods used in the Atlantic Canadian Fisheries.

Commercial catch rates in most fisheries are highly variable, so any effects caused by seismic exploration would be difficult to detect without a large and expensive sampling programme.

Catch rate estimates can often be obtained only from the more common smaller vessels employed in most fisheries (which therefore limit scope of work and logistic problems such as weather). Also, since a study might be based from a fishing vessel and since all fishing vessels are subject to fisheries regulation and limitations; therefore a vessel operating under a research permit requires more advance planning.

Dr. Kenchington detailed survey respondents' chief concerns regarding seismic effects on fisheries (see Appendix A for a full summary):

1. Death of animals and non-lethal injury effects (e.g., TTS) are significant concerns.
2. Do fish move or change their behaviour such that CPUE decreases.
3. Does feeding or spawning behaviour change such that future CPUE decreases?

Participants' Questions Following Dr. Kenchington's Presentation

Norval Collins (CEF) described a study of cod in Sydney Bight currently being conducted by DFO and fishermen that will use acoustically-tagged and bottom-mounted acoustic recorders to study the movements of these marked fish. The study has tagged cod from two stock groups and placed a 'picket line' of acoustic receivers, with the objective of determining whether fish from one area move out of one area into another.

Lesley Griffiths stated that the final report for this workshop will be available on three web sites (CNSOPB, CNOPB and National Energy Board)

Framework of the Research Programme

Facilitated Group Discussion

Denis Thomson listed the data gaps and the questions with highest priority that needed to be addressed. These included:

- Mechanism for effects on hearing,
- Thresholds for effects on east coast fish,
- Seismic effects on shellfish (scallop, crab, lobster),
- Masking effects of pulsed seismic,
- Long-term effects and recovery,
- Seismic effects on pelagic fish,
- Differences in hearing and behavioural responses to seismic of small fish versus large fish,
- Seismic effects on fish species with swim bladders versus those without, and
- Safe limits for spawning fish exposed to seismic sounds.

Trevor Kenchington distributed a handout detailing the summary of research suggestions arising from the pre-workshop stakeholder survey (see previous section and Appendix A). These research suggestions were then discussed by the group.

Comments and Questions From the Group

Several participants inquired about the availability of funds to conduct any research.

Wayne Eddy (Eastern Shore Fishermen's Protective Assoc.) and others expressed concerns that seismic testing and operations are already underway before these studies are to be conducted especially in spawning and nursery areas such as Sable Bank, some of which have been restricted to fishing by DFO. He noted that there was the recorded incident of loss of catch in area 3Ps due to seismic (Captain Symes experience, cited above). DFO's approach is precautionary with regards to fishing but not to seismic activities. **Ergil Ona** stated that in Norway, fisheries take priority and seismic operations must be approved with support of fishermen first; the procedure in Canada is less clear (perhaps the Norwegian process has been driven by previous lawsuits against seismic operators). **Andre D'Entremont** (C-NSOPB) stated that all seismic operations must first prepare a specific EA, and consult with fisheries interests that might be affected—the role of public consultation is foremost.

Brian Giroux suggested there should be more emphasis placed on behavioural issues than purely on catch concerns. **Norval Collins** disagreed with Brian, pointing out that changes in catch is the main way of monitoring seismic effects.

Earl Johnson (Fisherman, ESRF Member for Eastern Canada) would like to see if fish from an area could be tagged and captured before and after exposure to seismic sounds. This would determine if these fish are new immigrants to the area rather than returns or recaptures of "resident" fish as they recover behaviourally. He also wants tests of fish condition after exposure to seismic, and prohibition of seismic activities on spawning grounds.

John Brattey (DFO, St. John's) described DFO's tagging study experience and reiterated that there are large sample sizes needed to address questions since there are very low recovery rates for tagged fish (e.g., only 3 of 3,000 tagged fish were recovered in one study).

Paul Fanning suggested concentrating studies on behavioural effects rather than lethal effects and how these effects impact catchability, spawning success etc. Secondly, while supporting attempts to conduct experiments concurrent with present operations, he suggested we must not rule out directed studies which could be conducted without the logistical constraints of a "piggyback" on a commercial seismic or fisheries operation. **Laurie Wiglle** gave a cost estimate for a containerized seismic array (deployed on a trawler) of $30,000 per month.

Brian Giroux suggested that there are areas where field studies of seismic effects can be conducted on appropriate species and that have not yet been exposed to seismic exploration. Currently, there is sensitivity mapping being done with C-NSOPB, but two-thirds of the Scotian Shelf does not have the prospect of seismic exploration. **Mr. Giroux** felt that such field studies should focus on likely areas and relevant species, in particular the Cheticamp area and the Sydney Bight snow crab fishery. The deep water areas may lend themselves more to the large pelagic species (swordfish and tuna) and redfish. At the moment there is not a lot of directed fishing on Sable Island Bank and no evidence of seismic impacts on fish.

Paul Fanning disagreed with Giroux about the Scotian Shelf, suggesting that the eastern Scotian Shelf is the only place for a cod and haddock nursery.

Gerard Chidley raised the concern about seismic impacts on snow crab catches as "just about every Newfoundlander has a crab license".

Dr. Popper stated that there are no published data on the responses of crab to seismic sounds; several participants supported calls for a graduate-level study of the sound detection abilities of crab. **Dr. Ona** stated that there was a study (Kosheleva 1992) of the effects of seismic on a variety of invertebrates from exposure to a single airgun. Hearing and vibration sensors of invertebrates are different than those in fish. Several fishermen in the workshop believe that crab can detect seismic sounds.

Gerard Chidley mentioned an incident in NAFO Subdivision 3NO where crab catches dropped sharply after seismic operations were conducted in the area. **Andre D'Entremont** suggested use of a focussed breakout group on Workshop Day Two to design a crab/scallop/lobster study. **Dr. Gareth Harding (**Fisheries and Oceans Canada**)** noted that some benthic crustaceans make noise so there may be a function to sound and some species may have an ability to detect it.

An unidentified participant mentioned that sea perch (redfish, *Sebastes* spp.) is an important species on the South Shore of Nova Scotia and should be considered.

Norval Collins noted that a study of silver hake on Sable Island Bank may provide information on a species similar to cod in an area where there are seismic operations. With some argument, this example was retracted as too restrictive.

Gary Melvin (Fisheries and Oceans Canada) stated that there are differences in the logistics and reality/applicability of using a real or substitute seismic source (e.g., real seismic array versus a single airgun versus an underwater projector). There was a question of needing the seismic vessel to be separate; if it is the same there might not be the ability to react or manoeuvre. **Dr. Richardson** stated that these concerns have been the case in marine mammal work for some years, but that the applicability of using these smaller or alternate sound source do scale pretty well to those caused by a real seismic array, although directionality differences among sources comes into play. To look at some effects we need horizontal propagation estimates; smaller arrays can be designed to give a greater horizontal component. **Dr. McCauley** noted that good horizontal propagation is possible from a small array.

Bruce Batstone (Coastal Ocean Associates) asked for a monetary scale (level of effort) on similar seismic studies in other areas. **Dr. Ona** stated that a Norwegian seismic study cost 700,000 (U.S.$) plus in-kind support; the cost of the study on larvae resulted in the opening of an entire seismic operating season for the companies who had invested the funds. **Dr. McCauley** stated that the cost of their study would be $200-250,000 Cdn today. **Dr. Skalski's** California rockfish study would cost $500,000 US today. The Norwegian larval experiments cost $2,000,000 Norwegian, but were deemed cost effective for the industry, since results permitted regulators to open areas for seismic operations.

Bill Lang (U.S. Minerals Management Service) estimated that the cost of a proposed ramp-up study would be $750,000 US for the biological side and $1,000,000 US to move the seismic vessel to the Gulf of Mexico. **Dave Stanley** (BEAK International) reiterated the cost savings of "piggybacking" research on existing operations and initiating memoranda of understanding with industry.

Study Components to be Considered

Denis Thomson introduced the requirements for conducting studies of the acoustic properties of seismic sound. One of the following sound sources could be used.

(1) Real Seismic Operation	Real seismic operation; cannot select location for experiments as easily
(2) Real airgun array	Like real operation; select time and area; shorter duration so perhaps lower cost

(3) One or a few airguns	Not the real thing; cost may be lower?; selection of experiment location and timing important; need an adequate support vessel
(4) Underwater projector	Not as good as above; more control; lower cost; select location and timing, need an adequate support vessel

Denis Thomson stated that estimates of received sound levels were necessary and that this could be accomplished with the following combination of modelling and measurements:

1. Measurements at each location,
2. Modelling validated with measurements, or
3. Modelling alone.

Modelling would require information on water temperature, salinity and bottom characteristics, among others. **Mr. Malme** emphasized that continuous measurements of temperature and salinity were needed for modelling because these conditions vary. A propagation model, recording instruments, as well as physical measurements may be the best approach. A study could use continuous input of data to allow continuous validation of the model. This approach worked with a study of pile driving on the Sable Bank, Nova Scotia where model results were compared to actual measurements. In that study, a recorder 1.9 km from the source was used to estimate source levels. **Dr. Richardson** indicated that the option of modelling, plus measurement, seems like the best one.

Denis Thomson introduced the requirements for conducting studies of the biological effects of seismic sound (modelling and measurements in exposed and control areas). He suggested that the main test of effects would be a comparison of conditions in the study area and a control area before, during and after shooting.

(1) Before seismic (**not recommended**)	× in the experimental areas	× in the control areas
(2) During seismic	× in the experimental areas	× in the control areas
(3) After seismic	× in the experimental areas	× in the control areas

Where × is (are) the unit(s) to be measured such as catch per unit effort, some aspect of the behaviour of fish, direction of movement of fish, position of fish in the water column, etc. These could then be related to received sound levels to estimate levels associated with the onset of effects.

Dr. Skalski did not recommend the pre-seismic studies for this type of study because they would not provide additional information necessary to determine seismic effects, would add expense and would weaken the statistical basis of the experiments.

Dr. Ona noted that vessel avoidance by the fish could be a problem at the shallower depths used here (<200 m versus 500 m). **Denis Thomson** thought the effect would be a constant, but **Dr. Ona** disagreed and noted that it was very important.

Dr. Kenchington noted if you only have one control you have no estimate of variance. However multiple control areas may work. He would not necessarily expect fish behaviour to be similar between various areas

Dr. Skalski was asked what to do when there is no chance to conduct a BACI (**B**efore **A**fter **C**ontrol **I**mpact) or randomized design. He replied that the design is not obvious, although you do not necessarily need the "before" study. If the study is a 'true experiment', put more effort into true replicates. In a "during and after" study, the 'before' condition is used as a covariate. If you have to use real seismic (posed by **Dr. Richardson**), BACI is the most appropriate approach, and would use multiple study and control sites (e.g., repeat the experiment).

Dr. Ona noted that better statistical design might have improved the results of the Norwegian studies. Because trawling is a slow method of gathering data, you cannot account for the time factor when fish move out of the area quickly or environmental conditions change rapidly.

Discussion Topics and Format for Breakout Groups

A first attempt was made at identifying study priorities that should be addressed by breakout sessions. The following items were identified:

- Studies of sub-lethal effects, including acute exposure studies, investigating the behavioural responses of fish and the effects of behavioural responses on catchability and/or activities such as spawning,
- Studies of effects on catch, including temporal and/or species-specific variation,
- Effects on crab behaviour and distribution,
- Where seismic and fisheries operations overlap there could be opportunities for research on seismic effects,
- Study the sound detection abilities, and behavioural reactivity of invertebrates, such as crabs (laboratory studies and/or literature survey), and
- Acoustic properties and propagation modelling for seismic sounds.

Breakout groups were established to address specific kinds of studies, to discuss the relevant questions, and to design studies to address the questions. There was discussion about what kinds of studies should be done. The group agreed that there were four main areas of interest and that each should be discussed as a separate topic.

1a. Behavioural response experiments on fish (sub-lethal effects studied in a laboratory or highly controlled setting, and
1b. Behavioural response experiments on shellfish (hearing tests and sub-lethal effects in a laboratory or highly controlled setting).
2. Effects on behaviour/movement of fish, and
3. Effects on catch rates. Are there effects on large and small pelagic species? Are there catch reductions in East Coast groundfish; how long does catch reduction last and how far does it extend?

Three breakout groups were formed to address each topic. One group dealt with topics 1a and 1b and the other groups dealt with topics 2 and 3.

Study Design Issues

Denis Thomson presented a synthesis of what had been discussed and should be addressed by each breakout session when designing experiments.

(1) Use a pilot study with power analysis to produce optimal parameters for the main study. The main issues are to collect an adequate number of samples and to sample at an adequate number of locations.

(2) Is there a change? (Compare "Before" vs. "During" exposure conditions)

(3) How far do effects extend? (Sample a large enough area)

(4) Is there recovery? (Compare "During" vs. "After")

(5) How long does recovery take? (Sample over time)

(6) Should a reduced seismic array or a full seismic array be used for experiments? (Acoustic measurements need to be made with each experiment; some experiments, such as small cage work, can use measurements only; field experiments should use a combination of modelling updated with current temperature and salinity data and bottom mounted recorders).

If, after an experiment, the null hypothesis cannot be rejected (no effect of seismic), power analysis needs to be conducted on results to determine the power of the analysis to determine change. For example, suppose we conducted a hastily-designed field experiment and found no difference in experimental catch rate after exposure to seismic sound. A power analysis might show that, due to the influences of natural sources of variability (which we did not account for in our experimental design), we could only have detected a 99% change in catch rate. Alternately, such a power analysis might show that, due to the aforementioned sources of variability, we would have needed 200 replicate trials to show an 80% decline in catch rate. To minimize the risk of this kind of result, proper study design, pilot studies and power analysis prior to conducting experiments are highly recommended.

Dr. Skalski commented on statistical considerations for these types of studies; he compared and contrasted investigations here with the California rockfish study (Skalski et al. 1992). He noted that we must be careful to measure and, where possible, control for a variety of possible covariates, such as water depth, that could influence catch rates. Dr. Skalski also made the point that there are several types of study design available and that design choice would depend on the species being studied. With rockfish Dr. Skalski used a controlled study design because these fish were relatively stationary in an area; they did not move over large distances, even when exposed to seismic sounds (they did change their behaviour). Pelagic species off the Canadian East Coast are not so static. Pelagic, wide-ranging species might require longer-term or repeated studies (e.g., before, during and after measures). With pelagic species, we may have to build an investigation that starts with a simple model and sequential observations, measure a single variable and see if results fit the model predictions. Replication and randomization are important experimental design considerations. Finally, pre-exposure information may not provide much additional data on the effects of seismic exposure as fish behaviour may vary significantly on a seasonal and/or spatial basis.

To design appropriate studies, several topics were considered by each workshop breakout group. These included:

(a) Species and appropriate life stage to be used,
(b) Aims/Questions/Hypotheses to be addressed,
(c) Use of controlled experimental vs. field studies,
(d) Methods,
(e) Time frame,
(f) Crude cost estimate,
(g) Cost effective methods,
(h) Institutions capable of conducting the studies, and
(i) Use of traditional and anecdotal information from stakeholders (fishermen's reports, data collection).

WORKSHOP DAY TWO

Reports on Breakout Groups

Attendees divided themselves into three breakout groups on the morning of Workshop Day Two. In the afternoon, there was interchange of attendees among groups. It was felt that the interchange would stimulate the flow of ideas and help resolve contentious issues. The following sections summarize the results of the breakout sessions.

Experimental Protocol for *in situ* Studies of the Effects of Seismic Operations on Fish Behaviour

Rapporteurs: **Dr. Trevor Kenchington** (Gadus Associates) and **Patrick Stewart** (Envirosphere Consultants Limited).

(a) Species-Life Stage and Time Frame for the Studies

The species to be studied were discussed at length by the breakout group. It was thought that there were considerable advantages in focusing the available funding on a single species, rather than spreading it across several and ending with insufficient data to draw conclusions about behavioural impacts on any. However, it was pointed out that no conclusions about the impacts on herring could be extrapolated from the results of a study on groundfish or *vice versa*. Thus, it will be necessary to conduct separate experiments on those two fish groups. A third line of experiments should be carried out on halibut since it would be relatively easy. Halibut are robust and readily withstand handling and are not very mobile. Halibut would remain over an array of receivers for a prolonged period of time. Cod was selected as the groundfish species due to the difficulties commonly found in successfully tagging haddock or pollock (let alone redfish) (all these species show poor survival in tagging studies). Halibut cannot be detected readily by sonar, because they lack a swimbladder, while herring are hard to tag and are not amenable to tag-based experiments.

Experiments designed to use acoustic tags should involve cod in combination with echosounders. Such an experiment would likely have success on St. Pierre Bank, where reliable concentrations of cod occur, seismic activity and inter-jurisdictional interests overlap. The study should be conducted in the last four months of the year when cod are relatively plentiful, are suitably distributed, and seismic operations are scheduled for the area (see also recommendations from the fish catchability study group).

The herring study (using echosounders to locate and study the fish, perhaps on The Patch in the central Scotian Shelf), should be carried out before the cod study, both to develop skills and test methods that would later be used with cod. No further thought was given to the design of halibut and herring experiments, except for a suggestion that the halibut study could be conducted where they occur at deeper locations in coastal waters using acoustic tags only. That would allow the experiment to use primarily small, local boats—thus reducing costs. (**Dick Stewart** noted that halibut are now very scarce, making any experiments using them very difficult to conduct.) It was also noted that with herring, the task would involve observing the responses of entire behaviourally-synchronous schools, whereas with cod, and more so with halibut, the focus would have to be on individual fish responses.

A major concern was raised that the proposed work will take a number of years, whereas the currently-planned 3-D seismic surveys in offshore areas already under petroleum leases will typically be finished within five years. In the past, seismic surveys have tended to continue indefinitely in areas of interest to the petroleum industry, as more detailed information was collected, but the trend now is for 3-D seismic data to be gathered only once from each area.[1] Thus, the management issue might be over and any damage to fish stocks done before the research results become available. **André d'Entremont** pointed out, however, that other areas will be leased in the coming years and thus the petroleum industry will want to continue with seismic surveys for some time to come.

(b) Aims/Questions/Hypotheses for the Studies

This session was confined to discussions of possible research into fish behaviour, and the impacts of seismic-survey sounds on fish behaviour in the open sea. Catch rates or controlled experiments using caged fish were not considered as methods by this group because other groups addressed them.

(c) Experimental vs. Field Studies

The best way to conduct these experiments would be using field studies.

(d) Methods for the Studies

The use of a down-sized seismic array might produce a perception among stakeholders that the results of such experiments are not valid indicators of "real-world" impacts of seismic surveys. It would only be worth undertaking the study proposed above using down-sized arrays if there was prior stakeholder "buy-in" to the use of smaller arrays, with an agreement to continue to "full-scale" trials later if the smaller ones proposed here gave equivocal results.

There is a possibility that the tagged fish might respond to seismic disturbance in quite different ways than would untagged animals, particularly as a result of stress and damage caused during the capture, tagging and release process.

Short-term variability in fish behaviour (such as changes on a tidal cycle) may pose severe problems for the proposed experiment. This would be a particular problem when relying on hydroacoustic surveys, rather than acoustic tagging, as it is difficult to maintain contact with a fish aggregation over time.

The experiment would presumably need temporary fishery closures covering the areas of the receiver arrays since they would be placed in locations with abundant fish and yet would be susceptible to disruption by commercial fishing vessels seeking to operate in the same area.

It was noted that this sort of experiment would need to be accompanied by a publicity process to keep stakeholders fully informed of what was being done and why. The details of the design should be worked out with fishermen and other interested groups so that they understand what is

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[1] It should be noted that this has not proven to be the case in other regions (e.g., Alaska), where improving analysis technologies and a desire to characterize the changes in a producing petroleum reserve have necessitated repeated seismic surveys.

being done, the experiment benefits from their knowledge, and the process achieves stakeholder "buy-in". It is also, of course, necessary that the study meet professional standards for scientific research, thus ensuring that it is credible to all parties.

Preliminary studies would, of course, be required before any full-scale experiment could be conducted and the design of the final work would need to be modified in light of the initial results. (Some conceptual design for the full-scale work is needed nevertheless in order to determine what preliminary work is required.) Preliminary work should at a minimum, include:

(1) Trials to determine whether active acoustic tagging affects fish behaviour too severely and over too long a period for the proposed experiment to be viable (bringing the fish to the surface causes swim bladder damage which takes days to weeks to heal). Less invasive tagging methods might need to be adopted, such as attaching the tags to break-away baited hooks. That would require that the experiment be conducted in a time and place where cod, but only cod, take hooks or else would need a species-selective type of hook fishing, such as cod jigging. Capture of cod from even 50 m depth can result in swim bladder rupture, with prolonged consequences for the fish's ability to hear (though sensitivity to low-frequency seismic sound is less affected) as well as other aspects of the fishes' behaviour.

(2) Trials to determine the distances at which fish respond to seismic shooting by the experimental airgun array. This will not only determine the distance at which that gear should be towed past the array of receivers but will also show whether a "single pass" impact is realistic or whether mimicking even a 2-D survey requires multiple passes by the sound source.

(3) Initial trials with perhaps just an outer ring of seabed receivers to determine whether tagged fish do remain within a 10×10 km area for sufficient time to undertake a trial.

(4) Trials to determine whether cod dive into the "dead zone" (within a half pulse length of the seabed where they are not detectable with sounders or sonar) when stimulated by seismic sounds. If so, hydroacoustic surveys could not determine their behaviour and even acoustic tags might suffer detection problems.

Gerard Chidley suggested that an initial trial might be made in an enclosed bay so as to expose fewer fish to the seismic sounds.

Amidst other topics, the opportunities for behavioural experiments on large pelagic species were discussed briefly. It was agreed that planning for them would be premature until more detailed studies had shown whether or not those fish are sensitive to seismic sound.

Experiments designed to investigate the effects of seismic on the behaviour of spawning fish were also considered. There are conservation implications for experiments to expose a major spawning concentration to seismic disturbance in the course of an experiment, particularly since the current management position is that seismic surveys should avoid spawning grounds and seasons. Smaller spawning grounds might be risked in order to conduct a study, that might meet considerable opposition from local fishermen who depend on the fish from the selected spawning areas. On the other hand, knowledge of behavioural impacts on spawners is important in order to give scientific foundation to the existing management approach. It was agreed that the best way to proceed is to first study fish outside of spawning seasons and then to cautiously approach experiments on spawners, once the sound intensities that they will tolerate can be estimated with some reasonable precision. A smaller airgun array might be appropriate to limit any impacts. With groundfish, the effect is in any case likely to be displacement within extensive spawning grounds, unlike the situation with herring, which could be displaced from their small and discrete spawning beds entirely.

The possibility of using passive acoustics to detect fish activity (such as haddock spawning recorded as mating vocalizations) and the impacts on these activities caused by seismic sounds was discussed. **David Stanley** noted that attempts had been made to observe drum (a type of fish noted for its sound production) in the Gulf of Mexico by passive methods, but it had proven impossible to get quantitative measures of their activity. The group did not dismiss the potential for passive-acoustic approaches but there was no emphasis for support of this approach.

(e) Crude Cost Estimates for the Studies

The proposed experiment would be very expensive. The (disposable) acoustic tags cost approximately $1,000 Cdn each and the above design would require 225 tags just to test the effects of a "2-D like" seismic impact, plus a large number of moored and bottom-mounted receivers. The major expense, however, would be for ship time. It was recommended that there be three vessels involved. Towing the seismic array would require a large vessel, particularly because it would have to carry an air compressor with an estimated "footprint" for the on-deck package of 10×20 ft. The obvious solution would be a stern trawler that could trawl for fish to tag, as well as searching for fish aggregations with hydroacoustic equipment, when not towing the airguns. The other vessels could be smaller but would need to be equipped to run acoustic fish surveys, to track moving tagged fish with directional hydrophones and to deploy and recover the moored and seabed receivers, as well as being able to remain at sea for weeks. Each of the 15 proposed trials would be expected to take three to four days. However, with time to search for aggregations, plus down-time, preparation time in port, steaming time to the experimental area, it would be necessary to have each of the three vessels committed to the project for perhaps 120 days. With DFO research trawlers costing $15,000 or more per day (including crew, fuel and supplies), even the one large vessel required could cost nearly $2 million and the complete ship-time expense might exceed $3 million. Even if a cheaper vessel capable of operating the airgun array could be found, personnel and equipment costs are likely to drive the overall cost of the project to $3 million or more and that is only for the principal experiment into the effects of 2-D seismic surveys on cod behaviour. To that must be added the preliminary studies and the work on halibut and herring, plus any follow-up study examining the effects of 3-D surveys.

(f) Cost Effective Methods for the Studies

It was agreed that this experiment should be conducted separately from any trials of the effects of seismic sound on catch rates. Coordinating this experiment with a "real" seismic survey and also with commercial fishing operations would involve extensive down-time while waiting for everything to come together in time and space—if it were even possible to get all of the parts of a coordinated study together. Further, the large array of close-set acoustic receivers would also be incompatible with the nearby deployment of fishing gear. The only cost savings would be in operating the airgun array, since all other tasks for this experiment would still be required even if monitoring of commercial catch rates proceeded simultaneously. (Monitoring of catch rates would require work over extensive spatial and temporal scales, in contrast to the rather localized work proposed above. Thus, the vessels involved in the two studies would need to be in different places and to remain there for different periods.) Whatever the saving from the joint use of a common seismic source, it would be out-weighed by the costs of having the behaviour-experiment vessels and personnel waiting for a suitable conjunction between fish aggregations and the "real" seismic survey that is needed for meaningful studies of impacts on catch rates.

Norval Collins suggested linking studies of the effects of seismic sound to an existing DFO study of the migratory behaviour of two cod stocks in Sydney Bight (one a resident stock and the other migrants from the Gulf of St. Lawrence). That project is employing acoustic tags and on-bottom receivers (mostly arranged as a "picket line" down the edge of the Laurentian Channel). The group saw some merit in the idea but thought that it would be better to use DFO's study as part of the build-up of experience leading to the proposed experiment. It was pointed out that the Sydney Bight area has a problem of stock mixing which would complicate studies of behavioural impacts of seismic, while the timing of the DFO work would not readily match the schedule of any experiments into the effects of seismic.

Proposed Seismic Effects on Fish Behaviour Study Design

Paul Fanning outlined a proposed experimental design involving monitoring groundfish and pelagic species using a combination of ship-mounted sonar and acoustic transponder tags on individual fish, with an extensive array of on-bottom and moored receivers for the signals from the tags. (This was presented as an outline of a final experiment without the necessary preliminary studies, though it was recognized that those would be essential and would likely lead to substantial modifications of the proposal before it could be put into effect.) Much of the discussion during the session focused on developing this proposal concept. In its final form, which was still short of an operational design for an experiment, it featured the methodology described below.

Each control or experimental trial would be conducted on a separate fish aggregation. It was suggested that studies should include 15 aggregations (ten exposed to seismic, five not exposed). Each aggregation would require 48 to 60 hours (or as long as the fish remained available for study); the first 24 hours without stimulation and the remaining time with a passage of the "seismic ship", either shooting or not. (Plus 24 additional hours before observations for the tagged fish to recover from potential effects of handling and tagging.) Thus, the experiment would require 3 to 4 days per trial and 45 to 60 days to conduct all 15 trials.

Each aggregation of fish would be located using fish-finding sounders and sonar. This would require the involvement of experienced fishermen. The aggregation would then be surveyed using hydroacoustic equipment to develop a three-dimensional picture of fish distribution and behaviour.

A number of fish from the aggregation (perhaps 15—cost savings in tag use would be minor compared to ship-time costs involved in the experiment) would be caught and tagged with acoustic tags so that individual fish could be tracked over a period of days. This would require external tagging (T-bar tags) since recovery from the stress of tagging using internal tags can take as much as several days or more—by which time the cod aggregation could have dispersed away from the study site. The tags would provide location information for the tagged individuals but other types of behavioural data could also be obtained from them, such as depth, tail-beat frequency or heart rate.

An array of passive receivers (to detect the signals from the tags) would then be deployed around the aggregation. The array could be deployed prior to tagging and can be done relatively quickly. This array should cover an area no greater than 10×10 km; a sufficient area to observe fish behaviour over a period of a few days, provided that the seismic impact applied was not so great as to cause wholesale movement, out of the study area. The inner portion of this receiver array would involve moored receivers on a 500 m grid, possibly with radio links to the ships, allowing real-time, three-dimensional tracking of the fish. To minimize equipment costs, the outer portion could use on-bottom receivers at 1,000 m intervals that would have to be hauled at the end of each trial in order to determine, in two-dimensions, where the fish had been. (All receivers would have to be buoyed for rapid retrieval.) The ships used for the experiment would also be equipped with directional hydrophones to allow tracking of the fish and in particular determination of movements of any tagged fish beyond the array of receivers.

A period of observation would then commence which would include 24 hours for recovery from the stress and disturbance of the tagging and then likely 48 to 60 hours to observe behaviour, with aggregations typically dispersing within a few days of being first observed. A suite of identifiable fish behaviour types (possibly including depth changes and changes in swimming speed or direction) must be developed such that the behaviour of both tagged individuals and the aggregation as a whole could be scored at suitable time intervals through the observation period. Detecting such behaviour would involve continuous monitoring from the acoustic receivers, downloading and processing of data from the on-bottom receivers and repeated mapping of the aggregation using hydroacoustic methods.

Fish behaviour is expected to vary temporally and spatially. The study would attempt to describe the "state" of behaviour of the fish before and after seismic exposure (rather than the general pattern of "normal" behaviour). The initial 24-hour period of observation in each trial would determine the behaviour of the fish at that point in time. It was suggested that the five "control" trials would then continue for another 24 to 60 hours while the experimental protocol (see below) was followed in all respects except that the airguns would not be fired. In firing trials (10), the airguns would be fired during this later period. The "control" and "firing" trials would be randomized through the overall sequence but (pending experience from preliminary studies) no attempt would be made to operate a "blind" experiment as the data recording should not be subjective enough to require such complications. (Should a "blind" experiment be necessary, it might be better to record fish behaviour at sea but score it ashore. It would then only be necessary to conceal the firing or non-firing of the airguns from individuals in the laboratory, not from entire crews and scientific teams aboard multiple vessels at sea.)

At least in the first repetition of this experiment, the seismic source would pass the recording array once, while following a straight course (in a random direction); an imitation of the impacts of a 2-D seismic survey. The distance between the source and the array, at closest approach, would be determined so as to create some behavioural response by the fish without driving them out of the area of the array.

In subsequent experiments, the seismic source might pass repeatedly at different distances, thus mimicking a 3-D survey. Alternatively, "2-D" seismic source lines might be conducted at different distances from the array.

The sound source would be an array of airguns but smaller than those used in full-scale seismic surveys (but there were concerns from the some in the workshop group that a smaller array might not be as acceptable to stakeholders). This array should be designed to mimic the characteristics of seismic sound at some distance from the survey track but at a scaled-down intensity. That would minimize experimental disturbance to fish in surrounding areas, reduce the chance that the tagged fish would be driven entirely outside the array of receivers, and save the great costs of chartering a specialized seismic-survey vessel for the experiment.

The received sound intensities at the locations of the responding fish should be determined by using a propagation model in conjunction with field measurements taken at key points on the array of receivers and on the ships. The calibrated model would then serve to interpolate among the readings so as to give the intensities at any point of interest. (Archival tags capable of detecting and recording received sound levels are available but are too large for use on any but the largest fish.)

Following the period of behavioural observation, attempts will be made to capture the tagged fish (after locating them using the directional hydrophones) in order to determine whether physiological changes or sublethal damage had occurred during the experiment, as well as to recover and re-use the tags.

The areas to be used for this experiment should be those where "real" seismic surveys will operate or at least should be similar to such areas. It is desirable to get results that would be directly applicable to real surveys; this can only be done if the areas chosen for study have similar environments (and hence similar sound propagation and similar fish behaviour) to those where the surveys would occur. At the same time, however, it may be necessary to compromise this ideal in order to find sufficient fish for experimentation or to reduce costs sufficiently so that the experiment can be performed.

Unresolved Questions

There is a trade off on selection of the extent of the hydroacoustic surveys. Surveys covering a large area and tracked by ships would allow fish behaviour to be observed over a much wider area than a study that used an affordable array of fixed receivers. The large scale survey would have less precision than would tracking of multiple acoustic tags with fixed receiving gear. For any given amount of ship time, wider surveys would mean tracking fewer fish or fewer observations of more fish (though perhaps not more than with a fixed array.

There is a possibility of acoustic interference from other sources. The study site would have acoustic signals from multiple tags, sound pulses from hydroacoustic fish-counting equipment, plus the high-intensity (albeit low frequency) pulses from airguns. The acoustic receivers tracking the fish might be saturated by sound and unable to provide valid information on the positions of individual fish. The receivers should be tested under a variety of acoustic exposures to ensure their functionality prior to deployment in this experiment.

Catch Studies – Pelagic Species, Groundfish and Shellfish

Rapporteur: **Dr. Jack Lawson** (LGL Limited).

Spatial conflicts were considered to be the most common concern for fisheries/seismic interactions. Issues of multiple, overlapping or sequential seismic operations in the same area were also considered important.

The main issue addressed by the group were potential seismic-induced displacement of fish or reduced catchability of fish. Participants also felt that effects on spawning periods and areas should also be considered. This issue was addressed in the previous section.

(a) Species-Life Stage for the Studies

(i) Priority Species

Atlantic Cod.—Although there were concerns among some participants about the high variation in cod catch rates that are attributable to factors other than seismic, there is a strong desire to conduct a local study that generates conclusive results about the effect of seismic operations on the catchability of cod, rather than relying on the results of previous Norwegian studies. Several members of the group promoted the idea of considering NAFO Subdivision 3Ps as a study site since it is an area of combined jurisdiction [CNSOPB, CNOPB and France]. The main disadvantage of this area is that it is too small to conduct a large study such as the one done by Engås et al. (1995) off Norway or a follow-on study of how far effects extend and how long they last.

Redfish.—-This species is generally found on shelf breaks but is widely-distributed; they are long-lived and may be associated with cod in Newfoundland waters. This association could reduce experimental costs as catch rate data for both species could be obtained simultaneously. Redfish are good subjects for either acoustic or trawl studies and Norwegian type studies could be conducted on redfish.

(ii) Species for Feasibility Studies (first determine if catch studies are possible or necessary)

Snow Crab.—Studies on this species may be postponed until the "small studies" experiments demonstrate that these animals can indeed detect and respond to seismic noise. This species could be the subject of "elegant" statistical studies in that they can be caught and caged using the same methodology, and the distances between seismic sources and experimental cages can be manipulated precisely. Such precision is not possible with free-swimming fish. A pilot study is also required to determine baseline catch rates and required sampling effort to achieve sufficient data to measure seismic effects.

Swordfish/Tuna.—These deep water species are difficult to catch or tag relative to cod. It was believed that a pilot study of existing catch rate variability in the commercial fishery should be done to determine the experimental sample sizes that may be required in future to detect seismic effects. Results of this pilot study would determine whether a catch study was feasible.

Sand Lance.—A forage fish species of interest, especially near Sable Island, where seismic is being conducted. The Norwegians will soon be conducting a study of the effects of seismic on sand lance eggs. These eggs lie on the bottom and may sustain mechanical damage through vibration of sediment particles caused by seismic noise.

Capelin.—A forage fish species of interest, especially around Newfoundland.

Atlantic Herring.—An important species of international interest and a potential study subject. Experimenters must be cautious not to mistake silver hake for herring during sounder surveys. Any acoustic studies must require ground-truthing. Catch reduction studies would be difficult to conduct compared to other species.

(b) Aims/Questions/Hypotheses for the Studies

Given that we know there is evidence of seismic effects on cod catchability, is there evidence of post-operation recovery? How far does the decreased catchability extend from a seismic operation?

Is there evidence of seismic effects on catchability for pelagic species?

(c) Experimental vs. Field Studies

The only way to conduct these catch experiments would be using field studies.

(d) Methods for the Studies

Catch-based methods are expensive for directed sampling unless there is operational "piggy-backing" of fishing and seismic activities. This has been logistically problematic on the east coast so far. It is likely that fishermen will have to be compensated to conduct a properly-designed field experiment. If the number of fish near a seismic source declines, it is unlikely a fishing operation will continue in the area of reduced catch unless there is compensation. There may need to be incentives for seismic companies to operate in a study area.

Bottom trawling and pelagic trawling were considered as methods. Gillnets or long lines should also be considered and the best method appropriate for the species and area should be used. The variable to be measured would be catch per unit effort supplemented by abundance as measured with echosounder surveys.

The 3Ps/St. Pierre Bank area is considered to be the best candidate site for this study. FPI has groundfish survey data for this area, which could be analyzed as part of a pilot study. It was deemed desirable to examine existing commercial catch rate data to determine optimal locations to conduct the cod and redfish studies and to conduct power analyses to determine the study parameters (numbers of samples, % decline that could be detected, probability of making Type I and Type II statistical errors).

If a randomized design is used, participant vessels can not "target" their effort on fish aggregations as determined by their shipboard sonar systems and thus will be spending more time "fishing" in the experimental study areas than they might normally.

There are a variety of factors that influence the radius of seismic effects that could be studied. These could include (1) the possible distance that seismic sounds are above ambient levels; (2) the increased cost of sampling beyond the initial 10 km distance from the seismic source which was found to be the distance limit of most seismic effects in Norway; and (3) topographical boundaries for studies.

While there may be biological constraints to conducting these studies on cod and redfish concurrently, it may be useful to at least use the same research platforms and crews.

There were concerns from group members that using less than a full airgun source during seismic experiments would be unacceptable to fishermen, despite existing data showing that a smaller array could be designed to transmit similar sound energy into the water. It is possible to design a small array to have a similar horizontal sound output to a larger array. Given a fixed cost, it might be possible to design the experiment with more replicates and statistical power, if a small array on a charter vessel were used rather than a full sized array on a real seismic vessel. The problem with this approach is the public perception that a full-sized array would produce the most realistic results.

An offset, concurrent control area would require a duplication of the logistical requirements - but this would add power and credibility/defensibility to the experiment. There might be fewer sampling requirements in the control area, however (but then it would not be a balanced factorial design).

As a statistical concern, we should account for fish removals resulting from experimental sampling in areas of low cod or redfish density.

One could also approach the catchability problem using a non-catch assessment method (e.g., VEMCO's acoustic tagging system in which fixed receivers can detect the movement of tagged fish at ranges up to 2 km). The Norwegians planned to use such a system in controlled field experiments of seismic impacts by following the movements of 30 tagged fish before, during and after exposure to seismic sounds. They would also use a fish-following tag study with directional hydrophones to produce more extended movement trajectories.

(e) Time Frame for the Studies

Several group members suggested an examination of geo-referenced fisheries and seismic operations to determine areas and times of concern, then perhaps initially concentrate research efforts on these locations.

Each experimental replicate may last four weeks - although with the 10 by 10 n.mi area of sufficient cod density on the St. Pierre Bank, the cod survey may require less time.

Concerns were expressed that conducting studies at different times of year may produce spurious results since changes in water temperature affect seismic sound propagation. Some attendees suggested year-round studies. On the other hand, seasonal differences in fish behaviour that influence catchability may be more important than differences in sound propagation caused by variations in water temperature. In the end, it was agreed that both the cod and redfish studies should be conducted in the summer and fall.

(f) Crude Cost Estimates for the Studies

A fishing vessel costs approximately $6,000-$10,000 per day to operate; a seismic vessel costs approximately $30,000 per day. In the seismic study conducted in Norway, $125,000 was spent on a seismic vessel (five days), with an additional $15,000 per day for 30 days ($450,000) for a fishing vessel.

Thus, it was estimated that the minimum cost of a four week seismic experiment with one week of shooting would be at least a million Canadian dollars. This does not include the cost of collecting data on received sound levels (which might be done with ASARs or directed recordings), or the DFO, Fisheries Products International (FPI) and National Sea Products (NSP) fish catch databases.

Several members emphasized that there are many possible sources of funding for this research, other than the Environmental Studies Research Funding [ESRF].

A redfish study might be done with one large fishing vessel.

(g) Cost Effective Methods for the Studies

There was much emphasis on choosing study areas and times where seismic and fishing operations are already planned to occur so as to minimize costs (especially for seismic operations). The Norwegians further lowered costs by instrumenting seismic vessels with a scientific echosounder to assess fish densities between seismic shooting lines.

It may be possible to combine cod and redfish catch data collections, where possible, if there are periods of bycatch (e.g., October-November in 3Ps/St. Pierre Bank)

(h) Institutions Capable of Conducting the Studies

It was agreed that the research could be undertaken by a combination of local consulting firms and institutions with possible partnering with expertise outside Canada.

(i) Collection of Anecdotal Information from Stakeholders (fishermens' reports, data collection)

Traditional ecological knowledge will be very important in experimental design and feedback, particularly if FPI catch data are used in pilot studies. In addition, fishermen are knowledgeable about fish distribution, abundance and behaviour on local scales relevant to choosing study areas and methods.

After much discussion of the nine aforementioned topics, and with further feedback from members in the main session, the breakout group finalized the design of a directed study of the seismic effects on fish catchability. The design is presented in the table below.

Proposed Fish Catchability Study Design

Consideration	Atlantic Cod	Redfish
Pilot Study	DFO + FPI historical data	DFO + NSP historical data
Location	St. Pierre Bank	Laurentian Channel
Assessment Method	Bottom trawl + acoustics	Bottom trawl + acoustics
Extent of Effects	Same area sampled as seismic vessel is moved towards it (from 50 km)	Sample one large area at a variety of distances from the seismic vessel
Extent of Catch Reduction	Distance from the seismic array greater than the Norwegian study	Distance from the seismic array greater than the Norwegian study
Can We Measure Duration of Seismic Effects	Yes	Yes
Airgun Array	Full	Full
Season	Summer/Fall	Summer/Fall
Vessel Numbers	One fishing vessels and one seismic source vessel	Two fishing vessels (1 in the treatment area and 1 in a control area); one seismic source vessel
Vessel Equipment	Fishing vessel would have both a scientific echosounder (split beam) and fishing gear (instrumented to record trawl performance)	Fishing vessels would have both a scientific echosounder (split beam) and fishing gear
Sampling Design	Stratified random survey in the area where fish are normally caught, with sample size determined by a statistical analysis of the FPI groundfish catch data	Stratified random survey in the area where fish are normally caught, with sample size determined by a statistical analysis of the NSP groundfish catch data
Replicates	Two or three	Two or three
Duration of Study	Perhaps less than four weeks (with one week of seismic exposure)	Four weeks (with one week of seismic exposure)
Study Area	3Ps Limited extent	Shelf break unlimited area
Control Area	Only before and after sampling - not separate control areas	Control area close enough to minimize spatial differences in variables (perhaps 50 n.mi from the edge of the seismic area)
Other Considerations	Other vessels must be excluded from the trial area during the experiment	Other vessels must be excluded from the trial area during the experiment
	Short tow durations	Short tow durations

Small Experimental Studies - Fish

Rapporteur: **Leslie Griffiths** (Griffiths Muecke Associates)

These studies have a possible time frame of two to three years. All studies will require accurate acoustic modelling and measurement.

(a) Species-Life Stage for the Studies

The following species were selected based on their different types of ear structure, their current importance to commercial fisheries, and their ability to be successfully kept under experimental conditions. Swordfish is an important deepwater species, but it can not be kept under laboratory conditions.

Seismic Exposure Experiments	Ear Morphology Studies
Cod	Swordfish
Herring	Other large pelagic species
Flatfish	Redfish
Silver hake	Halibut

The morphology of the ear has not been studied for many species. Studies of ear morphology can yield data on the general hearing abilities of a fish at modest cost. **Dr. Popper** is interested in receiving good specimens, collected in the correct way, of various fish species. With these data, it is possible to make "semi-intelligent predictions" about a species' hearing range after looking at its ear structure.

(b) Aims/Questions/Hypotheses for the Studies

Hearing effects:

- What are the hearing parameters for each species (range and sensitivity to different frequencies?)
- Under what conditions does masking occur?
- Does seismic cause permanent change in hearing (PTS)?
- Does seismic cause temporary change in hearing (TTS)?

Behavioural effects:

- What is the immediate behavioural response?
- Does habituation occur?
- Does seismic interfere with migratory behaviour of cod?

Pathology Effects:

- Does damage to the fish ear occur?
- Are there endocrine effects?
- When and how does hearing damage recovery occur?
- What are the effects of seismic on different age classes of fish?

Implications of These Seismic Effects:

- If any of the above effects occur, what are the ecological implications for the fish?
- Are there concurrent effects on the fishery?

(c) Experimental vs. Field Studies

These studies would be carried out in both laboratory and field settings.

(d) Methods for the Studies

Fish would be caged in an open-water area (such as an enclosed bay). Then, the animals would be exposed to seismic sounds using the following protocol:

- make one pass with the seismic sound source, sacrifice a percentage of the animals to search for signs of physical damage,
- make additional passes and search for signs of physical damage,
- monitor behaviour during and after the pass, and
- monitor survival after the pass.

Later, place a number of fish (cod) into monitored holding pens to see if (a) recovery from physical damage occurs, and (b) behavioural or physiological problems emerge later. In addition, some of the caged fish would be released after attaching pinger tags and tracked for several days (as is being done in Placentia Bay, Newfoundland).

The ear morphology studies would be carried out in a laboratory. The fish would be dissected and the morphology of the ear compared to other fish with known hearing abilities.

(e) Time Frame for the Studies

It would take 2-3 years to get reliable results (but the answers are needed now - see comments at outset of subsection, above).

(f) Crude Cost Estimates for the Studies

Cage trials	$500,000
Cage and release	$250,000-300,000

(g) Cost Effective Methods for the Studies

The various studies in subsections (1) and (2) (shellfish and fish, laboratory and field) probably overlap and there may be opportunities to share costs, expertise and funding.

Small Experimental Studies - Shellfish

Rapporteur: **Leslie Griffiths** (Griffiths Muecke Associates)

There is minimal scientific literature about the effects of seismic on shellfish species.

Invertebrates use different kinds of sound receptors to detect sound energy and vibration than do fish. Sound detection would be tested when the animal is in the water column; vibration detection would be tested when the animal is on the bottom.

Crustacean larvae go through many life stages. During these life stages, crustaceans may occupy different ecological niches. This has implications for seismic studies. For example, when lobster larvae hatch they rise towards the surface and could interact with a seismic array.

All commercial species of shellfish move. They are not sedentary. Crabs can move up to 10 km a year; they tend to stop moving when water gets turbid. Depending on the life stage, larvae may direct their own movements or may simply move passively with currents.

Female crabs carry enough sperm to last three years. Female crabs spawn in muddy holes, and seem to congregate in known areas.

There is an anecdotal report of observed effects of seismic on crab fishing. **Gerard Chidley** reports that in an area off Cape Race, NF, catch rates were very high and were about 50 pounds per pot before seismic vessels started shooting. When shooting began catch dropped dramatically to about 1 pound per pot. The crab may have moved off into deeper water. Reports from fishermen 50 miles SE (where there was no seismic activity) indicated that there were no changes in crab catches there.

(a) Species-Life Stage for the Studies

There were four species of concern for the group:

- snow crabs
- lobster
- shrimp
- scallops (potentially both Icelandic and sea scallops)

Sea scallops are found mainly on Georges Bank (there was also some discussion as to whether the current moratorium reduced the immediate need to investigate this species); however, they are also found on St Pierre Bank and Western/Sable Island Banks.

Currently, seismic exploration plans involve shooting in areas where crab, shrimp and lobster are present but probably not scallops.

(b) Aims/Questions/Hypotheses for the Studies

The main questions to be addressed by these studies are:

- Can shellfish detect seismic sound?
- Can they detect seismic vibration transmitted through the sediment?
- If so, how? With what sensitivity? At what frequencies?
- For adults and larvae, are there pathological/sub-lethal effects of exposure to seismic sounds?
- For larvae (with an emphasis on late stage larvae):

Are there lethal seismic effects (percentage of population compared to normal mortality)?
Are there effects on settlement success (possible damage to sensory systems)?
Are there sub-lethal effects (damage to other systems, may take longer to become apparent)?

- For adults only:
  What are the behavioural/movement responses to sound or vibration changes?
  Would these responses change gonad development, recruitment, and/or spawning?
  Would these responses change availability to bait or traps?
  Are there seismic effects on shellfish pathology?

(c) Experimental vs. Field Studies

These studies would be carried out in both laboratory and field settings.

(d) Methods for the Studies

These studies would be conducted first on adult invertebrates.

Initially, adult animals would be exposed to sound/vibration in laboratory aquaria. Next, animals would be held in cages in a large bay and exposed to airgun sounds.
In both settings, the response types would be determined examining:

- behaviour
- endocrine and energy reserves
- pathology/sub-lethal effects
- gonad development

These studies would require trials with repetitive sound exposures, in addition to approaching and departing source sources (relative to the study subjects).

Monitoring methods would include:

- underwater video camera observations
- heart rate monitors
- histological assessments
- active tracking using telemetry

(i) Field Studies Using Full-scale Seismic Arrays

This work will require much collaborative effort with seismic operators, fishermen, regulators and scientists to look for CPUE effects before, during and after exposure to seismic sounds.

Initially, some effort should be expended to identify areas of potential or scheduled seismic/fisheries interaction. Then, experimenters would use the following techniques to investigate seismic effects:

- passive and active tagging
- towed underwater video recording
- caged animals for sub-lethal exposures

Would fishermen be willing to follow a randomized fishing pattern if this meant that they could lose catch versus their more efficient directed fishing techniques? If so, would they need to be compensated? The consensus of the group was that they would require compensation.

Is the double blind approach (as used in the California rockfish study described earlier by Dr. Skalski) a better way to conduct these experiments? In the double blind experiment, the fishermen do not know whether seismic is operating. A boat with the seimic array makes a pass and shows all evidence of shooting, however, some passes are made with active seismic and some with "fake" seismic. This reduces bias among the experimenters.

Is it possible to do a theoretical exercise looking at existing catch data prior to conducting these laboratory and field trials? This could be a useful exercise, but it may be difficult to identify the influence of other potentially confounding factors.

PanCanadian Petroleum Ltd. has started 2D seismic work north of Sable Island. **Stephen Full** of PanCanadian will ask fisheries consultants Canning and Pitt to obtain and analyse catch data (25-30 crab boats in area).

(ii) Field Studies Using Controlled Seismic Exposure

Initially, some effort should be expended to identify areas of high abundance of shellfish, and preferably individuals that have not already been exposed to seismic sounds.

This approach calls for the use of a small source array that can be towed by an ordinary vessel (such as a fishing trawler). The source is moved towards natural aggregations of shellfish or habitats of target species, with subsequent measures of:

- CPUE effects
- animal pathology (sub-lethal effects)
- changes in behaviour by tracking telemetered animals or underwater video recording
- histological changes

To measure variability, there would be a need to replicate a received sound grid pattern design that replicates different distances and received sound levels from a real seismic array. Using this approach, test animals could potentially be subject to multiple exposures and varying levels of seismic sounds and/or vibrations.

The group was unsure whether the behavioural confusion caused by such seismic exposure could kill these invertebrates through exhaustion or reduced feeding.

Would controlled seismic studies using limited sound sources (e.g., small airgun sub-array which had similar output characteristics to a large seismic array) be defensible to the public? How could the scientific value and experimental cost-savings be communicated effectively to stakeholders (i.e., it is not just "a cheap way out" as there are many advantages to this type of approach)?

(e) Time Frame for the Studies

Laboratory and bay studies	January 2001 to 2003
Field studies	2001/2002
Preliminary results	2002
Full seismic tests	January 2001 to early 2002
Some data available	2001/2003
Controlled field tests	January 2001 to 2003
Some data available	2001/2003

(f) Crude Cost Estimates for all Studies on all species

Laboratory studies	$500,000 over 3 years
Full seismic tests	$700,000 or $500,000 with in-kind support
Controlled seismic tests	$500,000 over 3 years

(h) Institutions Capable of Conducting the Studies

The following institutions and organizations could be involved:

- Fisheries and Oceans (BIO, Northwest Atlantic Centre, St Andrews etc.)
- Dalhousie University of Nova Scotia
- Memorial University of Newfoundland
- Consultants
- International collaborators
- Oil and gas companies
- Geophysical contractors
- Fishing industry
- Specialist acoustic groups
- DREA
- ESRF
- C-NSOPB, C-NOPB, NEB

Workshop Wrap-up Questions

After the presentation of the results of the breakout groups, there was a general discussion of the results.

There was much discussion about when proposed experiments could be expected to produce results. Many attendees suggested that research should initially focus on short-term projects like the laboratory experiments. These experiments could produce results within a relatively short time frame. For example, examination of fish collected near seismic operations for signs of physiological damage may provide some answers about the effects of seismic operations on fish. This approach would be most effective by examining tagged fish, or shellfish (crabs) in pots with nearby ASARs to examine physical effects of known exposure levels to seismic noise.

Throughout the workshop, fishermen stated that they wanted immediate answers. Since seismic exploration is currently underway, it may be preferable to employ a precautionary approach with regard to minimizing potential seismic effects (e.g., management regime, mitigation, protection of spawning areas). Fishermen felt that by the time studies were completed the seismic operations would be finished on the east coast.

The possibility of creating a GIS database of spawning aggregations was discussed, but the cost would be prohibitive and the present information would not be current (and would not remain current given the variation in biotic and abiotic conditions in this area). Several people pointed out that this kind of work was a DFO responsibility.

The study team was asked to suggest a means to take advantage of two vessels (fishing plus seismic) which will be operating in close proximity to each other in October 2000. An experiment could be designed to preliminary examine the duration and geographic extent of seismic effects. Power analysis will be important in designing the sampling regime for any experiment, and following the experiment, to determine the level of confidence in the results obtained by the research.

Basic anatomical studies of the hearing organs of redfish, swordfish and other fish could be conducted for $15,000-20,000 if fishermen and DFO could provide specimens.

Several participants raised research funding issues. While it was acknowledged that there are some ESRF funds that could be available in the short term, the funding applications would have to be submitted immediately. Subdivisions between short-, medium- and long-term studies might require varying funding solutions and approval timelines. In-kind support from seismic and fisheries will be important, but further logistic hurdles must be overcome.

The workshop concluded with a discussion of priorities for research. This topic is addressed at the end of the following section.

CONCLUSIONS AND RECOMMENDED METHODS AND STUDIES

This section summarizes the findings of the workshop. The following sections are meant to be a starting point for the design and prioritization of studies. The first sections deal with the general approach to each study and address study design, acoustic sources, and acoustic measurements. The sections that follow summarize the recommendations of the workshop participants with respect to methods that should be used for each type of study that was recommended. The final section recommends priorities for research, and discusses cost of studies and implementation of studies.

Considerations in Study Design

During the course of the workshop, participants received expert opinion, discussed theory and approach, and reached conclusions on common elements of several scientifically-sound and defensible study designs.

Statistical Considerations

Dr. Skalski recommended conducting a preliminary or pilot study focused on determining the variability of the response variable to be measured (e.g. catch rate, fish movement). The results of a power analysis on these data would determine the numbers of samples required to detect, with an acceptable level of confidence, a desired amount of change in the response variable. For example, if one wished to show a 50% change in echosounder density of fish, results of a power analysis of data collected during a preliminary study may show that 20 replicate samples are required in each of the study and control sites, before and after exposure to a seismic source. It is important to collect an adequate number of samples, and obtain these samples from an adequate number of locations.

Dr. Skalski recommended that scientists keep the experimental design and analysis as simple as possible because it enhances believability and improves interpretation. A power calculation after the experiment is finished is mandatory if the experimental outcome indicates that no effect was found (i.e the hypothesis of no effect cannot be rejected). The analysis would show how powerful the experimental design was in detecting change. It may be that no effect that was found because the test could only detect a very large change, larger than the one anticipated. In that case, the 'no effect' result may not be valid.

It was suggested that the main test of effects could be a comparison of selected variables in both study and control areas before and during (Is there an effect?) or during and after (How long does the effect last?) seismic activities are conducted. Some tests may require sampling before, during, and after seismic. The variables to be measured could include catch per unit effort, some aspect of the behaviour of fish, direction of movement of fish, position of fish in the water column, etc. Those variables could then be related to received sound levels to determine the levels that are associated with the onset of effects. The study should be designed to eliminate or minimize pseudo-replication (from a statistical perspective, repeated sampling that appears to be replicate sampling but is not), lowered efficiency (e.g., the need for more trials to meet objectives), and sources of criticism. The design should include measures of potentially important co-variates such as water depth, species composition, and acoustic exposure levels.

It was recommended that a Before vs. During design be used to determine if there is a change in the response variable and that a During vs. After design be used to determine if the response variable returns to pre-disturbance levels. For the catch studies, a During vs. After design was recommended. Before seismic sampling was not recommended because it would not provide additional information necessary to determine the effects of seismic noise, would add expense, and would weaken the statistical basis of the experiments.

Dr. Skalski also made the point that there are several types of study design and that the choice of design should be determined by the species being investigated. His group's study of California rockfish was a highly-controlled study because rockfish were sedentary in an area. The fish remained on their rock pinnacle, even when exposed to seismic sounds. Pelagic fish populations are not fixed in an area. Pelagic, wide-ranging species might require longer-term or repeated studies (e.g., "during" and "after" exposure measures). Investigations of pelagic species may need to start with a simple model and sequential observations. Even shellfish are capable of movement; a major question to be addressed is effects of seismic on distribution of shellfish, especially crabs. Highly-controlled studies of caged fish and shellfish are considered in a later section.

The Sound Source

Two potential sound sources were considered for the experiments. Most workshop participants believed that a full-scale seismic array, which necessitates use of a seismic vessel and increases costs, was preferable to a reduced array that could be operated from any vessel of suitable size. It was felt that the full array would lend more credibility to the studies, even though smaller arrays can be designed so that received sound levels are similar to those produced by a full-scale seismic array. Small arrays can be towed from a fishing vessel. Use of an underwater projector (playback of pre-recorded seismic sounds through an underwater speaker) was rejected because it appears that directionality differences among playback and real sources may become too great.

Acoustical Measurements and Modelling

Estimates of received sound levels are necessary to estimate effects in virtually all the proposed experiments. Because distance from the source is not a good predictor of received sound levels, such estimates must be obtained by measurement and/or subsequent modelling results. Development of an acoustic propagation loss model for any sound source, including seismic, must include spectrum analysis and knowledge of physical factors that affect sound transmission loss. Continuous measurements of water temperature and salinity are needed for such modelling because they affect sound speed, are variable, and can influence received sound levels. Further, continuous input of actual acoustical data would permit continuous validation of the acoustic model.

Because it would not be possible during large field studies to take measurements at each location where seismic work or sampling is done, a combined modelling and measurement approach seems like the best alternative for estimating received sound levels at the required distance from the source. (Small experimental studies conducted in a small fixed area could use fixed recorders only.) In large field studies, one would record the positions of the source and receptor, and model received sound levels at the receptor using up-to-date data validated with some field measurements.

Recommended Studies and Methods

Effects of Seismic Exposure on Fish Behaviour

Background

Discussions of possible research on the impact of seismic-survey sounds on fish behaviour focused on research in the open sea. Workshop participants identified three situations that could be studied.

(1) Acoustic tagging of cod, likely undertaken on St. Pierre Bank where reliable concentrations of fish occur and where seismic activity is expected to occur. This study would focus on individual fish, although echosounder surveys of the schools also would be done;

(2) An echosounder study of herring schools on The Patch (central Scotian Shelf), focused on schools of fish; and

(3) A halibut study on The Patch or in deep holes in coastal waters, focused on individual fish.

Use of a "down-sized" seismic array was considered but participants felt that its use might produce a perception among stakeholders that the results of such experiments were not valid indicators of "real-world" impacts of seismic surveys. It would only be worth undertaking studies such as those proposed in this section with down-sized arrays if there were prior stakeholder "buy-in" to the plan, and there was an agreement to proceed to "full-scale" trials if the ones using down-sized arrays gave equivocal results.

Experiments that would assess the effects of seismic noise on the behaviour of spawning fish were considered. There are serious questions concerning the ethics of exposing a major spawning concentration of fish to experimental seismic disturbance. It was agreed that the best way to proceed is initially to study fish outside of spawning seasons and then to cautiously approach experiments on spawning fish, once the sound intensities that they will tolerate can be estimated with some reasonable degree of precision. A smaller airgun array might be appropriate to limit any impacts.

Pilot Studies

Preliminary studies should determine the effects of acoustic tags on fish, the distance at which fish respond to seismic sources, whether fish remain within a predefined area (so bottom mounted receivers could be used), and whether cod dive to the bottom and cannot be detected by any means.

The breakout group recommended that studies of large pelagic fish should be deferred until smaller-scale studies determine whether the species of interest are sensitive to seismic sound.

Methods

The breakout group recommended that the full-scale behavioural experiment described in this section should be conducted separately from those designed to assess the effects of seismic sound on catch rates (see below).

Groundfish and, if deemed possible, pelagic species of interest, would be tracked using a combination of ship-mounted sonar (when possible), acoustic transponder tags on individual fish, and an extensive array of bottom and moored receivers.

Each control or experimental trial would be conducted on a separate school of fish. The experiment would consist of 15 trials (5 controls and 10 experiments), each lasting 3-4 days. Each aggregation would be located using fish-finding sounders and sonar. The school would then be surveyed using echo-sounding equipment to develop a three-dimensional image of fish distribution and behaviour within the school.

Acoustic tags would be used to examine behaviour of the fish before and after seismic exposure. About 15 fish from the aggregation would be caught at one time, tagged with acoustic tags, and tracked over a period of several days. The tracking would be done with an array of passive receivers deployed around the aggregation in a 10×10 km area. In the first repetition of the experiment, the seismic source would pass the recording array once, while following a straight course. The distance between the source and the array, at closest approach, would be determined to elicit some behavioural response from the tagged fish without driving them out of the area of the receiver array. In subsequent experiments, the seismic source might pass repeatedly at different distances.

The ships used for the experiment would also be equipped with directional hydrophones to allow tracking of the tagged fish, particularly those that swim beyond the array of receivers. Following tagging, the first 24 hours would be used to observe recovery from the potential stress and disturbance of the tagging procedure, and the next 48-60 hours to observe behavioural responses to seismic sounds.

Following the period of behavioural observation, attempts will be made to re-capture the tagged fish (after locating them using the directional hydrophones) in order to determine whether physiological changes or sublethal damage occurred during the experiment, and to recover and re-use the tags. The measurement of physiological change and sub-lethal damage would require a complicated set of controls (tagged and no seismic, not tagged and seismic, etc.). The breakout group estimated that the cost of this experiment might be several million dollars.

Effects of Seismic Exposure on Catch Rates

Background

The main questions addressed by this breakout group were

(1) Given that we know there is evidence of seismic effects on cod catchability, is there evidence of post-operation recovery? How far does the decreased catchability extend from a seismic operation?

(2) Is there evidence of seismic effects on catchability for pelagic species?

There was agreement that effects of seismic noise on catch rates of shellfish, especially crab, should be investigated. Full-scale field studies would be conducted only if results of the smaller-scale experimental studies (described below) showed that they respond to seismic sounds.

Catch-based methods using directed sampling are expensive unless there is operational "piggy-backing" of fishing and seismic operations. Fishermen leave an area if they are not catching fish. It is likely that fishermen will have to be compensated for their reduced catch rates if they remain to sample during a properly designed field experiment. Bottom and pelagic trawling were considered the most promising fishing methods to be tested.

The results of Norwegian experiments showed clearly that seismic activities reduced catchability of cod (*Gadus morhua*). Nevertheless, participants expressed a strong desire to conduct a local study that generates conclusive results about the effect of seismic operations on catchability of cod.

For the East Coast Canadian studies, workshop participants concluded that priority species should be cod and redfish (*Sebastes* spp.). Redfish are widely distributed along the Scotian Shelf break, and are thus good subjects for either acoustic or trawl studies. Several members of the group thought the cod study should be done in NAFO Subdivision 3Ps (St. Pierre Bank) because catch rates for cod were consistently high there and the area was targeted for seismic exploration. The main disadvantage of this site is that its area is too small to conduct a Norwegian-style field study related to catch reduction. Creative methods would need to be devised to design follow-up studies on how far seismic effects extend and how long they persist.

Swordfish and tuna are difficult to catch, tag, and study relative to cod. It was felt that a pilot study of existing catch rate variability in the commercial fishery should be done to determine the experimental sample sizes that may be required to detect seismic effects. Results of this pilot study would determine whether a catch study was feasible. Studies of herring and silver hake were deemed too difficult to perform.

Pilot Study

It was deemed desirable to examine existing commercial catch rate data, collected by Fisheries Products International, to determine optimal locations to conduct the cod and redfish field studies. Power analyses should be conducted on the data to characterize the study parameters (numbers of samples, % decline that could be detected, probability of making Type I and Type II errors, etc.).

Methods

If a randomized design is used, participant vessels would not fish in the usual manner, which involves searching for fish with echosounders and then targeting their effort on concentrations of fish. They would need to spend much more time “fishing” in the experimental study areas than they might normally. Fishing would be conducted in randomly selected areas within the area of known cod abundance. Echo sounder surveys would also need to be conducted in a random manner.

There are a variety of factors that influence the radius of seismic effects that we might be able to detect. They include (1) the distance at which seismic sounds are detectable above ambient noise levels; (2) the increased cost of sampling beyond the initial 10 km distance from the seismic source that was found to be the limit of most seismic effects observed in the Norwegian studies; and (3) topographical boundaries for studies.

There were concerns among breakout group members that using less than a full airgun source during seismic experiments would be unacceptable to fishermen, despite existing data showing that a smaller array could be designed to transmit similar sound energy into the water. Given a fixed cost, it would be possible to design the experiment with more replicates and statistical power if a small array on a charter vessel were used rather than a full-sized array on a real seismic vessel.

An offset, concurrent control area would add power and credibility/defensibility to the experiment but would require a duplication of the logistical requirements and cost.

Fish removals resulting from experimental sampling in areas of low cod or redfish density need to be considered for statistical purposes.

Ideally the study area would be one that is targeted for seismic exploration. However, the prime consideration for selection of an area is maximizing the chances of conducting a successful field study. The results can be extrapolated to other areas.

The following table summarizes the study designs considered by the group:

Proposed Fish Catchability Study Design

Consideration	Atlantic Cod	Redfish
Pilot Study	DFO + FPI historical data	DFO + NSP historical data
Location	St. Pierre Bank	Laurentian Channel
Assessment Method	Bottom trawl + acoustics	Bottom trawl + acoustics
Extent of Effects	Same area sampled as seismic vessel is moved towards it (from 50 km)	Sample one large area at a variety of distances from the seismic vessel
Extent of Catch Reduction	Distance from the seismic array greater than the Norwegian study	Distance from the seismic array greater than the Norwegian study
Can We Measure Duration of Seismic Effects	Yes	Yes
Airgun Array	Full	Full
Season	Summer/Fall	Summer/Fall
Vessel Numbers	One fishing vessel and one seismic source vessel	Two fishing vessels (1 in the treatment area and 1 in a control area); one seismic source vessel
Vessel Equipment	Fishing vessel would have both a scientific echosounder (split beam) and fishing gear (instrumented to record trawl performance)	Fishing vessels would have both a scientific echosounder (split beam) and fishing gear
Sampling Design	Stratified random survey in the area where fish are normally caught, with sample size determined by a statistical analysis of the FPI groundfish catch data	Stratified random survey in the area where fish are normally caught, with sample size determined by a statistical analysis of the NSP groundfish catch data
Replicates	Two or three	Two or three
Duration of Study	Perhaps less than four weeks (with one week of seismic exposure)	Four weeks (with one week of seismic exposure)
Study Area	3Ps - Limited in extent	Unlimited along slope
Control Area	Only before and after sampling - not separate control areas	Control area close enough to minimize spatial differences in variables (perhaps 50 n.mi from the edge of the seismic area)
Other Considerations	Other vessels must be excluded from the trial area during the experiment Short tow durations	Other vessels must be excluded from the trial area during the experiment Short tow durations

Smaller-scale Experimental Studies

Direct Effects on Fish

Some species such as cod may move away from the seismic area and not be exposed to seismic sounds for long periods of time. Other species, such as rockfish, will remain in the area when shooting is going on. The work that has been done suggests that exposure to loud, long-duration sound could cause physical damage to fish ears. There may be some regeneration of damaged sensory hair cells in the fish ear, but there is still some question as to whether such fish would hear normally.

The following species were selected for study based on their different types of ear structure, their current importance to commercial fisheries, and their ability to be kept successfully under experimental conditions. The swordfish is an important deepwater species, but it can not be kept under laboratory conditions.

Seismic Exposure Experiments	Ear Morphology Studies
Cod	Swordfish
Herring	Other large pelagic species
Flatfish	Redfish
Silver hake	Halibut

Fish would be caged in an open-water area (such as an enclosed bay). The experimental fish would be exposed to seismic sounds using the following protocol:

(1) Make one pass with the sound source, sacrifice a percentage of the animals to search for signs of physical damage;

(2) Make additional passes and search for signs of physical damage;

(3) Monitor behaviour during and after the pass(es); and

(4) Monitor survival after the pass(es).

Later, a number of fish (cod) would be placed into monitored holding pens to see if (a) recovery from physical damage occurs, and (b) behavioural or physiological problems emerge. In addition, some of the caged fish would be released after being tagged with pinger tags and tracked for several days, as has been done already in Placentia Bay, Newfoundland. Similar cage trial methods will be described in results of the Australian study by R. McCauley, to be published in the near future.

The ear morphology studies would be carried out in a laboratory. The fish would be dissected and the morphology and cellular microstructure of the ear compared, using various forms of microscopy, to control fish that had not been subject to the seismic sounds.

Effects of Seismic Exposure on Shellfish

There are no published data on the responses of crabs and lobster to seismic sounds. Some benthic crustaceans produce sounds, thus some also may have the ability to detect sounds. Several breakout group members believed that crab could detect seismic sounds. There was an incident in NAFO Divisions 3NO where crab catches dropped sharply after a seismic exploration program in the area. The catch reduction was not noted in more distant areas.

There were four species of concern identified by the breakout group:

1. snow crab;
2. lobster;

3. shrimp; and
4. scallops (potentially both Icelandic and sea scallops).

Laboratory Studies.—Initially, adult animals would be exposed to sound/vibration playback in laboratory aquaria. Next, animals would be held in cages in a large bay and exposed to airgun sounds. In both settings, the response types would be determined by investigating

1. behavioural responses;
2. endocrine and energy reserves;
3. pathology/sub-lethal effects; and
4. gonad development.

The studies would require trials with repetitive sound exposures and advancing and retreating sound sources (relative to the study subjects). Monitoring methods would include

1. underwater video-camera observations;
2. heart rate monitors;
3. histological assessments; and
4. active tracking using telemetry.

Field Studies on Crabs and other Shellfish Using Full-scale Seismic Arrays.—This work would require much collaborative effort among seismic operators, fishermen, regulators, and scientists to look for effects on CPUE (catch per unit effort) before, during, and after exposure to seismic sounds.

The breakout group recommended that, initially, some effort should be expended to identify areas of potential or scheduled interactions between seismic activities and crab fisheries. Then, experimenters would use those opportunities to employ the following techniques to investigate seismic effects:

1. passive and active tagging;
2. towed underwater video recording; and
3. caged animals for sub-lethal exposures.

The experiments would follow randomized patterns. Some members of the breakout group felt that it may be possible to do a theoretical exercise looking at existing catch data prior to conducting these laboratory and field trials. That could be a useful exercise, but it may be difficult to identify the influence of other potentially confounding factors.

Field Studies Using Controlled Seismic Exposure.—Initially, the breakout group recommended that some effort be expended to identify areas of high abundance of shellfish, preferably with little previous exposure to seismic sounds.

A small seismic array would be towed by an ordinary vessel such as a fishing trawler. The source would be moved towards aggregations or habitats of target species, with subsequent measures of

1. CPUE effects;
2. animal pathology (sub-lethal effects);

3. distance form the source and estimated received sound levels;
4. changes in behaviour by tracking telemetered animals or underwater video recording and
5. histological changes.

There would be a need to replicate the grid pattern design with the sound source. Therefore, test animals could potentially be subject to multiple exposures to, and different levels of, seismic sounds and/or vibrations.

Research Priorities and Recommendations

The workshop participants discussed priorities for future research. The following studies were deemed to be of worthy of consideration because they would provide key information about effects of seismic noise on valuable fisheries resources or were of great concern to stakeholders. Priorities for research were set by the study team based on the apparent priorities expressed by the majority of participants.

(1) The highest priority for Nova Scotia was considered to be studies of seismic effects on shellfish, especially crab and lobster, because nothing is known about their reactions to seismic noise, anecdotal information implies that there may be effects, and the fishery for them is very valuable. Studies would begin with laboratory experiments and experiments with cages in the nearshore environment. If the animals were found to react to seismic sounds, then experiments would progress to small-scale catch studies and then to the kind of full-scale catch studies described in Point 4, below. The cost of laboratory experiments, cage experiments and small scale catch studies for crab, lobster, and scallop, and limited studies of invertebrate larvae was estimated to be about $500,000 to $700,000 if all experiments were done.

The study team recommends that first priority be given to measurement of the behavioural reactions of crabs to seismic sounds in the laboratory and in small cages. The tests should be done in a graduated manner. The tests would be done as a series where Test 1 would determine whether crabs in the laboratory react in any way to typical seismic noise, other low frequency sounds, and vibrations and, if so, Test 2 would determine whether crabs in cages respond to typical received levels on the bottom and the duration and nature of such a response. If crabs were found to respond to seismic sounds, then experiments would proceed to Test 3, designed to determine if seismic sounds caused reduction in catch in a small-scale study. If seismic sounds caused a reduction in catchability, then full-scale field studies of effects of seismic noise on catch rates would be of very high priority, and a study such as that designed for cod in Point 4, below, should be done.

The cost of setting up and running each experiment would be relatively high, and there would be economies of scale if two or more species could be tested at once or sequentially. The cost of laboratory and cage trials on all four invertebrate species would be about $250,000 if done sequentially or if more than one species were tested at once. The study team would recommend that crab and lobster be tested first, at a cost of about $150,000. The initial laboratory tests on crab and lobster could be done for a relatively low cost (about $25,000 to $50,000, depending on the sophistication of the acoustic component). The initial tests would go a long way to answering the basic question of whether they react to seismic noise.

A small-scale field trial on one species would cost about $100,000 and would require some in-kind support and co-operation from fishermen. A full-scale study of effects of seismic noise on catch rates of crab would cost somewhat less than the one proposed for cod (see Point 4, below), about $500,000.

(2) An *ad hoc* study of effects of seismic noise on catch rate when cod fishing and seismic are scheduled for the same area was also of very high priority. There was a great deal of support for a limited kind of catch study that would show whether catch was affected on the Canadian East Coast as it was in Norwegian waters. This study would be conducted on an opportunistic basis when a seismic vessel and fish vessel were working in close proximity. The study should be designed with valid replication and so that efficiency is maximized (reducing the need for additional replicates) and sources of criticism are minimized. The cost may be about $50,000 plus. There may need to be compensation of the fishing vessel, as it would not normally fish in an area where it is not catching fish.

(3) The group felt that studies of valuable pelagic species were warranted, but conceded that such studies may be impossible to conduct because of large variability in the distribution and catch of these species. Anatomical studies of swordfish and tuna hearing structures should be conducted to yield information on their hearing abilities and provide some information on their susceptibility to seismic sounds. The cost would be about $15,000. In addition, a pilot study of variability in catch rates of large pelagic species should be undertaken to determine if catch studies are feasible. The study would be a statistical analysis of existing data on catch of swordfish and tuna. The cost would be less than $25,000. This kind of study should also be undertaken for other species prior to any field studies. Results could be used to enhance statistical power of the experiments. These studies would yield valuable results for minimal expenditure, and so are highly recommended.

(4) Field studies on the duration and extent on effects on catch of cod in area 3Ps and redfish on the slope were deemed to be of very high priority. These studies would take up where the Norwegian studies left off and concentrate on the distance at which effects occur and how long they last. Studies on catchability of cod like the Norwegian studies could not be conducted on St. Pierre Bank in area 3Ps because the area of high cod abundance is too small. Such studies could be conducted on redfish. The study should be done with a real seismic boat and fishing vessel. The cost would be $700,000 to $1,000,000, approximately the cost of the Norwegian study. The California rockfish study cost $700,000. This type of study is of lower priority that the first three on the list. We know that seismic reduces catch. This experiment is designed to address the questions, "How long do effects last?" and, "How far do they extend?" the study team does not feel that the study warrants a high priority because of the high cost and relatively high probability of obtaining poor or equivocal results (compared to other studies recommended here).

(5) Laboratory-based and small-scale experimental studies of behavioural and sub-lethal effects of seismic noise on fish were also deemed worthy of consideration. In the laboratory and in cages in nearshore waters, fish would be exposed to seismic sounds, and changes in behaviour would be monitored. Fish would then be examined for physical effects on hearing organs and changes in biochemistry that indicate stress. The studies recommended here would cost $250,000 to $500,000. Because set-up costs and costs of running the experiments (airgun source, acoustic measurements, cage maintenance) would be high, it would not be economical to run experiments on just one species or on one

species at a time. This study would have low priority. It has been done in other areas, and the general results could be applied to the East Coast. The study team recommends a scaled back version of this study that addresses effects on only a four or five species that include cod, herring, flatfish and silver hake. Emphasis should be on behavioural reactions and examinations for evidence of damage organs and tissues associated with hearing. The Australian study cost about $200,000 to $250,000 and examined about 12 species. However, it was done at a university with some low-cost labour and considerable support. Cage experiments on four species could cost about $100,000 and the necropsies about $15,000. However, the study team recommends that the services of Dr. Arthur Popper, or someone recommended by him, be retained to train a qualified East Coast scientist in methods of examining organs and tissues associated with fish hearing for damage. The scientist would bring some fish used in the experiment to Dr. Popper's (or alternate's) laboratory. Initial cost of the necropsies would be about $50,000 in the first (training year) and $15,000 in subsequent years. This scientist could also examine for damage in hearing organs and tissues in fish collected during other experiments.

(6) A behavioural study of effects on spawning was deemed of importance to resource managers. This study would use radio-tagged fish, bottom-mounted arrays of receivers (for tags), boats with receivers (for tags), and echo-sounders to study the behaviour of spawning fish exposed to seismic sounds. The cost would be about $2,500,000. Because of the prohibitive cost, this study would be given very low priority. If the necessary information were collected and made available (see below), potential effects could be mitigated by avoiding spawning areas at sensitive times.

Other studies briefly discussed at the workshop were as follows:

1. A GIS study that used existing data to map fish spawning locations should be done. It was agreed that this study was part of DFO’s mandate and should not be funded by ESRF. The study team recommend that the study of effects on spawning fish not be done. If mitigation by avoiding spawning areas is to be implemented, then this GIS study needs to be done by DFO.
2. Stakeholder knowledge of the attributes of fish that would be helpful, and in some cases essential, for designing studies should be assembled.
3. An additional potential study discussed by the group was the effects of seismic exploration on spawning migrations of cod. This study could be done off northern Cape Breton.

Implementation

Priorities for research would be based on the priority assigned to the project and the availability of funds. Stakeholders should be consulted prior to soliciting proposals, especially if their co-operation is needed to conduct the work. Proposals then would be solicited from interested parties to conduct the work.

The study team strongly suggests that each proposal for research contain provision for a Scientific Review Board for the study. The Scientific Review Board (SRB) would be an independent entity that would ensure the scientific integrity of the work and would enhance acceptance of results. The board would consist of six or seven members that included, as a minimum, a statistician, underwater acoustician, an expert on the species in question, one or two stakeholders representing the species in question, a scientist who has conducted similar research and representatives of industry. The offshore petroleum boards' advisory teams and ESRF Management Board could serve as a basis for the SRB. The SRB would review proposals for research, make recommendations about how the study should proceed, and review reports. The SRB would meet after project award to evaluate the proposed methodology and make recommendations as to how to best proceed. It would meet after the field/laboratory work is complete to discuss analysis, and again when the draft report is finished. The final results of each study should be a 'publication-grade' document.

It would be desirable to co-ordinate research programs with those being done in other countries, or at least to keep each other informed of plans for current and future research. Researchers would receive details of planned studies, preliminary results, reports on effectiveness of methods, and observations. Cost-effectiveness would be achieved by preventing duplication of effort.

There are several entities that could fund these or related studies and/or provide in kind support such as vessels, laboratory facilities and experimental areas. These include the Environmental Studies Research Fund, the Canada - Nova Scotia and Newfoundland Offshore Petroleum Boards, Department of Fisheries and Oceans, the fishing industry and the offshore oil and gas industry. The Workshop will provide guidance to the Management Board to help prioritize research, which they may eventually recommend to the Ministers of DIAND and NRCan for funding through the levy process. Because some of the recommended studies require complex support and logistics, co-operation among some combination of agencies NGOs, universities, stakeholders and industry would be required.

It would be desirable to co-ordinate research programs with those being done in other countries. There are five groups currently interested in conducting research on the effects of seismic exploration on fish.

- C-NSOPB, C-NOPB, ESRF on Canada's east coast,
- Institute of Marine Research in Bergen, Norway,
- Curtain University, Centre for Marine Science & Technology, Australia,
- Minerals Management Service, U.S.A. (not currently doing research, but may begin within several years), and
- Researchers in the U.K.

The first four groups were represented at the workshop and contacts are listed in Appendix C. Researchers in the U.K. were also active in this area. Results of a field study on effects on a nearshore fishery in England was summarized by Tunpenny and Nedwell (1994) and Wardle (2000; now retired) conducted a study on behavioural effects on rock reef fish. A contact in the U.K. would be Ray Johnstone, Environmental Protection Section, Fisheries Research Services, Marine Laboratory, Aberdeen. His address is listed at the end of Appendix C.

Contact with these groups should be established/maintained so that each is aware of what the other is doing. Each will benefit from sharing information in a timely manner, and cost-effectiveness will be achieved by preventing duplication of effort.

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APPENDIX A. PRE-WORKSHOP STAKEHOLDER SURVEY OF SEISMIC AND FISHERIES ISSUES ON THE EAST COAST

Griffiths Muecke Associates summarized results of a survey conducted prior to the workshop in which respondents were asked to provide answers to four questions. These answers were to be addressed by workshop participants during the design of experiments to study the effects of seismic operations on fisheries. The questions and answers provided by those surveyed are presented below.

1. What do you feel are the most important issues/problems that need to be addressed concerning the actual or potential interaction of seismic exploration and the offshore fishing industry?

- That seismic airguns could scare fish out of an area.
- The effect of seismic on larvae and on fish behaviour.
- The size of the area affected by seismic activity and the extent of the damage on fish. (Farwell, Seafood Producers Association of NS)
- What are the real effects? (as measured in the field, I don’t trust lab settings)
- What are possible mitigation measures?
- How much effect can be attributed to seismic and not just stock/seasonal/etc. variability?
- How can we develop a study that will be the definitive answer on effects? (We have too many studies now that contradict each other, and therefore have no credibility).
- Need agreement from everyone on the study design before any program is undertaken. (Full, PanCanadian)
- Biological effects e.g., damage to all life stages and behavioural effects on adults with effects evaluated in terms of significance to the species and significance to fishing operations. Operational effects. Also, space-use conflicts. (Lang, MMS)
- Fish health and reproduction, cumulative impacts of concurrent and adjacent seismic programs, seasonal differences in fish behaviour and movement, spatial variation, sensitive habitats, essential fishing grounds. (McNab, Oceans Office)
- It is critical that the issues are separated into those associated with the effects/interaction with the physical fishery and those associated with biology of the fishes. Both are important but require different approaches. Melvin, (DFO, Herring/acoustics) felt that the main issue should be: “Is there an effect on aquatic inhabitants in the vicinity of the seismic exploration activity, and if so how far reaching is it?”
- Impact of seismic surveys on spawning behaviour of finfish. (O’Boyle, DFO RAP co-ordination)
- Impact of seismic on fish spawning. (Taggart, Dalhousie University; Chapman GEAP)
- Vessel/gear interaction, biological impact (if known), priority use on the ocean, PR implication. (Peacock/Hansen, DFO Resource Management Branch)
- Timing of proposed seismic surveys and vulnerable life history stages present
- Amount of acoustic energy generated by survey equipment. (Stanley, Beak)
- The cost of lost fishing time; the low catch rates for the following 24 hours; physical impact on fish and larvae. (Mossman/Symes, National Sea Products)
- The short term and long term effects on renewable fishing resources be it groundfish, shellfish, or pelagic species. (Chidley, Captain, owner/operator)
- Effect of seismic exploration on fish stocks, long term damage, more than short term disruption of fish pattern. (Johnston, Fisherman, ESRF Board)

- Perceptions of impact to the fishery and fish are real, but data which exist are not sufficiently conclusive to demonstrate significant impacts. (Mead, Shell Canada)
- Short and longer term reaction of fish schools to seismic stimuli. (Lien, Memorial U)
- The magnitude and duration of behaviour responses in both pelagic and demersal fish species, as particularly sensitive times, e.g. feeding or pre-spawning aggregations. (Collins, CEF)
- Education of fishing industry/public/NGOs.
- Confidence building in government regulators and politicians.
- Bring the current focus on pressure groups (emotional) back to scientific fact. (Belford, JWEL)
- Education on both parts; timing of operations; specific species and areas of concern. (Kimball, Geophysical Services)

2. Which species are the most important to study?

- Regarding groundfish in NF waters, I would include cod, yellowtail flounder, Greenland halibut, American plaice, and redfish. (Brattey, DFO)
- Groundfish, herring, scallops, and lobster. (Farwell)
- Consideration should be given to selecting a sensitive species. (Chapman, GEAP)
- Each fishery group will have their own idea here, but in my mind (through looking at offshore blocks on the CNSOPB map) I would say that the swordfish fisheries would be one of the most important for Nova Scotia. However, everyone will probably steer towards cod, mackeral, haddock etc. (Full)
- No opinion. (Lang)
- Groundfish (cod, haddock, redfish, halibut), large pelagic species (swordfish, tunas, sharks), invertebrates (squid, lobster, crab, shrimp), prey species (e.g., sand lance), eggs, and larvae. (McNab)
- I was a bit disappointed to discover that cod appears to be the selected test species. Given the current stock status of this species it may be difficult to obtain sufficient catch rates in the study area. Other species (including pelagic species and larvae) may be more abundance in the actual exploration area then cod. The test species should be determined by their occurrence in possible exploration areas. (Melvin)
- Cod and haddock in 4VW. (O'Boyle)
- Groundfish, large pelagic species, crab, provided there are no large scale biological impacts. (Peacock/Hansen)
- Fish species with swim bladders. (Stanley)
- All groundfish species. (Mossman/Symes)
- Species which are non-migratory are most important due to the fact that you cannot work out a schedule of least impact. (Chidley)
- Cod, haddock. (Johnston)
- Let fishermen decide. (Mead)
- Herring and groundfish (cod, pollock, hake). (Lien)
- Cod, herring, lobster, snow crab. (Collins)
- Pelagic species, groundfish, marine mammals. (Belford)
- Unsure why one species would be more important than another. (Kimball)

3. What do you feel are the most important questions to be answered in the proposed offshore research program?

- How does seismic exploration affect normal fish behaviour?
- Does seismic shooting scare fish out of an area? Will fish return to an area later and if so, what percentage returns and after what time period?
- Is there any difference between 2D and 3D seismic on fish?
- What range of impact does seismic shooting have on groundfish?
- Are there any differences in the impacts on various species? (Farwell)
- See number 1 above. (Full)
- The existing background paper pretty much defines the key questions and seems to lead to concerns on long-term effects, habituation and, perhaps, cumulative impacts. To me, a very key question is how long do "effects" last when a seismic survey vessel passes through an area. A very important operational consideration before asking about the chronic, cumulative, habituation type questions is – what is the expectation for repeated exposures? In many situations, seismic operations do not represent a true chronic exposure event and this needs to be established. How long a given area is disturbed by a seismic survey event is a very key question but long-term effects may or may not be if repetition is several years apart or literally a one-shot event. (Lang)
- The "catchability" of fish appears to be the focus in the current proposal. What about physiological impacts and fish health? Behavioural modification that could effect mating rituals, reproduction and thus, recruitment? Effects on all year classes, not just mature fish ready for removal by the fishery? (McNab)
- The key question that must be addressed is " will the proposed approaches and tools actually address the questions being asked?" Or is there sufficient error around the approach to suggest uncertainty in the conclusions.
- Another important area of research is the effect and range on eggs and larvae of species in the exploration area. This has been outlined in the proposal, but the study species have not been identified. Again effort should concentrate species in the area. For example, if scallop larvae do not occur in the exploration area then studies of this species, while interesting, will not address industry concerns. (Melvin)
- Temporal and spatial distribution of spawning in relation to seismic survey activity. (O'Boyle)
- Where, when, why, what research done on locale and biology, alternate approaches, co-management applications, compensation. (Peacock/Hansen)
- Impact of exploration and development on the marine ecosystem and fisheries in the region. Education of managers, fishers and public on the impacts. (Stanley)
- What physical effects has seismic on the stocks, larvae and small fish? What effects on fish behaviour? (Mossman/Symes)
- Mortality rates on age groups of fish, habitat movement caused (if any), interaction between bait fish movements and bottom fish which interrupt the food chain. (Chidley)
- When fish are driven from an area is there any long term damage to them (as in old type seismic experiments). (Johnston)
- Are there measurable impacts on fishing success that can be directly connected to seismic operations? (Mead)
- Under what conditions can seismic exploration be conducted with the least impact on fish schools and the fishing industry. (Lien)
- The proposed methodology uses changes in fishing success for a range of gears to evaluate gross behaviour response and follows the Norwegian example. This is useful, but more emphasis on

studying what the fish are doing through tags and underwater video would help try to understand the behavioural responses. (Collins)

- What is the duration of effect on adult fish / mammals? (Belford)
- Long and short tem effects of seismic on marine ecosystems. (Kimball)

4. As we consider the structure of the research program, which elements or factors in the design do you think are critical to its success?

- Keep conditions (i.e. normal/common fishing conditions) constant as you measure fish before, during and after the seismic activity.
- Adequate funding to carry out studies recommended by the workshop. (Taggart, Dalhousie University
- Conduct studies in areas where fish do not, or are not migrating. (Chapman GEAP)
- Look at impacts at various distances from the seismic activity.
- Look for any patterns/changes in fish behaviour as a result of seismic activity in an area. (Farwell)
- Buy-in by Fisheries/DFO/CNSOPB/Oil and Gas on study design.
- Consideration towards logistics and availability (seismic vessels are transitory and expensive).
- Good look at variability question and how a real effect can be proven
- How mitigation measures (soft start, longer rise times) can reduce effects. (Full)
- Match your list of potential concerns to the reality of proposed industry operations to reduce interesting but not relevant experiments. Obviously a whole list of factors including costs, realistic field operations, statistically valid data, operational equipment and so on down to acts of God (good weather) are critical to success, but step one would seem to make sure what you study really is the problem at hand. (Lang)
- Hydrophone measurements of received sound levels to verify propagation models. Quantitative assessment of fish hearing and behavioural responses. *In situ* observations, possibly of caged or penned fish. (McNab)
- Elements critical to the success of this research program are the tools and approaches used to evaluate the impact/interaction of the seismic activity on the fishes and fishery. For example, the use of an echo-sounder to monitor the distribution and movement of fish such as cod is questionable. While hydroacoustics is used in some places to determine cod abundance, the use of this tool on a species that lives close to the bottom is uncertain. Furthermore, although the single beam system is likely to provide more area coverage than the trawling, it will be difficult to follow the movement of fish. A more appropriate tool would be a quantitative multi-beam sonar (narrow beam) with pan and tilt capabilities. Even then there will be a “dead zone” near the bottom where fish will be undetectable. (Melvin)
- Appropriate statistical design. (O’Boyle)
- Biological, timing, fisher interaction. (Peacock/Hansen)
- Workshop to identify issues (real and perceived), research to address the issues, public forums and education on results, revisit issues if required and identify new issues. (Stanley)
- Timing in offshore waters i.e. Halibut Channel. July and August are good months. For seismic work, fishing is very limited. Stocks are widely distributed and some have moved to inshore waters. Unsure if any spawning is taking place. (Mossman/Symes)
- A very open process with input from stakeholders; an action plan if problems arise due to effects on fishing / seismic gear. (Chidley)

- Some part of study should include captive fish to help answer #3. It is imperative to know if the fish are damaged or not. (Johnston)
- The up-front agreement by all parties on the design and objectives of any research project. Also need joint funding from government, oil industry, and fishing industry. (Mead)
- High resolution observation of school density, orientation and behaviour. (Lien)
- The length of time the study runs.
- Trying not to combine too many objectives so that results are unclear.
- Build on the experience elsewhere.
- Focusing on key areas of concern connected with the most important impacts: i.e.. effects on spawning or feeding behaviour at critical times. (Collins)
- Co-operation between industry and the fishing community, appropriate seasonality included in survey considerations, good science. (Belford)
- Oil industry participation, flexibility in studies to allow geophysical contractors to participate, minimizing vessel downtime. (Kimball)

APPENDIX B. LIST OF ACRONYMS AND DEFINITIONS

Airgun - A specialized acoustic sound source that creates underwater sound impulses by releasing a burst of compressed air into the water at great velocity.

Acoustic Intensity - is a fundamental measure of propagating sound, but is rarely measured directly. It is defined as the acoustical power per unit area in the direction of propagation; the units are watts/m^2. The intensity, power, and energy of an acoustic wave are proportional to the average of the pressure squared (mean square pressure) (for a more detailed discussion of acoustical issues see Chapter 2 in Richardson *et al*. 1995). For humans, sounds that are faint and barely perceptible have intensities near 1 pW/m^2, whereas those that are painful are near 10 watts/m^2.

Absolute Auditory Threshold - the minimum received sound level at which a sound with particular frequency and other properties can be perceived in the absence of significant background noise. A marine mammal can hear a fainter sound if the threshold is low than if it is high. The concepts of auditory threshold and auditory sensitivity are inversely related; a low threshold indicates high sensitivity, and vice versa.

ASAR - Autonomous seafloor acoustic recorder is an electronic recording device that is deployed to the seafloor where it records acoustic data for a period of time determined by battery life, storage capacity, acoustic sampling rate and duty cycle.

C-NOPB - Canada-Newfoundland Offshore Petroleum Board is a joint Federal/Provincial agency which regulates the offshore development of petroleum resources in Newfoundland waters.

C-NSOPB - Canada-Nova Scotia Offshore Petroleum Board is a joint Federal/Provincial agency which regulates the offshore development of petroleum resources in Nova Scotia waters.

CPUE - Catch per unit of effort. When conducting a study of catch, catch must be standardized for duration of tow, type of net and other factors such that catch rates can be compared.

Decibel (**dB**) - The marine mammal ear is sensitive to sound energy across a broad range of frequencies. This response is logarithmic, rather than nonlinear; thus acousticians employ a logarithmic scale for sound intensities and denote the scale in *decibels*. In decibels, the *intensity level* of a sound of intensity I is given by the equation:

$$\text{Intensity Level (dB)} = 10 \log (I/I_o)$$

where I_o is the reference intensity, for example, 1 pW/m^2. Because intensity is proportional to pressure squared, the *sound pressure level* (SPL) of a sound of pressure P is given by

$$\text{Sound Pressure Level (dB)} = 20 \log (P/P_o)$$

where P_o is the reference pressure, e.g., 1 µPa. The phrase “sound pressure level” implies a decibel measure and that a reference pressure has been used as the denominator of the ratio. When comparing sound sources in air and underwater, the “underwater scale” (dB re 1µPa) equals the standard “in-air” scale (dB re 0.002µbar) plus 26 dB (e.g., add 26 dB to aerial scales at re 20 µPa).

DFO - Department of Fisheries and Oceans is the Canadian federal agency responsible for fisheries and protection of ocean resources.

Environmental Studies Research Funds (**ESRF**) - A body that funds research related to the oil and gas industry and funded by a levy on participating companies.

Impulse - Authors discussing effects of explosions on animals often use positive acoustic *impulse* as the parameter related to effects. It is the total blast energy that an animal receives. Positive impulse is the integral of pressure over time, from arrival of the leading edge of the pulse until pressure becomes negative. Impulse is measured in Pascal-seconds (Pa·s); as contrasted with pressure, in Pa; or total energy in the pulse, proportional to $Pa^2 \cdot s$.

Inverse-square Spreading Loss - Sound levels decrease with distance from a sound source due to several factors. The most pervasive of these, inverse-square spreading loss, is a geometrical decrease of SPL by 6 dB with every doubling of distance from a point sound source.

Masking - Perception of biologically-important sounds is decreased due to interference by sound energy from other sources (including ambient noise).

Micropascal (µPa). A Pascal is a standard unit of pressure in the SI system of units. One Pascal is the pressure resulting from a force of one newton exerted over an area of one square meter. Older reports use a different pressure unit, the $dyne/cm^2$, also called a microbar (µbar). A bar is the pressure of 0.986923 standard atmospheres. The microbar and micropascal are directly related: 1 micropascal = 10^{-5} microbar. 20 µPa, is the sound pressure level at which responses of a young adult human to a 1 kHz tone are nominally at threshold, i.e. 70% positive, and takes the value 0 dB SPL. For humans, tone pulses and continuous noise that differ in sound pressure level by about 3 dB SPL are judged to be the same loudness.

NEB - National Energy Board.

Otolith - A small bone in the ear of a fish.

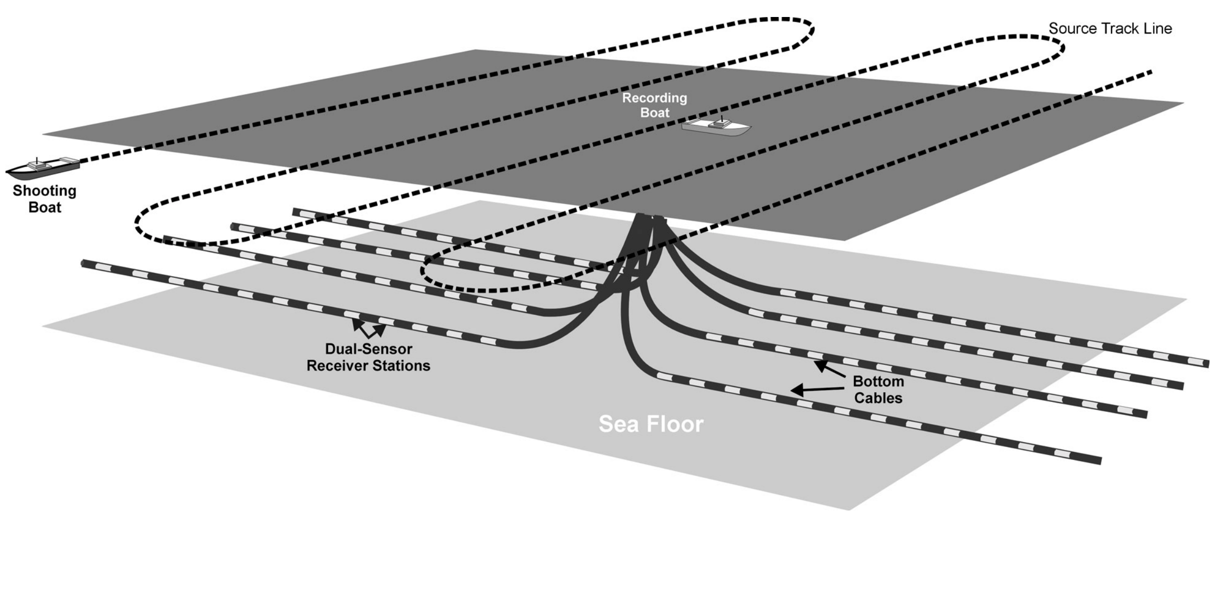
Peak Level - In describing a transient sound it is useful to present the *peak level* as well as some description of how the sound varies with time. The peak level may be described as being a particular pressure, or as a mean square pressure averaged over a relatively short interval. When transient sounds are so short as to be impulsive, they are best described in terms of their energy levels and energy density spectra.

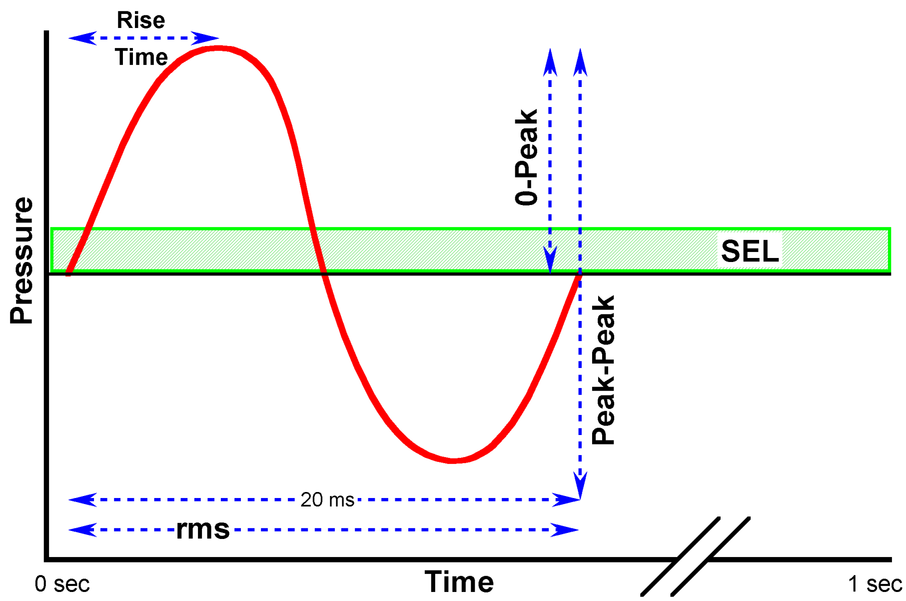
Seismic - The offshore oil and gas industry uses seismic exploration techniques to evaluate the geology that underlies the sea. These techniques involve beaming powerful sounds into the ocean bottom and monitoring the return patterns. Modern vessels conducting marine seismic surveys using the streamer method are 80-95 m in length and have a crew of about 40 people. The vessels are capable of travelling at about 14 knots (26 km/h) when in transit with no equipment deployed. When surveying equipment is in the water, vessel speed must be no less than 3.5 kts (6.5 km/h) and no more than 5.5 kts (10 km/h).

3D Seismic survey - In areas where hydrocarbons are known to exist in economic quantities, it is usually cost-effective to acquire a 3D seismic survey prior to the design and construction of production facilities. A 3D seismic survey provides a detailed ‘picture’ of the sub-surface, allowing the geoscientists and engineers to make realistic estimates of the amount and distribution of hydrocarbons within the reservoir. Marine 3D seismic surveys are carried out using high pressure "airguns" for the sound source. The returning signals (echoes) are recorded, during typical streamer surveys, by almost 3000 hydrophones (microphones) which are towed behind the survey vessel. For typical operations off the east coast of Canada, the seismic vessel tows 8 streamers. Each streamer is 4600 m long with 368 hydrophones spaced 12.5 m apart. The streamers are towed at a water depth of 7 or 8 m, and they are about 100 m apart; thus, the swath of towed equipment will be ~700 m wide.

2D seismic surveys are typically more regional in nature than are 3D seismic surveys. Survey lines tend to be much further apart (rarely closer than 1 km), and often are laid out in a number of different directions. The information that can be extracted from a 2D seismic dataset is much more limited than that available from a 3D seismic survey, but the 2D is appropriate for exploring large areas relatively inexpensively with the intent of identifying areas that warrant further exploration, perhaps the drilling of an exploration well or acquisition of a 3D survey. During 2D marine seismic surveys, the survey vessel tows a single streamer of between 4500 and 6000 m in length.

OBC Seismic Exploration - Ocean bottom cable system is a series of parallel cables containing acoustic recorders (hydrophones) that are laid out in a seismic "patch" rather than towed behind the vessel. The airgun is towed back and forth across the OBC array and the acoustic energy of the airguns passes down into the underlying geological structures and is reflected back to the OBC receivers. It can be used only in shallow water. In very shallow water, it is the only method that can be used.





Sound Exposure Level (**SEL**, also **Noise Exposure Level**) - Airborne impulsive sounds are usually measured on an energy basis, integrating the squared instantaneous sound pressure over a stated time interval or event to obtain the *Sound Exposure Level* or *SEL*. Usually, this value refers to a cumulative exposure to sound equivalent in energy to one second of sound at the stated level.

Sound Pressure Level (**SPL**) - Animals respond to sound as pressure. The corresponding subjective measure of sound intensity, "loudness", is closely proportional to pressure as long as the marine mammal is appropriately sensitive to the frequencies in the sound. For repetitive or continuous sound, a sound pressure level (SPL) is expressed as an average over a certain period of time. Because intensity is proportional to pressure squared, the *sound pressure level* (SPL) of a sound of pressure *P* is computed by:

$$\text{Sound Pressure Level (dB)} = 20 \log (P/P_o)$$

where P_o is the reference pressure, e.g., 1 µPa. The phrase "sound pressure level" implies a decibel measure and that a reference pressure has been used as the denominator of the ratio. Sound pressure levels are related as follows:

$$\text{SPL (dB re 1µPa)} = \text{SPL (dB re 1 µbar)} + 100$$

$$\text{SPL (dB re 1µPa)} = \text{SPL (dB re 0.0002 µbar)} + 26$$

For example, an SPL of -40 dB re 1 µbar, or re 1 dyne/cm^2, is 60dB re 1µPa (see Table 2.1 in Richardson *et al*. 1995).

Source Level - defined as the sound pressure level that would be measured at a standard reference distance (e.g., 1 m) from an ideal acoustic point source radiating the same amount of sound as the actual source being measured. This concept is necessary because sound measurements near large, distributed sources like ships depend strongly on source size and measurement location, and are difficult to relate to levels measured far away. Such near-field measurements are generally lower than would be obtained at the same distance from a point source radiating the same amount of energy.

Transmission Loss (**TL**, also **Propagation Loss**). A sound wave traveling from point A to point B diminishes in amplitude, or intensity, as it spreads out in space, is reflected, and is absorbed. If the source level (at 1 m) is 160 dB re 1μPa-m, the received level at a distance of 1km may be only 100dB re 1μPa; in this case TL is 60dB. TL is generally expressed in dB, representing a ratio of powers, intensities, or energies of a sound wave at two distances from the source. The distance at which the denominator measurement was taken is the reference distance for TL. Because dB scales are logarithmic, and log(ratio) equals log-(numerator) minus log(denominator), TL can be expressed as the difference, in dB, between the levels at the two distances.

Temporary Threshold Shift (**TTS**) - A temporary decrease in hearing sensitivity caused by exposure to sounds with high energy content, or large-amplitude pressure pulses.

Permanent Threshold Shift (**PTS**) - Unlike TTS, PTS is a permanent decrease in hearing sensitivity caused by damage to auditory organs following exposure to sounds with high energy content, or large-amplitude pressure pulses.

APPENDIX C. LIST OF PARTICIPANTS

The following is an alphabetical participant list for the workshop, and can be broken down as follows:

Fishermen or fisheries organizations - 9
Canadian government scientists (DFO) - 8
NS government (fish marketing) - 1
International scientists - 6
Regulatory agency personnel - 3
Oil and gas companies - 3
Consultants/technical personnel - 10
Project team 6

In addition to the international and Nova Scotian attendees, included above, were six participants from Newfoundland - DFO (2), fishermen (2), and consultants (2).

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