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# Report of the Seal Exclusion Zone Workshop

**11-13 May 2004**
**Cambridge Suites**
**Halifax, N.S.**

# Rapport de l'atelier sur les zones d'exclusion des phoques

**11 au 13 mai 2004**
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**Halifax, (N.-É.)**

**W.D. Bowen**
**Meeting Chairperson**

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## Foreword

The purpose of these proceedings is to archive the activities and discussions of the meeting, including research recommendations, uncertainties, and to provide a place to formally archive official minority opinions. As such, interpretations and opinions presented in this report may be factually incorrect or mis-leading, but are included to record as faithfully as possible what transpired at the meeting. No statements are to be taken as reflecting the consensus of the meeting unless they are clearly identified as such. Moreover, additional information and further review may result in a change of decision where tentative agreement had been reached.

## Avant-propos

Le présent compte rendu fait état des activités et des discussions qui ont eu lieu à la réunion, notamment en ce qui concerne les recommandations de recherche et les incertitudes; il sert aussi à consigner en bonne et due forme les opinions minoritaires officielles. Les interprétations et opinions qui y sont présentées peuvent être incorrectes sur le plan des faits ou trompeuses, mais elles sont intégrées au document pour que celui-ci reflète le plus fidèlement possible ce qui s’est dit à la réunion. Aucune déclaration ne doit être considérée comme une expression du consensus des participants, sauf s’il est clairement indiqué qu’elle l’est effectivement. En outre, des renseignements supplémentaires et un plus ample examen peuvent avoir pour effet de modifier une décision qui avait fait l'objet d'un accord préliminaire.

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## SUMMARY

In April 2003, The Minister of the Department of Fisheries and Oceans, Government of Canada announced a two-year science program to expand current research to advance our understanding of the complex interactions between seals and fish stocks. This programme had two main goals:

- to provide current information on the extent of seal predation on cod, and
- to provide scientific advice on management actions that could reduce current and future levels of seal predation on cod.

Seal Exclusion Zones have been advanced as a potential fisheries management tool. Although not explicitly defined, the concept appears based on the notion that by excluding seals from an area used by Atlantic cod, the reduction in seal predation mortality would promote the recovery of these cod stocks off eastern Canada. The use of a Seal Exclusion Zone (SEZ) to reduce seal predation of cod, and potentially other fish and invertebrate species eaten by seals, has an intuitive appeal. However, there has been little consideration of the feasibility and efficacy of SEZs in achieving management goals to reduce seal predation on depressed fish stocks, including Atlantic cod.

The Seal Exclusion Zone Workshop was held on 11-13 May, 2004, in Halifax, Nova Scotia to evaluate the feasibility and efficacy of SEZs. The meeting was attended by 19 participants from Canada, the United States, and Norway

Workshop participants concluded that excluding seals from an area will not be possible or practical in most marine environments. However, there may be situations where it may be possible to reduce the number of seals using an area. The ability to either exclude or reduce seals from an area will become dramatically more difficult as one moves from rivers to more open marine environments.

There appear to be few methods that could be used to exclude seals even from small estuaries let alone areas less well bounded by land. Physical barriers can be effective only in rivers, but negative effects on fish movement and high capital costs severely limit this approach. Translocation and acoustic deterrents are only partially effective in the short-term. However, there are known negative effects of sound on non-target species, such as odontocetes, which further reduce the practicality of using sound to exclude or reduce seals. Non-lethal removal is not practical because only small numbers of animals can be removed and there are high continuing costs of captive maintenance. Aversive conditioning has not been widely tested on seals, but evidence indicates that this will not be effective. Lethal removal can be effective for small numbers of nuisance seals that habitually forage in small, well-bounded areas such as rivers, but becomes less practical in larger, more oceanic environments or where the turnover rate of seals is high.

A process for selecting candidate areas for a SEZ/SIRZ should consider characteristics of the species of conservation concern and the predator, physical feature of the site, and potential ecological effects on non-target species. Once a site has been evaluated on the basis of these criteria, the likely benefit of the SEZ/SIRZ should be assessed. This can be done in several ways, but modelling alternative scenarios is strongly encouraged.

Conducting experiments to test the effectiveness of SEZ/SIRZ with respect to cod will be extremely difficult and in many cases may not be possible. Given the multi-year duration and considerable cost, such studies need to be well planned and an initial evaluation should be undertaken to estimate the likelihood that implementing a SEZ/SIRZ would have a positive effect on cod.

## RÉSUMÉ


En avril 2003, le ministre des Pêches et des Océans du gouvernement du Canada a annoncé le lancement d'un programme scientifique de deux ans visant à étendre les recherches entreprises jusqu'ici dans le but de faire progresser notre compréhension des interactions complexes entre les phoques et les stocks de poisson. Ce programme vise deux buts principaux :

- obtenir de l'information à jour sur l'ampleur de la prédation de la morue par les phoques;
- formuler des avis scientifiques sur les mesures de gestion susceptibles de réduire, maintenant et dans l'avenir, la prédation de la morue par les phoques.

La création de zones d'exclusion des phoques a été proposée comme outil de gestion possible. Quoiqu'elle n'ait pas été définie explicitement, cette notion semble fondée sur l'idée qu'en excluant les phoques d'une région fréquentée par la morue, la diminution de la mortalité due à la prédation de ce poisson par les phoques contribuerait au rétablissement de ses stocks dans les eaux de l'est du Canada. L'utilisation de zones d'exclusion des phoques (ZEP) pour réduire la prédation de la morue par les phoques, voire la prédation des autres poissons et des invertébrés que consomment aussi les phoques, est une idée qui paraît attirante. Toutefois, on a peu étudié la faisabilité et l'efficacité de l'implantation de telles ZEP comme moyen d'atteindre l'objectif de gestion qui consiste à réduire la prédation par les phoques parmi les stocks de poisson appauvris, notamment les stocks de morue.

L'atelier sur les zones d'exclusion des phoques tenu à Halifax (Nouvelle-Écosse) du 11 au 13 mai 2004 avait pour but d'évaluer la faisabilité et l'efficacité des ZEP. Il a réuni 19 participants venant du Canada, des États-Unis et de Norvège.

Les participants à cet atelier ont conclu que dans la plupart des milieux marins il serait matériellement impossible d'exclure les phoques d'une zone. Dans certaines situations, on pourrait peut-être parvenir à réduire le nombre de phoques qui fréquentent une zone. Toutefois, il sera considérablement plus difficile d'exclure les phoques ou d'en réduire le nombre au fur et à mesure qu'on progressera des rivières vers le large.

Il semble y avoir peu de moyens d'exclure les phoques d'une zone, même des petits estuaires et à plus forte raison des eaux moins enclavées. Les barrières matérielles ne peuvent être efficaces que dans les rivières; cependant, leur utilité se trouve limitée par leurs effets néfastes sur la migration des poissons et par les frais d'investissement qu'elles nécessitent. La translocation et les moyens acoustiques de dissuasion ne sont que partiellement efficaces à court terme. Toutefois, on sait que le son a aussi des effets néfastes sur les espèces non visées, comme les odontocètes, ce qui diminue encore l'efficacité d'un recours à ce moyen pour exclure les phoques ou en réduire le nombre. Les prélèvements non létaux ne constituent pas une

solution pratique, parce qu'ils se limitent à un petit nombre d'individus et que le maintien en captivité entraîne des coûts constants élevés. La thérapie par aversion n'a pas été éprouvée à grande échelle sur les phoques, mais tout indique qu'elle ne donnerait pas de bons résultats. L'abattage peut se révéler efficace dans le cas d'un faible nombre de phoques nuisibles qui recherchent leur nourriture dans des petites zones bien délimitées, comme les rivières, mais il est moins facile d'y recourir dans des milieux plus vastes et situés plus au large, où le taux de renouvellement des phoques est élevé.

Un processus de sélection d'éventuelles ZEP ou ZRIP (zones de réduction des impacts des phoques) devrait tenir compte des caractéristiques des espèces dont la conservation inquiète et de celles du prédateur, des caractéristiques physiques des lieux et des effets écologiques possibles sur les espèces non visées. Une fois une zone évaluée en fonction de ces critères, il conviendrait d'envisager les avantages éventuels qui découleraient de sa désignation comme ZEP/ZRIP. Cela peut se faire de plusieurs manières, mais on encourage vivement la modélisation des divers scénarios.

La réalisation d'études visant à éprouver l'efficacité des ZEP/ZRIP pour la morue sera extrêmement difficile, voire impossible dans de nombreux cas. Étant donné leur caractère pluriannuel et leur coût considérable, de telles études doivent être très bien planifiées et il conviendrait d'entreprendre une évaluation initiale pour déterminer dans quelle mesure la mise en œuvre d'une ZEP/ZRIP est susceptible d'avoir un effet favorable sur la morue.

## BACKGROUND

On April 24, 2003, the Government of Canada announced the closure of three Atlantic cod (*Gadus morhua*) stocks in the Gulf of St. Lawrence and off eastern Newfoundland and southern Labrador. Recent scientific assessments of those stocks determined that they were at historically low levels and had shown little or no signs of recovery despite a decade of severe conservation measures. The scientific assessments concluded that predation by seals may be a factor contributing to the high mortality of cod in those areas.

Three species of seals are generally considered the most significant within the context of seal predation on cod and other groundfish because they are abundant and are known to consume those fish species. The magnitude of predation mortality caused by seals varies geographically. Harp (*Phoca groenlandica*) and hooded (*Cystophora cisterna*) seals are major predators off northeast Newfoundland and in the Gulf of St. Lawrence, whereas grey seals (*Halichoerus grypus*) are also important predators in the Gulf of St. Lawrence and on the Scotian Shelf off Nova Scotia (Hammill and Stenson 2000).

Included in the Canadian Government announcement, The Minister of the Department of Fisheries and Oceans also announced a two-year science program to expand current research to advance our understanding of the complex interactions between seals and fish stocks. This programme had two main goals:

- to provide current information on the extent of seal predation on cod, and
- to provide scientific advice on management actions that could reduce current and future levels of seal predation on cod.

Seal Exclusion Zones have been advanced as a potential fisheries management tool (e.g., FRCC 2001). Although not explicitly defined, the concept appears based on the notion that by excluding seals from an area used by Atlantic cod, the reduction in seal predation mortality would promote the recovery of these cod stocks off eastern Canada. As initially conceived by persons living in eastern Newfoundland, the idea was to prevent further depletion of cod spawner biomass in areas where the few remaining aggregations of large cod might be particularly vulnerable to direct predation and incidental mortality associated with cold water. The use of Seal Exclusion Zone (SEZ) to reduce seal predation of cod, and potentially other fish and invertebrate species eaten by seals, has an intuitive appeal. However, there has been little consideration of the feasibility and efficacy of SEZs in achieving management goals to reduce seal predation on depressed fish stocks, including Atlantic cod.

The Seal Exclusion Zone Workshop was held on 11-13 May, 2004, in Halifax, Nova Scotia. The meeting was attended by 19 participants from Canada, the United States, and Norway (Appendix 1). The Agenda and summaries of the presentations given at the Workshop are given in Appendices 2 and 3, respectively.

## WELCOME AND RAPPORTEURS

D. Bowen, Chairperson, welcomed the participants and provided an overview of the workshop objectives. J. Lawson, R. Merrick, G. Stenson, and A. Trites each served as rapporteurs for parts of the meeting.

## WORKSHOP OBJECTIVES

The overall objective of the workshop was to conduct a scientific evaluation of the value of a SEZ as a fisheries management tool. The intent was to establish general principles and criteria that would help fisheries managers in considering the potential benefits of SEZ. Although the workshop focused on the interactions between seals and Atlantic cod, it was intended that the framework would be applicable to other prey species of conservation concern. To meet this overall objective, participants considered the following issues:

- how to operationally define a seal exclusion zone,
- the extent to which exclusions zones are feasible in coastal and open ocean environments,
- criteria for selection of exclusion zones,
- potential seal exclusion techniques (e.g., physical barriers, sound, hunting),
- the extent to which seal exclusion zones are likely to benefit cod,
- experimental designs to test the efficacy of exclusion zones (if such zones are thought feasible), and
- preliminary results of a pilot SEZ in Smith Sound, Newfoundland.

## MARINE ECOSYSTEMS

Before considering a proposal for the use of a SEZ as a management tool to reduce the impact of seals on Atlantic cod, it is important to understand the ecological context within which such management actions are embedded. Ecosystems are examples of complex systems (Levin 1999). Complex systems are difficult to measure over short periods of time because of the disparate scales affecting how such systems function.

The structure and functioning of marine ecosystems reflect the myriad of interactions between the physical and biological components at a broad range of spatial and temporal scales (NRC 2002). Human activities also act at different scales and in the context of a SEZ would selectively impact top predators. These impacts may have cascading effects on lower trophic levels and could be propagated more broadly and have longer-lasting effects than might otherwise have been imagined. Even in relatively simple marine ecosystems, such as the Benguela Current off South Africa involving hake, fur seal, and hake fisheries interactions, it might be possible to predict the direction of the effect of reducing the abundance of seals on the yield from the fishery, but predicting the magnitude would be unlikely (Butterworth 1992).

In the context of predation by a marine mammal (i.e., a seal) on commercially exploited prey or prey populations of conservation concern, DeMaster and Sisson (1992) identified four ecological principles that can affect the way in which a prey population might respond to the reduction in predation by seals:

1. prey species almost always have more than one predator,
2. pinniped species rarely are dependent on only one species of prey,
3. recruitment rate of most fish stocks is highly variable, and
4. fish, as a predator group, consume more fish than do other predators (i.e., seabirds, cetaceans, and pinnipeds).

Points 1 and 2 recognize that, although reducing the number of seals will result in a reduction of predation mortality in the short term, longer-term effects on the prey population are difficult to predict as other predators may increase their predation and seal numbers may be more strongly influenced by other prey species than the one of concern such that overall seal population size may not be reduced. Point 3 reminds us that recruitment in many fish population is variable being affected by a number of factors including ocean climate, such that measuring the effect of reducing seal predation on population size will be quite difficult as noted by Butterworth (1992). Point 4 is important because it places seal predation in context of the total predation mortality experienced by the prey population. Bax (1991) compared fish mortality from fish, fisheries and marine mammals in six ecosystems and found that fish were considerably more important than marine mammals in all of these systems. Trites et al. (1997) and Livingston (1993) reported similar findings for the Pacific Ocean and the eastern Bering Sea, respectively.

Thus, consideration of the complexity of ecosystems and these general features of the interaction between seals and fish should play an important role in deciding if a SEZ may be useful.

## WHAT ARE SEAL EXCLUSION ZONES?

The concept of excluding predators from an area to reduce predation on domestic animals has a long history in the terrestrial environment. The use of predator exclusion nets at aquaculture sites is evidence that, at least in principle, the concept also can be applied to the marine environment. The Fisheries Resource Conservation Council (FRCC) called attention to the concept of seal exclusion zones in their advice for conservation requirements for the cod stock in NAFO sub areas 2J3KL (FRCC 2001). They stated that "… areas be identified where cod are aggregated during the winter or where seals are inflicting high mortality on cod, and these areas be designated as seal exclusion zones. Within these areas, measures must be taken immediately to protect and conserve cod."

Taken literally, a Seal Exclusion Zone would be an area where seals would be excluded for all or part of the year given that seals were feeding or having another negative impact on an important aggregation of cod. The complete exclusion of seals from a restricted area of cod habitat would undoubtedly be difficult if not impossible in most areas. More generally, we could imagine areas where the number of seals negatively affecting cod, or another fish of conservation concern, was reduced but not eliminated. The more general concept of a Seal Impact Reduction Zone (SIRZ) would be applicable in a greater number of marine situations. In both cases, however, we require that:

1) seals are responsible for a high mortality rate on cod,
2) there is a large enough fraction of the cod stock such that a reduction in seal predation mortality or harassment leading to fish mortality could be expected to have a positive effect on cod dynamics, and
3) the interaction is to some extent predictable in space and time.

Furthermore, in implementing a SEZ/SIRZ the intention is to exclude or reduce the seal population in a restricted geographical area. Although exclusion or reduction will have local effects, there is no expectation that the exclusion or reduction of seals in a SEZ/SIRZ will have a negative impact on the seal population as a whole. Finally, the participants noted that the use of a SEZ/SIRZ might also be used 1) to preserve genetic diversity in a highly structured fish population, or 2) to prevent or reduce other types of seal impact such as precipitating or exacerbating cold water mortality events in cod.

## CRITERIA FOR SEZ/SIRZ

Given the challenges associated with the use of SEZs/SIRZs to reduce seal impacts, it is desirable to establish some general principles for their use and criteria to aid in the identification of candidate areas. Although not explicitly considered by the workshop, participants noted that factors such as socio-economic benefit, ability to manage the zone effectively (e.g., logistics, regulations), and other factors may need to be evaluated prior to undertaking a SEZ/SIRZ program. It was also noted that the implementation of a SEZ/SIRZ would require detailed discussions between scientists and managers.

Workshop participants envisioned a hierarchical process for concluding that a SEZ/SIRZ might be an effective management tool. The first step in the process would be to use the criteria below to determine if the situation was likely amenable to the use of a SEZ/SIRZ. If the conclusion was "yes" to this first step, then available data would be used to develop models to evaluate the potential benefit of reducing seal numbers on the prey population. If these analyses suggested a likely benefit, then consideration of the means by which seal numbers were to be reduced in the zone would be undertaken along with planning the monitoring needed to determine if the program was achieving the management objective.

### *General Principles*

1. There should be an assessment of whether seals are or have the reasonable potential of inflicting high predation mortality or of having other negative impacts leading to mortality of local cod aggregations, the significance of the local cod aggregation, and whether the interactions between seals and cod are predictable in time and space.

2. There should be a clearly articulated objective for the management action. The objective will determine the extent to which a SEZ/SIRZ might be effective, will ensure that a suitable zone is selected and that measures by which success will be judged are identified.

3. There should be performance measures to evaluate the efficacy of the management action. Some performance measures, such as the number of seals using the zone, would be measured over the short-term (i.e., months), whereas others, such as the benefit to cod abundance, would be measured over longer periods of time (i.e., years).

4. There should be a carefully designed program to monitor performance measures to determine the effectiveness of the exclusion/reduction in seals numbers.

5. The proposed SEZ/SIRZ should not pose a conservation threat to the seal population.

6. The proposed SEZ/SIRZ should have minimal negative effects on non-target species.

### *Criteria for Candidacy*

The participants identified four criteria that could be used as a means of determining if a SEZ/SIRZ was an appropriate management tool in a given situation. These criteria include characteristics of the prey, the biology of seals, the physical setting, and other ecological relationships within the proposed zone.

Prey –

- o There is a conservation concern for the species
- o There is a biologically significant component of the population/stock that aggregates predictably in time/space

Predator -

- o The predator consumes the prey species or has some other negative impact of concern (e.g., harassment leading to high fish mortality) with some predictability. Impacts with distinct seasonal patterns or of longer duration may be more amenable to such management zones since they are easier to predict and to implement.

Physical environment -

- o A SEZ/SIRZ will be more practical in geographically restricted areas (see Fig. 1) as there will be a more reasonable expectation that the predator can be reduced or excluded from the area. Generally, smaller areas bounded by land or other barriers will be more feasible. Sea state and other environmental conditions (e.g., presence of ice) also will determine feasibility. The importance of these physical characteristics may vary with the techniques being used to exclude or reduce seals.

Fig. 1 Feasibility of SEZ/SIRZ in relation to physical setting

River > Estuary > Embayment/Fjord > Bay > Inland Sea > Continental Shelf

Feasible ——→ Less feasible ——→ Not feasible ——→

Ecological relationships –

- o The ecological relationship between predator and prey should be relatively well understood (at the scale of the SEZ under consideration).
- o Trophic relationships should be known well enough to be reasonably confident that the action will not have a negative impact on the target prey species through ecosystem effects.
- o There should be a basic understanding of other potential important trophic interactions that could be negatively affected by exclusion/reduction of seals from an area.

With respect to the first bullet, Workshop participants acknowledged that our understanding of the ecological interactions between seals and their prey is incomplete. To date, most of the focus has been on determining diet composition and estimating the amount of prey that would need to be consumed to meet energy requirements. Foraging comprises an important part of the energy budget so seals would be expected to be efficient predators. Apart from recent information from animal-borne video cameras on seals (e.g., Bowen et al. 2002) and limited observations in rivers or estuaries, we know relatively little about how seals fed in the wild. Belly-biting, where only the belly is eaten by the seal, is difficult to observe in the wild, but has been documented in instances prey were artificially vulnerable, such as when seals are attacking fish in pens or taking fish from gillnets. With respect to the use of a SEZ/SIRZ to protect cod, there have been reports of cold-water events where aggregations of cod become trapped in cold water and suffer high mortality. In some, but not all cases, seals have been observed in association with these events, and in a few instances cod have been recovered with belly bites. However, the role of seals in these events is not understood, and it remains unknown whether seals may be initiating such events by driving prey into cold water, or are merely attracted to aggregations of cod once they become trapped in cold water. The workshop participants acknowledged these types of events should also be considered in evaluating a SEZ/SIRZ proposal, but not enough was known to permit a scientific assessment.

If the seal-prey interaction met the above criteria, then a more detailed analysis would be undertaken. The objective of this more detailed analysis would be to determine, to the extent possible, if there was a reasonable expectation that reduction of seal impacts (e.g., predation, competition or harassment) **would have a positive effect on the prey at the population level**. Although the types and quality of information may vary at different proposed sites, minimum requirements for such an assessment would be:

- an estimate of the size of the fish population in the proposed zone relative to total size of this component of the stock,
- an estimate of the number of seals in the proposed zone,
- an estimate of the diet of seals in the proposed zone, and
- an estimate of the duration of predation (or other negative impact, such as harassment).

With these data it would be possible to estimate the seal mortality rate on the fish aggregation. If this rate is judged significant then the feasibility of implementing a SEZ/SIRZ would be undertaken. The development of quantitative models is one way to effectively integrate current information and to evaluate presumed benefit to the fish aggregation.

The above approach may not be applicable for certain questions, such as assessing the prevention of an event that has not yet occurred within the proposed SEZ, but has been reported elsewhere. For such questions one might use risk assessment methods. A risk assessment could be used to complement analytical work and to assist managers in making a decision on a SEZ/SIRZ. If the issue is not amenable to modeling or an analytical approach (i.e., insufficient quantitative data), a risk assessment framework as detailed below may be a valuable tool for deciding on a course of action. Typically, a risk assessment framework identifies potential threats and uses two axes to evaluate their risks, in particular likelihood of occurrence and severity of impact. With respect to seal management, biological risks may relate, for example, to predation on various commercial species, predation on a species-at-risk, contribution of seals to catastrophic fish mortality events, or conservation of the predator. Interventions are then scored using well established techniques. In the absence of hard data on each of the threats, such a framework typically involves scoring by a group of experts. In addition to biological or conservation risks, other threats could be considered, e.g. socio-economic, political, or operational, but participation should then be extended to a broader range of experts (managers, policy makers, etc.). Such an approach has been used in fields where events of low probability could have “high” impact and where the knowledge base is not necessarily quantitative. Risk analysis also can be useful for identifying and focusing research priorities that would facilitate more quantitative analytical approaches.

## METHODS TO EXCLUDE OR REDUCE SEAL NUMBERS

A number of methods have been used to exclude or reduce the number of terrestrial and marine predators feeding in an area with varying degrees of success (e.g., Pfeifer 1988, Treves and

Karanth 2003). The effectiveness of a given method of exclusion or reduction may vary, to some degree, among seal species, given differences in sensory sensitivity and behaviour. For example, migratory or wide ranging pinnipeds (e.g., harp, hooded and grey seals) may respond to novel stimuli more effectively than resident species that inhabit an area for extended periods, such as harbour seals (*Phoca vitulina*). Also, it may be more difficult to reduce numbers of pinnipeds if individuals spend only a short time feeding in an area, resulting in a high turnover rate of animals in the SEZ/SIRZ.

### *Relocation*

Relocation of individual pinnipeds to another part of their range has been attempted with limited success in several species. Olesiuk et al. (1995) relocated 3 harbour seals to each of five sites (n = 15 total) that were 20-270 km from capture locations. All but one of the seals returned to the original locations within periods ranging from a day to several months, including all three of the seals that were moved 270 km. The authors concluded that relocation was likely to provide only short-term reduction in numbers. In northern elephants seals (*Mirounga angustirostris*), 88% of 75 individuals relocated 24 to 99 km returned to their capture site in an average of 21 d (Oliver et al. 1998). Homing rate increased with age and all of the seals that did not return were ≤ 17 months of age. Ridgeway and Robson (1985) relocated 3 captive California seal lions (*Zalphous californianus*) about 115 km and all three animals returned within a week. The same three sea lions and a fourth were relocated several months later some 240 km. At least two returned to the captive facility within 9 d, and the other two smaller animals could have returned to the general area, but were not been observed. Similarly, during the 1988/89 season, a total of 39 sea lions were captured at Ballard Locks and transported to the outer coast of Washington. Over 75% returned to Puget Sound in an average of fifteen days and the effort therefore did not reduce predation. During the 1989/90 run, six sea lions were captured and relocated back to their breeding area off southern California. Three of the six returned to Puget Sound; one in 30 days and the other two in approximately 45 days from their release (Jeffries and Scordino 1997). Thus, homing ability and site fidelity seem to be well developed in pinnipeds and thus relocation would appear to have limited use in connection with a marine SEZ/SIRZ.

Even in cases were only short-term effects were intended, relocation is expensive, only small numbers of individuals can be handled, nuisance individual seals can be very difficult to identify and capture, and relocation over great distances may raises issues of parasite or disease transmission and mixing of genetically different groups.

### *Non-lethal Removals*

Removing individual pinnipeds from the wild and maintaining them in captivity has been done to reduce the number of seal lions at Ballard Locks, Washington. However, this is more expensive over the long term than relocation in the wild, given the added maintenance cost in captivity, can only be used for small numbers of individuals, and target animals can be difficult to identify and capture. Also the risk of disease transmission to wild seal stocks should these captive seals ever be returned to the wild greatly limits such an option. As such, non-lethal removal is unlikely to be a useful approach in situations involving seals and groundfish, such as Atlantic cod.

### *Physical Barriers*

Physical barriers have been used to exclude seals from a portion of the river or locks used by salmonid fish (e.g., Pfeifer 1988; Olesiuk et al.1996; Brown et al. 2003). Although a physical barrier was effective in excluding harbour seals from the upper fetches of the Puntledge River and Courtenay Rivers, British Columbia, the barriers also delayed the migrating salmon it was meant to conserve, concentrating them in the very area that the excluded seals were concentrated, resulting in additional fish mortality by seals. The barrier, which spanned about 75 m across the river, was labour intensive and had significant ongoing operational costs associated with cleaning debris, boat traffic and public safety. The costs of constructing, installing, and removing the barrier fence was approximately $200,000 (DFO Puntledge River Committee 1999 cited in Brown et al. 2003). At the Ballard Locks, the conclusion of a review panel was that the barrier to exclude sea lions was not effective and delayed fish passage under some condition such that those fish were subjected to predation for greater periods (Pfeifer 1988).

Given that physical barriers would only be logistically practical when used in small areas (i.e., rivers), that such barriers require large capital investment, are operationally expensive, and can have negative effect on the fish species they are meant to conserve, barriers would not seem to be a useful means of creating exclusion zones to conserve demersal species, such as Atlantic cod.

***Acoustic Deterrents***

A number of acoustic sources have been used to reduce the number of pinnipeds using an area. These include Acoustic Harassment Devices (AHDs), cracker shells, underwater firecrackers (also called seal bombs), and the playback of predator sounds (e.g., killer whale vocalizations). AHDs produce very loud sounds (195 dB re 1 µPa at 1 m) generally broadcast in the 10 KHz frequency band, near the maximum sensitivity of seals. AHDs are meant to provide an unpleasant stimulus that will cause seals to avoid the area (Mate et al. 1986). Despite their wide-spread use, there is little scientific evidence that they are effective for more than short periods after their introduction, if at all. An AHD unit was ineffective at reducing predation by sea lions on salmon at Ballard Locks (see Pfeifer 1988). Yurk and Trites (2000) found that a AHD was effective in deterring feeding by harbour seals in the Puntledge River, but subsequent studies showed the effect was short-lived (Andrew Trites pers. comm.). An AHD installed across the Puntledge River did not deter harbour seals from moving upstream to feed on juvenile salmon (Olesiuk et al. 1995), and an AHD placed near a barrier on the Courtenay River, British Columbia did not deter harbour seal activity near the barrier (Brown et al. 2003).

Overall, there seems limited evidence for the effectiveness of AHDs against pinnipeds, presumably because seals habituate rapidly to the sound (Jacobs and Terhune 2002). Furthermore, AHDs are known to have negative effects (i.e., avoidance of habitat) on non-target species such as harbour porpoise, *Phocoena phocoena* (Olesiuk et al. 2002) and killer whales, *Orcinus orca* (Morton and Symonds 2002). The duration of the negative effects on harbour porpoises is poorly known, but the evidence for short-term negative effects could limit the use of AHDs to areas where these cetacean species are not present. The number of killer whales using the Broughton Archipelago, British Columbia was significantly depressed for the five years that AHDs were used in the area. Evidence of limited effectiveness against seals coupled with known negative effects on non-target species and the growing concern about the negative effects of noise pollution in the world's oceans (e.g., NRC 2003) indicate that AHDs will be of little value in the creation of a SEZ/SIRZ.

Explosives such as underwater firecrackers and cracker shells have been have used with some short-term success, but again because of rapid habituation there seems to be little potential for longer-term reduction in seal numbers (Pfeifer 1988, reviewed in Richardson et al. 1995). In general, pinnipeds seem quite tolerant of explosions and therefore would not appear to be a useful means of excluding or reducing the number of seals foraging in an area. Furthermore, the use of explosives poses safety issues and may have negative effects on non-target marine mammals and fish.

Broadcasting playbacks of predator vocalizations (e.g., killer whales) as a means of reducing the number of seals using an area has had only limited success as the pinnipeds appeared to quickly habituate (Shaughnessy et al. 1981; Anderson and Hawkins 1987; Pfeifer 1988). A recent study showed that harbour seals responded strongly to playbacks of calls from local transient (mammal-eating) and from unfamiliar killer whale populations, but did not respond to the calls of local resident (fish-eating) killer whale populations, suggesting that seals may habituate to call of harmless killer whales (Deecke et al. 2002). Thus it seems likely that playbacks of seal predator vocalizations would provide only temporary reduction in the number of seals using an area.

### *Lethal Removals*

Seals have been lethally removed by shooting in a number of countries. Although this would appear to be a simple method to exclude or reduce the number of seals in an area, seals become wary of hunters and this can make shooting less effective over time. Pemberton and Shaughnessy (1993) found that shooting was an inefficient and ineffective means of protecting fish farms from Australian fur seals (*Arctocephalus pusillus doriferus*) because many of the attacks occurred at night. Similarly, a decade of shooting harbour seals at fish farms did not reduce the numbers of nuisance seals that had to be removed (Jamieson and Olesiuk 2001). Selective lethal removal of harbour seals in Courtenay River, British Columbia was effective at eliminating most of the nuisance individual seals that habitually foraged in the river on outmigrating fry and smolts, and depressed chinook runs (Olesiuk, unpublished data), but was not effective at stopping the seasonal influx of seals during the much larger pink and chum salmon returns (Brown et al. 2003), but in the Puntledge River, shooting of harbour seals did reduce the number of seals using the river (Olesiuk et al. 1996).

Hunting may be effective in reducing the number of seals in the short term, but may be ineffective over the longer term, particularly in areas of high natural turnover of seals. Hunting at sea may require high capital costs for equipment and incurs high operating costs. Hunting is also restricted to good weather conditions and the number of hunters operation in an area may be limited by safety considerations. There is also the issue that non-target species could be negatively affected by shooting in situations where species are difficult to identify in the field (e.g., harbour vs. juvenile grey seals). Setting nets to entangle seals may also be effective, but this is currently not permitted in Canada with the exception of aboriginal subsistence harvests.

### *Aversive Conditioning*

Chemicals that cause aversive responses when ingested have been used on terrestrial carnivores to attempt to control predation. However, they have resulted in limited success because they do not inhibit predation per se, their effect is temporary, and they can have unpredictable and unintended effects on non-target species (Mason et al. 2001). Dead steelhead fish that had been treated with an emetic were given to California sea lions, but all individuals refused the second treatment and all had resumed normal predation within five days after the initial treatment (Pfeifer 1988). This led to the conclusion that aversive food responses had no potential for effectively controlling sea lion predation.

## BIOLOGICAL CONSIDERATIONS

The identification of instances where cod might benefit from a SEZ/SIRZ requires some understanding of the seasonal distribution of predator and prey, the feeding ecology of seals, and the population status and dynamics of cod. Several participants provided general overviews of current understanding of these aspects of the biology of harp, hooded, and grey seals and Atlantic cod stocks off Newfoundland, in the southern Gulf of St. Lawrence, and on the eastern Scotia Shelf (see Appendix 3).

### *Seal Distribution and Foraging Ecology*

Our general understanding of the geographic range of seal species inhabiting eastern Canadian waters is good. Harbour seals have largely a coastal distribution with rather local movements. Grey seals are more widespread, inhabiting both inshore and offshore parts of the continental shelf with seasonal changes in distribution. Although, not generally considered migratory, grey seals annually leave much of their range in the Gulf of St. Lawrence during winter ice cover. Harp seals inhabit both inshore and offshore continental shelf areas, but exhibit a long-distance seasonal migration with most individuals summering in the north and returning to the southern parts of their range during winter. In the course of their migration, some harp seals also transit the deep ocean basins. By contrast, hooded seals primarily use the deeper ocean associated with the edge of the continental shelf and routinely transit the deep ocean basins during their long-distance seasonal migration. Thus, harbour and grey seals are annual residents of areas used by Atlantic cod, whereas harp and hooded seals overlap with cod only seasonally.

Although these general characteristics of distribution are reasonably well understood, how the populations are distributed at finer spatial and temporal scales is still poorly known. Only in the past decade or so has it been possible, using satellite transmitters, to study the movements of free-ranging grey, harp and hooded seals and thus to determine the distribution of foraging locations within the broadly defined geographic ranges (Austin et al. 2004; Bowen et al. submitted). Because satellite tags are expensive, relatively few individuals of these species have been studied to date, although in general we currently know more about grey seals that the other two species. These studies have yielded some findings of interest with respect to the feasibility of a SEZ/SIRZ. First, individual grey, harp and hooded seals often move 100s of kilometres within relatively short periods of time such that particular areas of the ocean may experience high turnover rates. Second, these studies have revealed “hot spots” (i.e., areas frequently used by a number of seals) throughout the grey seal range. Although some of these hot spots are located in coastal areas many are associated with the offshore banks. Third, there are large areas of the continental shelf that are apparently not used for foraging. For example, relatively few of the satellite locations of grey seals occur in the Northwest Atlantic Fisheries Organization (NAFO) subarea 4X relative to the eastern Scotian Shelf. Finally, given that such a small fraction of these seal populations have been studied, extrapolating the distribution of the small sample of instrumented seals to the entire population distribution is difficult and may not reflect the abundance of seals in particular areas of their range.

### *Seal Diets*

We have a good understanding of the types of prey species eaten by grey and harp seals (e.g., Bowen et al. 1993, Lawson and Stenson 1997, Lawson et al. 1998), but we know considerably less about the diets of hooded seals (Ross 1993, Hammill and Stenson 2000). Studies indicate that the species composition of the diet varies over time (seasonal and longer-term variation) and geographically. Different age groups can also differ in the prey species consumed, and recent data indicate strong differences between the diets of adult male and female grey seals

(Beck et al. submitted). Our understanding of the basis for these differences is limited. There is evidence to suggest that difference in prey species abundance and distribution play an important role, but other factors are also important (e.g., prey quality, prey profitability).

Seal diets have traditionally been determined from the analysis of stomach contents and faeces. Although these methods have provided considerable information, it is well known that diets derived in this way suffer from a number of potential biases in estimating the relative importance of different types of prey (e.g., Jobling and Breiby 1986, Bowen 2000). To overcome some of these problems, other methods have been developed. Among the more promising is quantitative fatty acid signature analysis (QFASA; Iverson et al. 2004). This method quantitatively compares the fatty acid composition of seal blubber with the signatures of potential prey species to estimate the mixture of prey which provides the closest fit to the observed fatty acid composition of the seal. Although QFASA will be less affected by some of the problems of methods that depend on hard parts, QFASA estimates may be prone to false positives if prey species have highly similar fatty acid compositions. This new method is being used to provide current information on the diets of grey, harp, and hooded seals. Current information is critical in the assessment of seal-fish interactions because seals diet can vary so dramatically over time and space.

A feature of QFASA is that it provides an estimate of the diet that represents the feeding of that seal over a period of weeks to months. By contrast, stomach or faecal contents often represent only the last meal and therefore may not be representative of longer term feeding. However, when evaluating an area for a SEZ/SIRZ, both types of information could be important depending on whether the short-term or longer-term diet is of interest.

### *Cod Distribution and Population Dynamics*

Atlantic cod have historically been distributed throughout marine waters of Atlantic Canada from northern Labrador to beyond Canadian jurisdiction in the Gulf of Maine and on Georges Bank. Ten stocks have been recognized for management purposes. An eleventh stock, on Flemish Cap east of the Grand Banks, is entirely outside Canada’s 200 nm limit, and has received little recent attention from Canadian cod biologists.

The most northern stock, the NAFO sub areas 2GH stock off northern and central Labrador, has been at a very low level and closed to directed commercial fishing since the mid-1980s. The other stocks exhibited some level of decline during the past few decades (Smedbol et al. 2002), with the most dramatic declines occurring during the late 1980s and early 1990s. The northern (NAFO 2J3KL) cod stock off southern Labrador and eastern Newfoundland experienced the most severe decline at this time, and was closed to directed commercial fishing in 1992. Other stocks southward to the mid-Scotian Shelf (NAFO sub areas 3NO, 3Ps, 3Pn4RS, 4TVn (Nov-Apr), 4Vn (May-Oct), and 4VsW) were closed at various times in 1993 and 1994. The two Gulf stocks (NAFO sub areas 3Pn4RS, 4TVn (Nov-Apr)), the southern Newfoundland stock (NAFO sub area 3Ps) and the inshore portion of the northern cod stock were reopened at low quota levels in the late 1990s. Stocks on the southern Grand Bank (NAFO sub areas 3NO) and the eastern Scotian Shelf (NAFO 4VsW) were not reopened. There is a remarkable contrast between the two stocks on either side of the Atlantic end of the Laurentian Channel; the 3Ps stock on the northeast side recovered fairly well after a few years under a fisheries moratorium and has supported a directed commercial fishery since 1997 (DFO 2003c), whereas the 4VsW stock on the southwest side continued to decline after imposition of a moratorium, was not reopened for directed commercial fishing, and is currently at or near its all-time low (DFO 2003b). The two stocks in the Gulf of St. Lawrence remain near their historic lows (DFO 2003a, 2004). They were closed to directed fishing in 2003, but opened once again in 2004. The entire area of the northern cod stock was closed in 2003 and remained closed in 2004.

The failure of the northern cod stock and the two Gulf cod stocks to recover upon cessation of directed commercial fishing has been attributed to various factors, with the importance of individual factors varying from stock to stock (Rice et al. 2003). An observation common to these three stocks (Rice et al. 2003), the eastern Scotian Shelf cod stock (DFO 2003b) and the Sydney Bight resident stock (DFO 2002a) is that total mortality, as deduced from catch rates at age in research bottom-trawl surveys, remained high after the stocks declined and directed commercial fishing was stopped. In addition, tag return data indicate high natural mortality of adult cod in the inshore of eastern Newfoundland, especially in Div. 3K. It has been concluded (Fu et al. 2001; Rice et al. 2003) that predation by seals has contributed to the high cod mortality and to the lack of recovery in these cod stocks.

Cod can be found from the shoreline to 900 m or more. Young cod tend to have a different distribution than older cod. Often the young cod are in shallower water. The stocks to the north and east of Newfoundland (NAFO sub areas 2GH and 2J3KL) and in the Gulf of St. Lawrence (NAFO sub areas 3Pn4RS and 4TVn) live mainly in waters that become ice-covered in winter. These stocks undergo seasonal migrations from relatively shallow feeding areas on the shelf to relatively deep overwintering areas near the shelf break and upper slope (NAFO sub areas 2GH and 2J+3KL) or along the Laurentian Channel (the Gulf stocks). Other stocks undertake more limited migrations. The cod tend to be densely aggregated and relatively immobile while overwintering but more spread out and more active while on their feeding grounds.

Areas that have been suggested as potential seal exclusion zones include inlets along the northeast and east coasts of Newfoundland (NAFO sub areas 3KL), where attention has been focused on Smith Sound in Trinity Bay, and Sydney Bight off the east coast of Cape Breton Island (NAFO sub area 4Vn).

Eastern Newfoundland: Although the northern cod stock as a whole is at an extremely low level, some populations in the bays along the northeast and east coasts of Newfoundland (NAFO sub areas 3KL) appear to have been more productive during the 1990s than offshore populations. These inshore populations overwinter in relatively deep (200 m) inlets which become very cold in winter, and indeed may freeze over, but remain a little warmer toward the bottom. The largest such population occurs in Smith Sound (Trinity Bay), where the cod form dense and relatively immobile aggregations at 200 m or more.

Sydney Bight: The NAFO sub areas 4TVn cod stock migrates from the southern Gulf of St. Lawrence to Sydney Bight, where in winter it is found in the same general area as the Sydney Bight (NAFO sub area 4Vn) resident stock.

## DESIGN PRINCIPLES FOR LARGE-SCALE FIELD EXPERIMENTS

There are certain principles that apply to any large-scale field experiment. All experiments are based on the following logical model:

Observations > Models > Hypotheses > Predictions > Alternative or Null hypotheses > Experiments > Interpretation of Results.

This framework (Underwood 1997) emphasizes that good experiments can only be designed and undertaken if there are adequate quantitative observations from which to reasonably construct alternative models (i.e., explanations) and predictions.

Having made some observations, a first step in designing a field experiment must be to define the problem and the objectives of the study. This is often difficult, but without a clear statement of the problem and the objectives, it is impossible to design an appropriate study. Having defined the problem and objectives, consideration needs to be given to the response variables to be measured, identifying the experimental unit, the number and randomization of treatments, what controls will be used, and number of replicates of the experiment. Alternative hypotheses that could explain the results of the experiment should also be explicitly considered at this stage. A frequent problem with field studies is that the variables to be measured will often respond in the same way under multiple hypotheses, with the result that it is impossible to unambiguously interpret the results of the experiment (Bowen et al. 2001). Thus careful attention to the alternative hypotheses and the response variables to be measured is critical. It is also important to carefully outline the statistical analysis of the data prior to conducting the study. Finally, a statistical power analysis should be conducted to determine the appropriate sample size and replication to be confident of being able to detect treatment effects should they occur.

Manipulative experiments are preferred where possible, but there are many areas of ecology where this is simply not feasible. Although rivers might be selected in such a way that could provide for both controls and replicates of an experiment, it is difficult to imagine how this could be done in most situations in which a SEZ/SIRZ might be considered as a possible management tool for cod and other demersal fish. In most cases, a single site is of interest or perhaps several sites, where baseline differences would make comparison difficult. Nevertheless, well-planned, logically constructed observational studies to test a priori hypotheses can be informative, but only those that are replicated in time or space can have any claim as being convincing (Underwood et al. 2000). Before/after contrasts at a single site are rarely informative as the change in the response variable could have been due to any intrinsic cause or coincidental with the treatment because there is no way to determine that such changes are not widespread, occurring in areas where no treatment has been applied (Underwood 1991). It has proven particularly difficult to achieve convincing results in large-scale field experiments, unless the effect of the treatment is large (Raffaelli and Moller 2000). Other methods can be used to determine if changes in response variables are non-random after a treatment has been applied to an area, but these methods require a long time series of measures to fit the models (e.g., Box and Tiao 1975). However, these methods do not permit confident conclusions about causation. Furthermore, given the lack of long time series on seals and prey at small scales, these methods are unlikely to be useful in the evaluation of a SEZ/SIRZ.

It cannot be overemphasized how difficult it will be to conduct large-scale field studies to test hypotheses about the effects of a SEZ/SIRZ on cod. This is due to:

- the difficulty in making replicated observations,
- the high natural variability in the cod stock recruitment,
- the imprecision associated with estimating both seal and fish abundance and seal predation mortality, and
- the long duration needed for such studies.

Evaluating the efficacy of a SEZ/SIRZ would require that the study be conducted for multiple years (most likely 5-10 yr) to have any expectation of measuring changes that might be associated with the exclusion or reduction in seal predation. Thus, these studies will be expensive and sustained funding over such a long period could be a severe obstacle. The potential difficulty of inferring the effect of a SEZ/SIRZ on cod is underscored by the observation that the "experiment" of removing trawlers on the eastern Scotian Shelf has not resulted in a measurable change in the total mortality rate being experienced by the 4VsW cod stock (DFO 2002b).

No one could seriously propose a long-term and expensive field experiment involving a SEZ/SIRZ before making a preliminary assessment of the likelihood that a reduction in seal predation mortality would be of benefit to cod. How could we get an impression that such an action could be useful? One could proceed by using the available data on seal numbers, their diet, and the size of the prey aggregation to be protected by the SEZ/SIRZ to estimate the predation mortality due to seals under various assumptions about the duration of predation, the nature of other effects (e.g., harassment) and the relationship between the fish being protected by the SEZ/SIRZ and the remainder of the fish stock. This kind of analysis could be conducted for Smith Sound, Newfoundland.

## EXAMPLES OF SEZ/SIRZ EVALUATION

Several locations have been identified as candidates for a SEZ/SIRZ. Of these, Smith Sound, Newfoundland and Sydney Bight, Nova Scotia have received particular attention. Participants used these two sites to illustrate the use of selection criteria outlined above (see ***Criteria for candidacy***).

### *Smith Sound, Newfoundland*

Criterion 1: Prey

Since the mid 1990s, a significant component of the near shore Northern cod stock complex has aggregated in Smith Sound during the winter. This aggregation is predictable with fish arriving in the Sound in late autumn or early winter and leaving in spring.

Thus, criterion 1 is satisfied.

Criterion 2: Predator

Harp seals are known to use Smith Sound during the period when the cod are present. Both the number of seals and their residence time is uncertain, but appears to be highly variable. Analysis of stomach contents of seals shot in the Sound during winter indicates that seals do consume cod, although these data also suggest that the cod mainly eaten are somewhat younger than the adult aggregation of conservation concern.

Nevertheless, criterion 2 is largely satisfied.

Criterion 3: Physical characteristics of site

Smith Sound is a fjord-like area of deep water (technically not a fjord as it is connected to the sea at both ends) some 20 km long and 1-2 km wide within Trinity Bay, Newfoundland. The Sound also develops cold surface waters that can lead to cold water mortality events of cod. Although still a reasonably large area, the Sound has physical characteristics which should facilitate the exclusion or reduction in the number of seals feeding in the area used by cod.

Criterion 3 is satisfied.

Criterion 4: Ecological considerations

Although relatively little research has been directed in Smith Sound, enough is known to have a reasonable expectation that there would not be negative effects on cod or non-target species by reducing the number of seals. In other areas along the north east coast of Newfoundland, seals have been reported to drive fish into shallow areas causing fish mortality. Although the physical and ecological circumstances under which this could occur is not understood, it could happen in many places, including Smith Sound.

Criterion 4 seems reasonably satisfied.

Workshop participants concluded that Smith Sound met the conditions to be considered further as a candidate for a SEZ/SIRZ. The next stage in the process of evaluation would involve assessing the likely benefits to cod of establishing a SEZ/SIRZ and the feasibility of excluding or reducing the number of seals using the area. This further evaluation would require setting objectives for management and developing models to explore different management scenarios. Given the inevitable uncertainties about the factors affecting the dynamics of cod, modelling should provide valuable insight into the likelihood of achieving the objectives.

Research undertaken in the past winter to determine if the number of seals could be reduced in Smith sound has provided useful information on the numbers and kinds of seals feeding and their diets (see Appendix 3). As such, the Workshop participants recommended that the research be continued with the goals of improving the ability to estimate seal numbers, consider increasing number of hunters to increase the precision of information on seal distribution and CPUE, and carry out a statistical power analysis to determine how many surveys would be needed to determine a measurable effect of hunting.

***Sydney Bight, Nova Scotia***

Criterion 1: Prey

Two stocks of cod inhabit Sydney Bight and neighbouring areas during winter: a portion of the 4T stock, which migrates from the southern Gulf of St. Lawrence, and the resident 4Vn stock. The 4T fish are further offshore at the edge of the Bight. There is a significant component of the 4Vn cod stock in the area during the summer. Cod are not highly aggregated in the area but there are concentrations that are somewhat predictable.

Thus, criterion 1 is weakly satisfied.

Criterion 2: Predator

Grey and harbour seals are known to use Sydney Bight throughout the year. Both the number of seals and their residence time is uncertain, but presumably variable. There are no data on the foods eaten by seals in the area. Analysis of stomach contents of seals shot south of the Bight on the east coast of cape Breton during the late 1980s showed that some cod was consumed by both species (Bowen et al. 1993, Bowen and Harrison 1996).

In the absence of recent data on the diet of seals in the area, Criterion 2 is not satisfied. This is because seal diets are known to change over time in response to changes in prey species abundance and distribution.

Criterion 3: Physical characteristics of site

Sydney Bight is a large, roughly triangular indentation in the coast of northern Cape Breton, Nova Scotia, about 50 km along each side and 85 km along the base. The Bight faces the open ocean and thus is not well bounded by land.

Criterion 3 is not satisfied.

Criterion 4: Ecological considerations

It was not possible in the context of the Workshop to evaluate this for the Sydney Bight area. Therefore, participants could not meaningfully access Criterion 4 for this site.

Nevertheless, based on a preliminary assessment, Sydney Bight would not rate highly as a site for a SEZ/ZIRZ.

Our assessment of these two sites is meant only to illustrate the kind of process that might be used to establish candidate locations. We provided one set of criteria, there may be others. The important point is that some formal process should be used to make decisions about the benefit of SEZ/SIRZ as management tools.

## CONCLUSIONS

The concept of excluding seals from an area will not be possible or practical in most marine environments. However, there may be situations where it may be possible to reduce the number of seals using an area. The ability to either exclude or reduce seals from an area will become dramatically more difficult as one moves from rivers to more open marine environments.

There appear to be few methods that could be used to exclude seals even from small estuaries let alone areas less well bounded by land. Physical barriers can be effective only in rivers, but negative effects on fish movement and high capital costs severely limit this approach. Translocation and acoustic deterrents are only partially effective in the short-term. However, there are known negative effects of sound on non-target species, such as odontocetes, which further reduce the practicality of using sound to exclude or reduce seals. Non-lethal removal is not practical because only small numbers of animals can be removed and there are high continuing costs of captive maintenance. Aversive conditioning has not been widely tested on seals, but evidence indicates that this will not be effective. Lethal removal can be effective for small numbers of nuisance seals that habitually forage in small, well-bounded areas such as rivers, but becomes less practical in larger, more oceanic environments or where the turnover rate of seals is high.

A process for selecting candidate areas for a SEZ/SIRZ should consider characteristics of the species of conservation concern and the predator, physical feature of the site, and potential ecological effects on non-target species. Once a site has been evaluated on the basis of these criteria, the likely benefit of the SEZ/SIRZ should be assessed. This can be done in several ways, but modelling alternative scenarios is strongly encouraged.

Conducting experiments to test the effectiveness of SEZ/SIRZ with respect to cod will be extremely difficult and in many cases may not be possible. Given the multi-year duration and considerable cost, such studies need to be well planned and an initial evaluation should be undertaken to estimate the likelihood that implementing a SEZ/SIRZ would have a positive effect on cod.

In general, participants concluded that there would be little opportunity to use a SEZ/SIRZ as a management tool to benefit cod. Nevertheless, Smith Sound appears to satisfy the selection criteria rather well, and thus further evaluation of this site as a SIRZ could be useful in assessing both the feasibility of implementation and likelihood of expecting a positive effect on cod.

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**Appendix 1**

| Participant | Affiliation |
|---|---|
| T. Haug | Institute of Marine Research, Tromso, Norway |
| A. Trites | University of British Columbia, Vancouver, BC |
| R. Merrick | NMFS, Woods Hole, MA, USA |
| T. Loughlin | NMFS, Seattle, Washington, USA |
| A. York | Seattle, Washington, USA |
| I. McLaren | Dalhousie University, Halifax, NS |
| J. Lawson | DFO, St. John’s, NL |
| George Lilly | DFO, St. John’s, NL |
| G. Stenson | DFO, St. John’s, NL |
| Denis Rivard | DFO, Ottawa, ON |
| P. Simon | DFO, Ottawa, ON |
| D. Pearcey | DFO, Ottawa, ON |
| D. Bowen, Chair | DFO, Dartmouth, NS |
| W. Stobo | DFO, Dartmouth, NS |
| R. Mohn | DFO, Dartmouth, NS |
| P. Olesiuk | DFO, Nanaimo, BC |
| M. Hammill | DFO, Mont Joli, PQ |
| G. Chouinard | DFO, Moncton, NB |

## Appendix 2: Agenda

**Seal Exclusion Zone Workshop**
**May 11-13**
**Cambridge Suites, Halifax**

### Day 1

| | |
|---|---|
| 09:00 – 09:10 | Welcome (Bowen) |
| 09:10 – 09:30 | Background, Objectives of the Workshop (Bowen) |

***Seal Exclusion Zones[1]***

| | |
|---|---|
| 09:30 – 10:00 | What are they? How can they be operationally defined? (Bowen) |
| 10:00 – 10:30 | Criterion for selection of exclusion zones? (Stenson) |
| 10:30 – 10:45 | *Break* |
| 10:45 – 11:30 | Continue discussion of selection criteria |
| 11:30 – 12:30 | Feasible habitats for exclusion zones (Hammill) |
| 12:30 – 13:30 | *Lunch* |

***Methods for Excluding Seals from an Area[1]***

| | |
|---|---|
| 13:30 – 14:00 | Physical barriers (Olesiuk) |
| 14:00 – 14:30 | Relocation (Olesiuk) |
| 14:30 – 15:30 | Hunting (Stenson – Smith Sound experience) |
| 15:30 – 15:45 | *Break* |
| 15:45 – 16:15 | Acoustics (Lawson) |
| 16:15 – 17:30 | General discussion – drafting |
| 17:30 | Adjourn |
| 19:00 | *Social/dinner* (Bowen/Iverson) |

### Day 2

***Seal Exclusion Zone Experimental Design[1]***

| | |
|---|---|
| 09:00 – 09:15 | Science and management questions (Bowen) |
| 09:15 – 09:45 | Seal foraging ecology (Hammill/Bowen/Stenson) |
| 09:45 – 10:45 | Cod distribution/abundance (Lilly/Chouinard/Mohn) |
| 10:45 – 11:00 | *Break* |
| 11:00 – 12:30 | Designing studies: 1) reduced predation (York) |
| 12:30 – 13:30 | *Lunch* |
| 13:30 – 15:00 | Designing studies: 2) benefit to target species (York) |
| 15:00 – 15:30 | *Break* |
| 15:30 – 17:00 | Further discussion or Break-out groups if needed/drafting |
| 17:00 | Adjourn |

**Day 3**

| | |
|---|---|
| 09:00 – 09:15 | Review recommendations to date (Bowen) |
| 09:15 – 10:30 | Break-out groups, drafting |
| 10:30 – 11:00 | *Break* |
| 11:00 – 12:30 | Drafting |
| 12:30 – 13:30 | *Lunch* |
| 13:30 – 15:00 | Review recommendations, report structure, assignments, review of draft report (Bowen/Hammill/Stenson) |
| 15:00 – 15:30 | *Break* |
| 15:30 – 16:30 | continued |
| 16:30 – 17:00 | |
| 17:00 | Adjourn |

[1]*Note* - each topic is designed as a discussion session that will be lead by the person named. However, we encourage participants to present their experiences and thoughts on all aspects of the subjects discussed.

## Appendix 3: Summaries of Presentations Given at the Workshop

### *Seal Exclusion Zones. What are they? How can they be operationally defined?*

W. Don Bowen, Marine Fish Division, Bedford Institute of Oceanography, Department of Fisheries and Oceans Canada, Dartmouth, N. S.

The notion of excluding predators to protect prey species has a long history, but seems to have been advanced as a potential management tool to reduce seal predation on Atlantic cod relatively recently. Implicit in the concept of a Seal Exclusion zone is the idea that:

1) there is an area of co-occurrence of seals and cod;
2) seals are inflicting high mortality rate on cod;
3) a large enough fraction of the cod population would be protected to have a positive effect on dynamics, and
4) the interaction is predictable in space and time, and of significant duration.

Taken literally, this would be an area of co-occurrence in the marine environment where seals were excluded. There would appear to be few areas in the marine environment where this would seem possible.

More generally seal exclusion zones might better be defined as: restricted areas where seal numbers are reduced for the purpose of reducing predation on a commercially harvested target fish species of conservation concern. The broader concept might be termed SEAL PREDATION REDUCTION AREAS (SPRA). The key point is that the establishment of such areas results in site-specific reduction in predation, which may have limited population effects on seals, but has a positive effect on the prey.

### *Criteria for Selection of Exclusion Zones*

Garry Stenson, Department of Fisheries and Oceans Canada, Newfoundland and Labrador Region, NAFC, P.O. Box 5667, 80 East White Hills Road, St. John's, NL, A1C 5X1.

We are unaware of any other attempt to identify criteria for implementing seal exclusion zones. The United Nations Environmental Program (UNEP 1994) sponsored a series of workshops to identify criteria that should be considered when proposing a cull of marine mammals to benefit fisheries. Although many of the requirements are similar, the primary goal of a cull is to reduce the predator population. In contrast, the intention of a Seal Exclusion Zone (SEZ) is to reduce the predator population in a specific geographical area; there is no expectation that this reduction will have an impact at the population level of the predator. As such, the criteria that must be considered will be different than those identified by UNEP.

Before initiating a SEZ it is imperative that there be a clearly defined objective outlining the goals of the programme. It is also important that the detailed programme design be developed and discussed with scientists, managers and local fishermen/sealers in order to improve the likelihood of meeting the objectives. Both short and long term performance measures should be identified to evaluate the efficacy of the SEZ programme. Monitoring regimes should be developed to determine the effectiveness of the activities during the programme and to monitor the impact of the activity once it ends.

In order to decide if, and where, a SEZ may be beneficial we need to understand the movements, distribution and population dynamics of both the prey and the predator populations.

Although detailed knowledge of these aspects would be preferable, they are seldom available. However, we often have a general understanding that would allow us to identify a geographically defined area where co-occurrence of predator and prey occur on the appropriate time scale. If the primary interaction of concern is predation, the diet (including a measure of its variability) of predator species in the area of concern must be known. Because of the high geographic and temporal variability observed in seal diets, it is not sufficient to assume that because the predator eats a particular prey in one area, it will do so in another area or time. In order to determine if a reduction in the number of seals in an area will benefit the prey species, it is also necessary to understand the relative importance of mortality caused by the predator. Based upon this information, there should be a reasonable expectation that a reduction in seal numbers in this area will result in the increased survival of the prey population, i.e. that it will benefit the prey on a population level. It may be difficult to quantify the degree of impact, but simple models may provide an indication of the expected direction.

Since reducing the seal population is not a goal of a SEZ and DFO's commitment to implementing the Precautionary Approach in the management of seals (DFO 2003), the proposed implementation of a SEZ should not pose a conservation threat to the predator population. If is also important that we have enough of an understanding of the ecological interactions occurring in the area to be reasonably confident that the SEZ programme will have no (or at least minimal) negative effects on non-target species.

Although they are not scientific issues *per se*, the design of a SEZ should take into account the need for the programme to be managed effectively. It should result in a positive cost/benefit ratio although this may not be measured in strictly economic terms. Finally, any seal removal programme must be carried out in a humane and publicly acceptable manner. To ensure this, public consultations should be an integral part of the development and implementation of any SEZ.

In summary the criteria for establishing a SEZ should include:

1. Goals and programme design that are clearly-defined prior to initiation, and benefit from public consultation
2. Both short and long term performance measures to evaluate the efficacy of the SEZ programme
3. Monitoring regimes to determine both the effectiveness of activities during the programme and the long term impacts of the activity.
4. Knowledge of the movements, distribution and population dynamics of prey and predator populations which show co-occurrence of the predator and a significant proportion of the prey population in a geographically define area.
5. An understanding of the outcome of the activity sufficient to be confident that the action will not affect non-target species negatively or pose a conservation threat to the predator population.
6. A reasonable expectation that implementing a SEZ will benefit the prey species at the population level.

In addition, the programme should provide a positive benefit in comparison to the cost and be carried out in a publicly acceptable manner that can be managed effectively.

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***The use of acoustic and physical barriers and the translocation and culling of nuisance harbour seals in an attempt to mitigate predation on salmon stocks: lessons from the Puntledge River, British Columbia***

Olesiuk, Peter F., Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, B.C., V9T 6N7.

The recovery of harbour seal populations in B.C. during the 1970-90s (Olesiuk et al. 1990a; Olesiuk 1999a) prompted concern over their impact on other fishery resources, particularly salmon. Broad-based diet studies in the Strait of Georgia using scat analysis indicated that salmon comprised only about 4% of the overall diet (Olesiuk et al. 1990b), and bio-energetic models indicated that total salmon consumption by seals was only about 3% of total escapement (Olesiuk 1993). However, seal predation on salmon tended to be concentrated near river mouths and in estuaries, some of which supported small and depressed salmon stocks, and in some cases these overlapped with large, healthy runs that attract many predators. The focus of studies thus shifted towards assessing local impacts of seals on specific salmon stocks for which there conservation concerns.

Detailed foraging studies were conducted in Comox Harbour and the lower Puntledge River, which supported critically depressed summer and fall chinook stocks that had been reduced to a few hundred spawners, as well as large pink and chum runs typically numbering in the tens of thousands of spawners. Surface observations were conducted to determine the species, location and timing of salmon predation by seals (Bigg et al. 1990; Olesiuk et al. 1996). The study indicated that seals foraged on pre-spawning salmon throughout the estuary, and that small numbers of seals also entered the lower 3.5 km of the Puntledge River during high tides. Although the seals foraging in the river represented only a small fraction of total abundance, they accounted for two-thirds of predation on adult salmon. During the spring out migration of juvenile salmon, seals also congregated beneath the 5th Street Bridge at night and used light cast from the bridge to silhouette and forage on salmon fry and smolts (Olesiuk et al. 1995a). Given the localized nature of predation on salmon, the studies suggested that impacts could be largely mitigated by excluding seals from the lower Puntledge River.

The first attempt to block access to the Puntledge River by seals was made by establishing an acoustic barrier across the river (see Appendix I in Olesiuk et al. 1995a). The acoustic barrier was generated with an *AirMar dB Plus II* AHD, one of the more powerful models available and widely deployed at salmon farms in an attempt to deter seal attacks (Haller and Lemon 1994, Tillapaugh et al. 1994; Johnston and Woodley 1998). Its 4 transducers were installed at 20 m intervals across the Puntledge River about a kilometre below the 5th Street Bridge. The effectiveness of the barrier assessed by monitoring the arrival times and abundance of seals foraging at the 5th Street Bridge, where they congregated predictably every night to feed on out migrating fry and smolts. The experiment indicated seals were undeterred by the acoustic barrier, and animals arrived at the 5th Street Bridge at dusk in about the numbers expected had there been no barrier. Indeed, identification of recognizable individuals indicated that most of seals that had been observed foraging at the bridge had penetrated the barrier. Although controlled experiments indicated that the AHD was initially an effective deterrent when installed directly beneath the 5th Street Bridge and activated randomly on selected nights (Yurk and Trites 2000), longer-term use showed that seals habituated within a matter of days (Munro 1998). Experiments elsewhere indicated that non-target animals such as harbour porpoise were more sensitive to the sound field and displaced from areas within several kilometers of

AHDs (Olesiuk et al. 2002), which created environmental concerns over the widespread use of the devices.

A second attempt to block access to the Puntledge River by seals was made by establishing a physical barrier. A fence was constructed using a floating broomstick design, with vertical aluminum bars spaced 16.5 cm (6-1/2”) on centre. The spacing was established based on the minimum gap that would physically prevent passage of a 2-3 year old seal carcass (few pups or yearlings had been observed in the Puntledge River), but still allow passage of the largest chinook salmon, some of which weigh up to 15-20 kg. The bottom of the fence was hinged and anchored to the river bed on a steel rail, and the top equipped with floats that allowed it to rise and fall with the tide. The fence was equipped with leads that extended onto shore to prevent seals from going around it, and with a panel that could be lowered to accommodate small vessel traffic (the river is considered a navigable waterway). An AHD was installed a few meters downriver of the fence in an attempt to deter seals from foraging in the immediate area, and cement triads placed along one side of the river to complex the shoreline and provide salmon with a refuge from seals. The fence was manned continuously while in operation to open navigation panels, provide daily cleaning and maintenance, and to make observations of foraging seals and migrating salmon. Once reinforced, the fence provided an effective barrier for excluding seals from upper fetches of the river (Brown et al. 2003). However, keeping the fence clean proved to be a major effort, especially during the summer period of algal growth. Moreover, migrating salmon appeared reluctant to pass through the fence and often circled back downstream. Seals were undeterred by the AHD, and there was little evidence of fish taking refuge in the triads. The area immediately below the fence quickly developed into a preferred foraging area, making it necessary to open the fence to allow the safe passage of fish (Brown et al. 2003). Although physical barrier proved unfeasible in the Puntledge River, there is some evidence they can be effective at mitigating seal attacks at fish farms (Jamieson and Olesiuk 1999).

The seals that congregated at the 5$^{th}$ Street Bridge to feed on out migrating salmon fry and smolts provided a unique opportunity to observe foraging seals. Based on their distinctive pelage patterns, it became evident the same individuals were foraging at the bridge on a nightly basis, and at least in some cases had been exhibiting the behaviour for a number of years. Olesiuk et al. (1995a) estimated that the 20 most prevalent individuals accounted for 79-89% of total fry and smolt consumption. Subsequent studies using sonic and VHF telemetry indicated that seals captured while foraging at the bridge on fry and smolts continued to forage in the river on a regular basis when adult chinook salmon were returning following the spring fry and smolt out migration. In contrast, seals captured and tagged in Comox Harbour indicated they were using the estuary primarily to rest, rarely entered the river, and tended to forage 10-20 km offshore where hake were likely the most prevalent prey. These observations suggested that chinook stocks could be protected by eliminating a relatively small number of nuisance seals that habitually foraged in the lower Puntledge River.

Harbour seals in the Strait of Georgia appear to be relatively sedentary species, and typically forage within 10-20 km of haulout sites to which they return on a regular basis (Olesiuk 1999b). Nevertheless, an experiment to translocate seals indicated they exhibit a high degree of site fidelity and well developed homing ability. Fifteen seals were captured at a haulout site near Nanaimo, fitted with VHF transmitters, and relocated to various release sites as far away as Bamfield on the west side of Vancouver Island, representing a minimum swimming distance of about 270 km. Fourteen of the 15 seals (93%) returned to the capture site - including all 3 released at Bamfield - within periods ranging from less than a day to just under two months (Olesiuk et al. 1995b).

Given the difficulties with capturing seals in the Puntledge River, and likelihood they would soon return, the decision was made to cull the nuisance animals. During 1997-98, a total of 52 seals were shot in the river during the chinook return when mainly habitual rivers foragers were present. Subsequent observations indicated that the number of seals foraging on outmigrating fry and smolts at the 5$^{th}$ Street Bridge had been sharply reduced, and new seals do not appear to have replaced those that were culled. Numbers of both summer and autumn chinook returning to the Puntledge River have increased dramatically since the cull. However, chinook returns have also increased dramatically in the neighbouring Quinsam and Campbell Rivers, where seals have not been a major issue and no cull was conducted, suggesting that more widespread factors such as improved marine survival and reduced fishing pressure may have contributed to the increase in chinook returns. A long-term assessment of the effectiveness of the cull is currently underway.

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### *Hunting and Smith Sound Pilot Experiment*

Garry Stenson

<u>Smith Sound SEZ Experiment</u>

To investigate the effectiveness and feasibility of using Seal Exclusion Zones to protect cod from seal predation, a pilot experiment was established in Smith Sound, Newfoundland. The objective of the study was to determine if the number of seals in the area could be reduced significantly and maintained once the program ended. It was not possible to quantify the impact of seal removals on the survival of cod directly within the time frame of this study. The use of acoustic deterrents, physical barriers, and relocation was not considered feasible and therefore the lethal removal of seals was chosen as a method to exclude seals.

The study design consisted of a series of surveys to estimate the number of seals in the Sound. Once the numbers present was determined, a small group of local, trained sealers would remove seals over a one month period. The number of seals remaining in the sound would then be estimated during additional surveys. Information on the numbers of seals sighted, locations of animals killed and trends in CPUE during hunting was recorded in logbooks kept by the hunters.

The program began with public consultations to explain the objectives of the study and to obtain stakeholders' opinions on the area to be included in the study and the method of seal removals. Based on these meetings, it was decided that animals would be removed by licensed hunters using legally-approved firearms. The use of nets would not be permitted. Because of safety concerns and the need to collect scientific data, it was decided that only a small number of sealers would be part of the experiment. A total of four hunting enterprises were chosen to participate; two of the hunters were current collectors for DFO while the other two were chosen by a random draw of sealers who had expressed interest in participating. Biological samples were obtained from each seal to obtain information on species, age, sex, reproductive state and diet.

The experiment ran from September 2003 through February 2004. Eight surveys, consisting of 13 transects spaced 3 km apart, were carried out during this period. Very few seals were sighted during the survey (0-2 seals/survey). This suggests that the number of seals in the area were generally low and unlikely to be more than a few hundred at any one time. The survey results were consistent with reports from local sealers and fishermen who reported that the numbers of seals present in the sound were generally low, but could vary greatly from day to day.

Sealers spent a total of 44 days on the water during the hunting period (14 Jan. – 19 Feb. 2004). Two of the hunters went out on relatively few days while the other two were active for approximately half of the days. Hunters reported sighting 323 seals of which 85 were shot. A total 78 seals were recovered and sampled. The majority (63) of the seals recovered were reported to be harp seals (38 beaters, 11 bedlamers, 11 old harps, rest unknown). In addition, 11 hooded (mostly bluebacks), 3 ringed, and 1 harbour seal were recovered.

Only two hunters provided enough data to examine trends in CPUE. For one, CPUE varied greatly among days, but no trends were visible. For the other, the number of seals shot per nautical mile traveled was higher during the first few days of hunting than later in the period, but the overall effort during the earlier period was small.

Only 24 of the harp and 4 of the hooded seals sampled had food in their stomachs. Although only two of the hooded seals had eaten Atlantic cod, they accounted for over 95% of the total reconstructed biomass present. Atlantic cod also accounted for almost 70% of the energy in the diet of harp seals in the sound. Arctic cod contributed ~30% of the energy consumed while the remainder was made up of small amounts of a number of other species. The majority of the cod consumed by harp seals were 10-15 cm in length. The average length of all cod consumed was 18.1 cm (SD=10.37 cm, range 7-44 cm).

A second experiment will begin in April and run through June. The study design will be modified to increase the number of hunters involved and the likelihood of sighting seals by increasing the number of transects in each survey.

Excluding Seals by Hunting

Based upon our experience in Smith Sound some general characteristics of the suitability of hunting for excluding seals from an area can be drawn. By its very nature, hunting results in the lethal removal of individuals. If the number of seals in the area is great there may be impacts at the population level. The Malouf Commission on Seals and Sealing (Anon 1986) concluded that shooting is a humane method of killing seals. In contrast, the use of nets was considered to be cruel.

One advantage to hunting is that biological samples can be obtained from animals that are recovered. These data provide valuable information on the species involved, potential age and/or sex segregation and diet of the seals in the area which can improve our understanding of the interactions that are occurring.

The use of firearms can raise safety concerns, especially in confined areas such as a sound or small bay where SEZ are more likely to be feasible. It is difficult to shoot seals from small boats and therefore, hunters must be very skilful. Searching for seals, shooting, retrieving animals and collecting biological samples is labour intensive and can only be carried out during daylight hours when the weather is favourable. This is illustrated by the observation that even the most dedicated hunters could only go out on half of the days during the Smith Sound experiment. As a result, the efficacy of hunting to reduce the number of seals in an area is questionable. In our study, only a small proportion of the seals observed were actually shot. If the number of seals varies greatly among days, the ability of hunters to reduce seals may be even lower.

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***An overview of the acoustic deterrence methodologies and their efficacy in displacing pinnipeds***

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Many types of deterrents have been used worldwide for years in fisheries to prevent interaction with marine mammals (e.g., Mate and Harvey 1987, Jefferson and Curry 1996, Reeves et al. 1996) such as longline depredation and predation at aquaculture sites.

Deterring pinnipeds from areas where fish are being caught or raised in aquaculture settings has been attempted with a variety of approaches employing acoustic stimuli (for a recent review see Petras 2003). Deterrence efforts involving these stimuli (such as acoustic devices, under-water firecrackers, cracker shells, and predator sound playback) are based on the assumption that noise can be used to startle, warn, scare, or cause physical distress to pinnipeds, moving them out of areas where fish are vulnerable to predation or away from fishing gear.

This summary describes the technologies that have been employed during attempts to deter or displace pinnipeds, and the efficacy with which these acoustic methods have achieved (or not) the desired results.

### *1.1 Acoustic Deterrence Methodologies*

1.1.1 Acoustic Deterrent Devices (ADDs)

Pingers are small acoustic alarms that are attached at intervals along a fishing net or other underwater gear to (primarily) warn cetaceans of its presence. They emit sound outside the normal hearing range of the target fish (10-15 kHz at approximately 140 dB re 1µPa-m) and thus usually have little effect on catches. They appear to work as a short-term measure in reducing the bycatch of small cetaceans, and seem to elicit very short-range displacements (e.g., Koschinski and Culik 1997, Dawson et al. 1998, Trippel et al. 1999, Kastelein et al. 2001, Berggren et al. 2002). However, like many other deterrence methods cetaceans and other marine mammals may either habituate to them, or learn to associate them with a possible food source nearby.

Pinger alarms have not been effective in deterring seals and sea lions (Jefferson and Curry 1996): simply alerting these animals of the presence of nets has often proven to have a “dinner bell" effect for pinnipeds. For example ADDs were deployed in the Hiram M. Chittenden Locks to prevent California sea lions (*Zalophus californianus*) from feeding on migrating steelhead trout. These proved ineffective possibly since the sound pressure was insufficient to avoid habituation by the sea lions (NMFS and WDFW 1995).

Dukane NetMark 1000™ pingers (www.dukane.com/seacom/Products/ComMarine.htm) are the most commonly-used pingers in both experiments and commercial fishing operations around the world.

1.1.2 Acoustic Harassment Devices (AHDs)

Acoustic harassment devices (AHD) are similar in concept to ADDs, but they broadcast significantly more sound energy {Akamatsu et al. (1996) reported that underwater impulsive sounds transmitted at 210 dB re 1 μPa at 1 m (or a pure tone with 165 dB source level) were sufficient to cause exposed captive Steller sea lions to leave the water}. AHDs are designed to emit sound at frequencies (12-17 kHz) and high intensities that are likely to inflict pain or discomfort to designated receivers – usually pinnipeds (for reviews see Mate and Harvey 1987, Reeves et al. 1996). The effective range of AHDs is dependent upon the effects of a variety of hydrophysical characteristics that influence sound propagation (e.g., water depth, temperature, and Salinity, ambient noise). These acoustic transmitters are usually used near aquaculture operations to reduce or eliminate pinniped predation in captive fish.

AHD transducers generate loud underwater sounds that increase in intensity over 60-70 sec (Figure 1):

- the Airmar produces source sounds that range from 10-40 kHz with greatest amplitudes (195 dB re 1 μPa at 1 m) at approximately 27 kHz.
- the Ferranti-Thompson Seal Scrammer emits a 200 dB re 1 μPa signal at 25 kHz

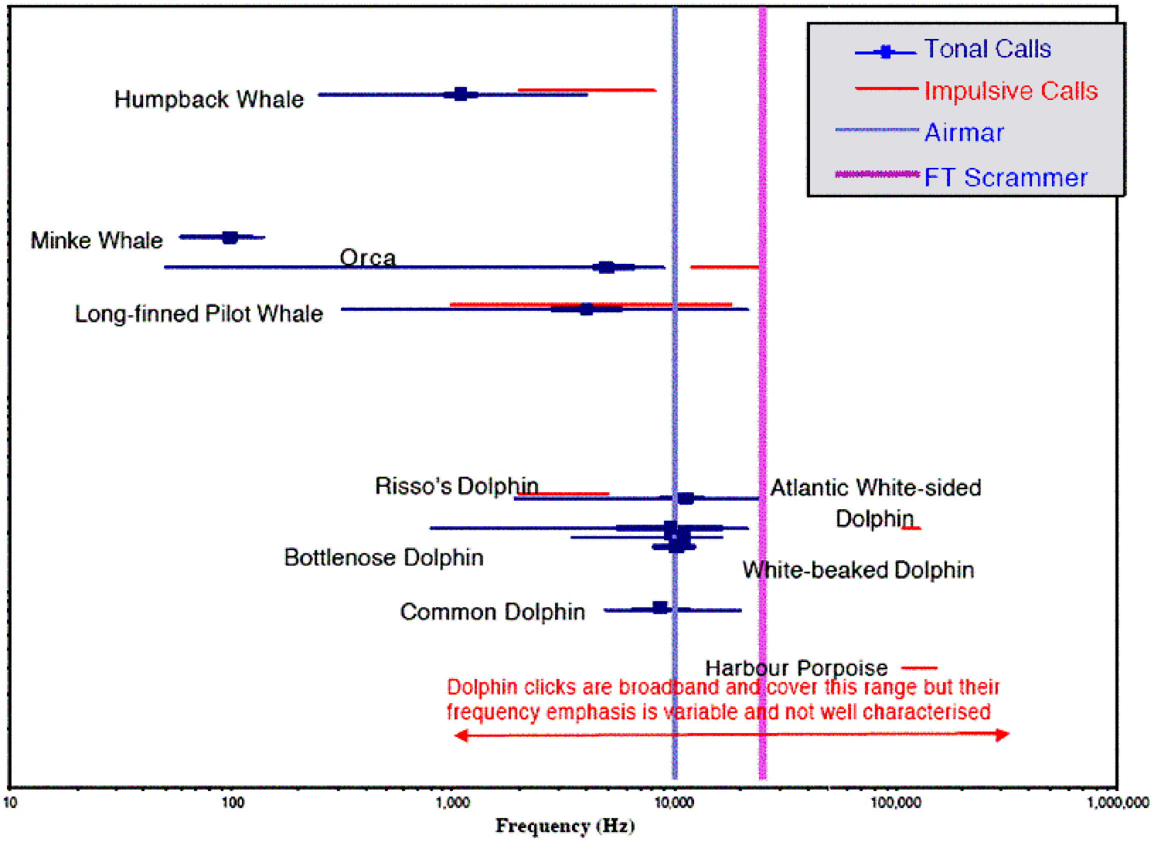


Figure 1. Comparison of documented vocal frequencies of a selection of mysticete and odontocete cetaceans, with the primary operational frequencies of two common AHD devices (modified from Figure 6 of Gordon et al. 2004).

While AHDs have been shown to be initially effective in certain situations, their effectiveness diminishes rapidly as pinnipeds habituate to the noise (perhaps through changes in behaviour that diminish the sound intensity levels to which they are exposed).

Yurk and Trites (2000) deployed four "Seal Scarer" projectors (Airmar Technology) at a specialised harbour seal (*Phoca vitulina*) seal feeding site in the Puntledge River in Courtenay, British Columbia. At this location seals swam on their backs near a bridge while capturing passing fish against a background of overhead lights. These broadcast broadband underwater sounds at 27 kHz with a maximum source intensity at 10 kHz of 194 dB re 1 μPa/V at 1 m. The Airmar projectors achieved maximum output at 1 minute from onset, after which it broadcast with a 2 second duty cycle. The authours concluded that, for this relatively small river system and unique predation scenario, the Airmar acoustic deterrence method was more effective than a floating cork line or eliminating bridge lights in deterring harbour seals from feeding on out-migrating juvenile salmonids.

AHDs were also deployed in an attempt to deter harbour seals from preying on salmon released from seines in the Klamath River; in this case the AHDs were not shown to be effective in reducing this seal predation. This supports the opinions of several researchers that in situations such as these the AHDs may act as attractants to pinnipeds by advertising the presence of fishing gear (Richardson et al. 1995, Jefferson and Curry 1996).

Studies have also shown that the effectiveness of AHDs appears to decrease over time, at intervals from weeks to several years (Petras 2003). With a significant caveat, AHDs were found to be somewhat effective in reducing California sea lion (*Zalophus californianus*) predation on an endangered steelhead (*Oncorhynchus mykiss*) in the Hiram M. Chittenden Locks in Seattle, WA. Given the small size and enclosed structure of these locks, AHDs were effective in creating a completely ensonified area near the entrance (Bain 1997). However, the AHDs appeared to be effective only with previously-unexposed sea lions; sea lions with previous exposure to the sounds of the AHDs modified their behaviour to minimise exposure to the underwater noise (see below) and continued eating the steelhead. If these "experienced" sea lions were removed from the area, the AHD array was then a more successful deterrent to the naïve sea lions remaining (NMFS 1997)—although the reduction in the size of the steelhead run may have also had an effect.

The "habituation" to AHDs by California sea lions may have actually been a result of a behavioural change whereby the sea lions changed their behaviour such that they swam near the acoustic sources with their heads out of the water (Mate and Harvey 1987, Richardson et al. 1995, Jefferson and Curry 1996)—presumably to avoid the most intense sound levels, as underwater sounds do not propagate well into the air.

1.1.3 Firecrackers

Underwater firecrackers ("seal bombs") have been used as a means to disperse pinnipeds for many years and in many countries. While such small-scale underwater explosive devices have been effecttive in the short-term in many situations, but over the long-term and with continued use, both seals and sea lions learn to avoid or habituate to the noise (Gearin et al. 1986, Pfeifer 1989). At the Ballard Locks in Washington, firecrackers were effective in reducing predation rates of California sea lions during their first season of use. They became ineffective subsequently since the sea lions ignored or became tolerant of the explosions (Pfeifer 1989). These sea lions also learned to evade close exposure to firecrackers by diving and surfacing in unpredictable patterns. This pattern of tolerance and avoidance has also been reported in areas where harbour seals interact with fisheries (and see next section).

1.1.4 Cracker Shells

Cracker shells are shotgun shells containing an explosive projectile designed to explode about 50 to 75 yards from the point of discharge. Although the noise from these shells may startle pinnipeds and cause them to flee temporarily, there is usually no physical discomfort to the animals involved since the explosion is in the air or on the water surface. Cracker shells have been no more effective than seal bombs, again, because the pinnipeds appear to have habituated to them. For example, cracker shells have been used in fishery interaction situations with harbour seals with limited effectiveness because the seals have learned to avoid (by diving in erratic patterns) or ignore the noise.

As for firecrackers, deployment of these devices is not without risks to people handling the devices, and especially for those people and animals that might be nearby during nighttime operations.

1.1.5 Pulsed Power Generator

An electrical power (arc) discharge can be used to generate a compression wave in water and a sound similar to the ADDs described above, but at higher sound output (see NMFS 1999). While laboratory tests of this type of device were equivocal, the California Coastal Commission did not approve field tests for this device due to concerns over potential hearing damage to exposed animals, and disturbance of non-target marine mammal species.

1.1.6 Playback of Predator Sounds

The effectiveness of predator vocalizations to frighten sea lions and other marine mammals has not been shown to be consistent in field tests (Fish and Vania 1971, Shaughnessy et al. 1981). Pinnipeds sometimes have shown immediate avoidance responses to the projection of killer whale sound recordings, but generally they have habituated quickly. In once case, sea lions were attracted to field broadcasts of predator vocalizations in Baja California.

Sounds from transient killer whales (which are known to prey on marine mammals) elicit avoidance responses by some marine mammals, whereas playback of sounds from resident (usually fish-eating) whales did not elicit responses. This is evidence that marine mammals, such as pinnipeds, that could become potential prey to marine mammals such as killer whales have evolved mechanisms to learn which predator vocal patterns are associated with potential threats. This ability to learn which predator sounds are not threatening will likely mitigate the effectiveness of predator sound playback in deterring pinnipeds.

### *1.2 Concerns for Collateral Impacts Resulting From The Use of Acoustic Deterrence*

Although AHDs are designed to operate at critical thresholds to cause discomfort or pain based on the hearing sensitivity of the target species (usually pinnipeds) and ambient noise (e.g., Jefferson and Curry 1996, Petras 2003), there is evidence that they could also interfere with the ability of some cetacean species to communicate or hear environmental sounds.

Studies by Olesiuk et al. (2002) and Johnston (2002) found that AHDs had a significant effect on the relative abundance and distribution of harbour porpoises (*Phocoena phocoena*) in nearby waters, with numbers and residency times of these cetaceans being lower in areas where AHDs were active. While they reported strong displacement effects within hundreds of metres of active AHDs, displacement effects were still detectable at far greater distances (up to 3.5 km). Active AHDs deployed by a fish farm (not within the Broughton Archipelago study area of Olesiuk et al.) appeared to cause changes in the local abundance of some cetacean species. For example, killer whale (*Orcinus orca*) sightings decreased significantly during the seven years in which AHD were in operation (Morton and Symonds 2002). Sightings of Pacific white-sided dolphins (L*agenorhynchus obliquidens*) also declined (Morton 2000). A variety of baleen whales were displaced when AHDs were in operation on the coast of Newfoundland (Nordeen and Lien 2001). Such displacements from feeding habitat could have serious repercussions for SARA-listed cetacean species that must maintain high rates of food intake (Read and Hohn 1995).

There is also concern that acoustic deterrent devices can produce enough sound, particularly where the acoustic fields of multiple transmitters overlap (e.g., Johnston and Woodley 1998), to mask biologically-important sounds for marine mammals. While such masking has not been tested directly, there are a number of studies that address manmade sounds as masking sources on a general level (e.g., Bain and Dahlheim 1994, Southall 2000, Erbe 2002).

Due to uncertainties about potentially negative co-lateral impacts on cetacean species exposed to sounds from AHD devices, Iwama et al. (1997) recommended to the Department of Fisheries and Oceans that the use of AHDs be eliminated in Canada.

It should also be noted that the effects of AHDs on other marine species, fish, and birds are untested (Petras 2003). For instance, American shad (*Alosa sapidissima*) and blueback herring (*Alosa aestivalis*) can detect high frequency sounds within the range of AHD transmissions. They may move out of an area with an active AHD which could then have an impact on predators such as pinnipeds that are foraging for these fish.

### *1.3 Summary*

Effective, long-term, non-lethal approaches to reduce or eliminate pinniped occurrence and predation have been extremely difficult to develop. There appears to be no effective, long-term acoustic approach that can be used to eliminate or reduce pinniped depredations in most situations. Some non-lethal acoustic deterrence measures appear to be initially effective on “naïve” pinnipeds, but become ineffective over time, or when used on “naïve” pinnipeds in the presence of “experienced” individuals that do not react to deterrence.

Acoustic deterrence has been attempted using a variety of acoustic stimuli, but with little success:

- Pingers – appear to work only for small cetaceans in a localised area
- AHD – appear to elicit variable responses across species and areas; most seals either habituate to or minimize exposure to AHD sounds; AHDs may work in special cases (such as with naïve seals in enclosed areas);
- Cracker shells and seal bombs – pinnipeds habituate to this method and minimize exposure; some risk to deployment staff
- Pulse power generator – electrical arc generates a compression wave in water and sound similar to ADDs; serious concern of potential hearing damage in marine mammals so may it not be an environmentally-acceptable method
- Predator playback – pinnipeds either do not react or habituate rapidly

AHD sounds could cause displacement of other species such as cetaceans, or mask biologically significant sounds. For these reasons there is a recommendation that DFO eliminate the use of AHDs in Canadian waters.

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### *Ecology of Grey Seals at Sable Island*

W. Don Bowen

The grey seal (*Halichoerus grypus*) is a size-dimorphic member of the Family Phocidae, with males being about 20% longer and 50% heavier than females. Most females give birth to a single pup each year, beginning at age 4 years and continuing for several decades. Grey seals disperse widely over the continental shelf during the non-breeding season (Stobo et al. 1990), but show high levels of philopatry. In the Northwest Atlantic, major breeding colonies are located on the sea ice in the southern Gulf of St. Lawrence and on Sable Island, Nova Scotia. Smaller colonies are found on near shore islands off Cape Breton and along the Eastern Shore of Nova Scotia (Mansfield and Beck 1977; Hammill et al. 1998). Grey seals are currently the most abundant pinniped species on the Scotian Shelf off Nova Scotia throughout the year and in the Gulf of St. Lawrence during summer and fall. Grey seal pup production on Sable Island, Nova Scotia has been monitored since the early 1960s. Abundance estimates indicate that pup production in this population, now the largest grey seal colony in the world, has been increasing exponentially at a rate, $r$ = 0.12 (Bowen et al. 2003). An aerial photographic survey was conducted in January 2004 to provide a current estimate of the number of pup born on the Island and to determine if the exponential rate of increase has continued.

Satellite tags placed on adult male and female grey seals throughout the year show that most grey seal locations were confined to the continental shelves off eastern Canada and the United States, although transit within and among shelves occasionally occurred over deeper waters. Within this range, the areas < 100 m depth were used particularly often. Some offshore banks are clearly delimited by the distribution of locations, with Sable Island, Western and Middle Banks (areas near Sable Island) being used by most seals. Individuals show considerable variation in habitat use, but three broad types of movement behaviour are evident (Austin et al. 2004).

Grey seals consume a variety of both demersal and pelagic prey, however, typical only a handful of species comprise most of the food consumed (e.g., Bowen et al. 1993, Bowen et al. 1994). These prey species may differ by geographic area, by season, and interannually. Adult males and females also have significantly different diets with males tending to consume a wider range of prey than females (Beck et al. in review). Sandlance, and redfish tended to dominate the diet throughout the 1990s, but capelin, herring, turbot, hakes, skakes, flounders, and gadoids were also eaten to a lesser degree.

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### *Seal Ecology in the Gulf of St. Lawrence*

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#### Grey Seals

The Gulf of St. Lawrence component of the Northwest Atlantic grey seal population has not followed the same population trajectory as animals on Sable Island. A combination of mark-recapture experiments and aerial surveys suggests that pup production increased from about 5,000 animals in the mid-80s to 11,000 in 1996, and then declined to about 5,000 animals in 2000. The decline may be linked to deterioration in ice conditions (whelping habitat).

Information on diet composition has been reconstructed from stomach and intestine samples of animals shot in the northern gulf from about 1986-92 and from the southern Gulf (1995-present). In the northern Gulf, capelin, and lumpfish were important prey species early in the summer, while cod, herring and mackerel were important prey species in samples collected in late summer. In the southern Gulf, cod, flatfish, sandlance, cunner and white hake are important prey species depending on region of collection.

Monitoring of grey seal movements using satellite telemetry indicates that grey seals may forage at some distance from their haulout site, but that animals tend to return to a preferred site or sites. Movements are more extensive in early spring, with many animals moving over the Middle Bank region on the Scotian Shelf or the Burgeo area off southern Newfoundland. Males tend to show greater displacements than do females.

#### Hooded Seals

Diet data are not available for hooded seals in the Gulf, although a few biopsies have been obtained from live-captured animals to obtain information on fatty acid profiles for diet composition. Satellite transmitter deployments indicate that at the end of the breeding season, hooded seals leave the southern Gulf and move over the central and northern slopes of the deep (300-500m) Laurentian channel that extends through the middle of the Gulf as far west as the Saguenay river area. Hooded seals occur in this channel area, between the entrance to the estuary in the west and Cabot Strait in the east until early May. At this time they leave the Gulf, for Greenland primarily through Cabot Strait.

**Harp Seals**

Harp seals, hooded seals and grey seals all occur in the Gulf of St. Lawrence at different times of the year. All three species whelp on the ice in the southern Gulf. Harp seals normally whelp on the pack ice to the north of the Magdalen Islands in march, while the hooded seal also whelps in March on the ice just to the north of Prince Edward Island. Grey seals breed in January on the ice in Northumberland Strait, south of Prince Edward Island.

Seal diet information has been obtained for grey and harp seals by reconstruction using otoliths recovered from stomach and intestines. Among harp seals a comparison of diets obtained using reconstruction from hard parts and diets suggested from stable isotope signatures, indicates that material recovered from the small intestine tends to underestimate the importance of invertebrates in the diet. As a result, only stomach content material is now examined in harp seals.

Diet composition varies considerably throughout the Gulf. Capelin, herring and Atlantic cod are important prey species in samples collected from the northeastern part of the Gulf, while capelin and invertebrates tend to dominate diets from the western part of the Gulf and estuary

Mesoscale information on distribution and movements are limited. Aerial surveys of the Gulf, flown in late March indicate that few animals occur along the west coast of Newfoundland, while large numbers of animals are concentrated in the western part of NAFO zone 4S and the eastern portion of the St. Lawrence estuary.

**Conclusions**

- Gulf greys have had a much different population trajectory than Sable Island grey seals
- Grey seals are found primarily over the continental shelf
- Hooded seals are concentrated in channel, or along the slope of the channel.
- Harp seals largely estuary
- Diet strongly influenced by sampling location and season.

***Ecology of Harp and Hooded Seals in Newfoundland and Labrador Waters***

Garry Stenson

Harp and hooded seals are considered to be important predators of commercial fish stocks in the waters of Newfoundland and Labrador (Hammill and Stenson 2000). Harp seals are a medium-sized pinniped that summer in the Arctic and winter off the coast of Newfoundland and in the Gulf of St. Lawrence. The Northwest Atlantic harp seal population was thought to have declined through the 1950s and 60s to less than 2 million animals (Healey and Stenson 2000). After the implementation of quotas in the early 1970s, however, the number of harp seals began to increase and the population has been relatively stable at a little over 5 million seals since the mid 1990s (2000 estimate = 5.2 million, 95% C.I. 4.0-6.4 million; Healey and Stenson 2000).

In order to determine seasonal movements and diving behaviour of harp seals, satellite transmitters were deployed on 22 seals during the 1995-1997 period (Stenson and Sjare 1997). Seasonal movements varied greatly among individuals and between years; there were no differences between males and females. Harp seals spent much of their time in offshore areas of the continental shelf, ranging from the northern Scotian Shelf and Grand Banks of Newfoundland in the spring and winter, north to Baffin Bay, southeastern Greenland and Hudson Strait in the summer. The Grand Banks appeared to be an important wintering area in both years. Harp seals are capable of diving to depths of over 500m but the majority of dives are to 200m or less (Stenson and Sjare 1997).

The diets of harp seals in nearshore areas of Newfoundland are well known; less is known about the diet of seals in offshore areas (Lawson and Stenson 1995, 1997; Lawson et al 1995; Stenson and Perry 2001). Generally, they consume primarily small pelagic fish such as capelin, Arctic cod, sand lance and herring. However, there is significant geographic and temporal variation in the diet. Atlantic cod appear to be more important in the nearshore diet in recent years, particularly in Trinity and Bonavista Bays. Examining the age of cod consumed by seals indicates that there has been a shift from mostly 0 and 1 year old cod in the diet towards older fish since the mid 1990s. In addition, belly-biting of adult cod has been reported in various areas of the northeast coast. The significance of this additional type mortality is not known as it is not detectable using traditional diet reconstruction methods.

Hooded seals are one of the largest species in the northwest Atlantic with females reaching over 200 kg and males over 400 kg. Like harp seals, hooded seals are seasonal migrants summering in the Artic and wintering off Newfoundland and in the Gulf of St. Lawrence. There are no current estimates of abundance for northwest Atlantic hooded seals. The most recent surveys were carried out in 1990 (1991 in the Gulf). At that time, pup production off Newfoundland was estimated to be 83,100 (Stenson et al 1997) and 2,006 in the Gulf (Hammill et al 1992). This results in an estimated total population of approximately 470,000 (Hammill and Stenson 2000).

The seasonal distribution of hooded seals has been estimated based upon satellite telemetry information from a small number of transmitters deployed after the breeding period. In contrast to harp seals, hooded seals are generally found along the continental shelf edges or over the deep ocean (Stenson and Hammill, unpublished data). Following breeding hooded seals move to the shelf edge of the Grand Banks or Flemish Cap. Some individuals move to the Rekyjanes Ridge area of the mid Atlantic. By late June all of the seals were found off southeast Greenland where they moulted. There is little information on the return migration, but hooded seals have been observed along the edge of the northern Grand Banks by December. There appears to be an under-representation of juveniles among the seals that are found in Atlantic Canadian waters. Hooded seals are known to dive more than 1,000m deep although the majority of the dives observed were less than 300m.

There is relatively few data on the diet of hooded seals and the data that is available is primarily from the early 1990s (Ross 1993, Hammill and Stenson 2000). Squid appear to be important prey along with deep-water fish species such as Greenland halibut, redfish and pleuronectids. This is not unexpected given their tendency to make deep dives along the shelf edge where these fish are found. Atlantic cod were also an important prey among seals collected in offshore areas during the early 1990s. It is not known if they are still an important part of the diet in this area as there has been little seal sampling carried out since 1994.

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### *The distribution of Northern (2J+3KL) Cod, with Emphasis on the Inshore and Smith Sound, and Notes Regarding Cod-Seal "Events"*

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#### Status of Northern (2J+3KL) Cod

A brief summary of the history of the northern (2J+3KL) cod stock, which occupies waters off southern Labrador and eastern Newfoundland, is available from DFO (2004). Additional details may be found in Lilly et al. (2003) and references therein.

The biomass of the northern cod stock complex was about 3 million t in the early 1960s. Fishing intensity increased greatly in the 1960s as non-Canadian fleets exploited the dense offshore overwintering aggregations. The stock declined to about 0.5 million t in the mid-1970s. After extension of fisheries jurisdiction in 1977, the stock increased to just over 1 million t in the mid-1980s, but then declined during the late 1980s and collapsed to an extremely low level during the early 1990s. A moratorium on commercial fishing was declared in July 1992.

Historically, many cod migrated from overwintering areas offshore to feeding areas inshore. By the mid-1990s it was apparent that these offshore populations were barely detectable. In autumn 2003 the offshore biomass index from research bottom-trawl surveys was at about 1% of the average in the 1980s. During the past decade the number of young produced each year appears to have been low, as expected from a greatly reduced spawner biomass, and the young cod have suffered very high mortality, such that very few survive beyond about age 5.

The extremely low abundance of the offshore populations has increased the prominence of inshore populations and made it easier to discern their dynamics. It became apparent in the mid-1990s that there were aggregations of cod in the inshore in Div. 3L and southern Div. 3K. These inshore populations appeared to be more productive during the 1990s than populations in the offshore. A small fishery directed at these inshore populations was reintroduced in 1998. The monitoring and sampling of the catches, together with several fishery-independent indices from the inshore alone were used in a sequential population analysis to reconstruct the inshore population for the period 1995-2003 (Lilly et al. 2003). This analysis indicated that the biomass of exploitable cod (assumed to be ages 4 and older) had peaked at just under 60,000 t in 1996 and had declined to about 30,000 t in 2003. The fishery was closed indefinitely in April 2003.

**General Distribution Pattern**

Changes with Age

Most scientific studies agree that the major nursery area for the northern cod stock is shallow water along the coast of southern Labrador and eastern Newfoundland, although young cod also occur on the plateau of Grand Bank. For the coastal areas, the young-of-the-year (age 0) cod are mainly inshore. By age 1 the cod are starting to appear in the offshore, and by age 3 or 4 they have a distribution that largely overlaps that of the older fish. This pattern appears to have continued since the collapse of the offshore populations in the early 1990s.

Seasonal Changes in Distribution

Cod toward the northern end of the species' range in the western Atlantic tend to move seasonally between overwintering areas and feeding areas. For most cod in the northern cod stock area, the overwintering area was near the shelf break in 300-500 m from Hamilton Bank in Div. 2J to the Nose of the Bank in Div. 3L. At some time in the spring most of these fish moved onto the shelf, and many of them migrated into the shallow, coastal waters where they fed on capelin that had approached the coast to spawn. The cod then moved back across the shelf during the autumn. Not all cod had this pattern. For example, some cod moved during summer to feeding areas on the plateau of Grand Bank. Others spent the whole year in inshore waters, moving from deep inlets during winter to shallow feeding areas in summer.

It is not known if some of the cod that currently overwinter offshore make seasonal feeding migrations to the inshore.

Changes that Occurred Over Time

During the period of the collapse (late 1980s and early 1990s), the fish disappeared first off Labrador in the north and then from the plateau of Grand Bank in the south. By 1993 the remaining fish were found mainly near the outer shelf east of Cape Freels (essentially along the 3K/3L line). By 1994 no aggregations were found during the standard bottom-trawl surveys, but a few small aggregations were detected during acoustic studies. Since the mid-1990s the fish have been broadly distributed at very low density throughout much of the stock area.

Inshore Populations

There is evidence from before the collapse that not all cod moved offshore in the winter. Some remained near the coastal shelves in deep water below the Cold Intermediate Layer (CIL) of the Labrador Current, and some remained within the bays of eastern Newfoundland, often in narrow fjord-like environments.

We know relatively little about the historic status of these inshore populations. Templeman (1958) described the distribution of catch in the inshore fishery of the late 1940s: “Within the east coast area, cod are most abundant near the projecting island and headland areas such as the Cape Bauld - St. Anthony, Fogo Island, Cape Freels, Cape Bonavista, Bay de Verde - Grates Point areas and in the areas to the east of the Avalon Peninsula. … As a rule far fewer cod are available in the deep inlets and warmer water at the heads of the east coast bays than at the headlands.”

There is evidence that some of the fish that were caught in the inner reaches of the bays belonged to “bay stocks”. Reports of the presence of cod in spawning condition in the bays of eastern Newfoundland may be found in the scientific literature as early as the 1890s, when Neilsen described how he obtained fish in spawning condition for the Dildo Island Marine Hatchery in Trinity Bay in May-June (Neilsen 1895). During the 1980s, areas of largest catch had in common a closeness to the schools of cod migrating toward the coast from their offshore overwintering areas. If all cod caught in the inshore shallow-water fishery arrived from the offshore, then the earliest landings would be expected at the headlands. However, substantial landings occurred in the inner parts of Bonavista and Trinity Bays several weeks prior to the big increase in landings at the tips of the headlands (Lilly 1996).

Cod have for many years been caught through holes cut in the ice in sheltered inlets and embayments of the east and northeast coasts (e.g. Neis et al. 1996). Neis et al. (1999) reported, based on interviews with fish harvesters, that small winter fisheries were conducted by jigging and gillnetting through the ice in Bull Arm and Southwest Arm (Trinity Bay) and in the Charleston area of Southern Bay (Bonavista Bay).

The only such areas that have been studied extensively using scientific techniques are the three fjord-like arms near Random Island on the western side of Trinity Bay. Most attention in the late 1980s and early 1990s was focused on the two southern arms (Northwest Arm and Southwest Arm) where DFO and especially the Fisheries Oceanography Group at Memorial University of Newfoundland conducted tagging experiments and documented various aspects of the biology of cod that overwintered inshore, including their movements and spawning (Wroblewski, et al. 1994, 1995; Smedbol and Wroblewski 1997). The focus shifted to Smith Sound following discovery of a large and dense aggregation of cod in spring 1995 (Rose 1996; Brattey 1997; Rose 2003).

**Cod-Seal “Events”**

Reports of cod in shallow water became frequent in the winters of 1997-1998, 1998-1999 and 1999-2000. These reports came primarily from two areas: Notre Dame Bay on the northeast coast and southwestern Bonavista Bay on the east coast. [See Lilly et al. (1999) for a brief catalogue of some of the earlier events.]

Reports from Notre Dame Bay included the following. From January 11 to approximately January 16, 1999, cod were found dead and dying in and below ice in Virgin Arm. It was estimated by Fishery Officers, who interviewed divers and other people who harvested the fish, that perhaps 200,000 lbs (91 t) of cod died. A sample (n=193) of these fish, obtained by divers, had a mean length of 59 cm (range 35-95 cm). The fish were to all appearances healthy and in good condition. Harp seals were reported in the area and some of the larger cod in the sample had bites taken from their bellies.

Reports from southwestern Bonavista Bay were more frequent and included numerous descriptions of predation by harp seals on cod. In early February, 1998, many dead cod were observed in Southern Bay Reach. Many harp seals were reported in the area. From February 28 to March 3, 1998, cod were seen swimming with fins above the surface, and 200 lbs of cod were found dead on the shore. Seals were reported in the area and an observer reported seeing a seal taking a bite out of a cod's belly. On January 11-13, 1999, many cod were observed swimming near the surface at Cannings Cove and Jamestown. Seals were again seen in the area and an observer reported seeing seals with cod in their mouths, shaking the cod and tearing out the guts. On January 20, 1999, an observer saw a very large number of seals near Deer Island (at the headland between Goose Bay and Sweet Bay) coming to the surface with cod in their mouths. They would take a clean cut out of the belly, taking the liver but leaving the gonad. As reported by The Telegram (St. John's, NL, February 23, 1999), in February 1999 seals were observed preying on cod in a small cove on Deer Island. The seals would shake the cod "and the gut would stay in the mouth and the fish would fly off". The presence of large numbers of dead cod on the bottom was confirmed by a diver. One cod recovered with a large bite from its belly was reported to be about 3 feet (91 cm) long. Observers say that they never before experienced incidents such as the above.

The following is a brief overview of information gleaned from newspaper accounts and reports by fishery officers and DFO scientific staff. Observations of seals preying on cod by belly-feeding have been reported mainly from early winter to early spring and mainly from Notre Dame Bay (NDB), Bonavista Bay and Trinity Bay. There have been several instances in which divers have reported cod lying on the bottom with holes in their bellies. There have been several well-documented incidents from eastern Notre Dame Bay and southwestern Bonavista Bay in which cod have been found milling about lethargically in cold shallow water. In some of these incidents seals have been observed on the periphery, especially near dawn and dusk. The most notable such incidents occurred at Virgin Arm in NDB in 1999 and at several locations in southwestern Bonavista Bay in 1998-2000. These incidents have generally occurred adjacent to deep water where the cod may have been overwintering. Some people think the cod were herded by the seals into the shallow water, where some of the cod then died from seal predation and perhaps from exposure to the cold water and ice. Cod have been harvested in a few of these situations and most such cod have been lethargic but alive. If cod die from exposure to cold and ice after fleeing from seals, then such mortality may be considered "fatal harassment" (McLaren et al. 2001). Another possible cause of incidents where cod have been found milling about in cold shallow water is that the cod entered the shallow water for some other reason, such as the pursuit of prey. Seal predation associated with such incidents might be opportunistic. Observations of belly-feeding continue to the present. There have been no recent reports of "events" as dramatic as those that occurred during 1998-2000.

There is evidence that natural mortality of adult cod has been high in Notre Dame Bay and Bonavista Bay. The opening of a cod-directed fishery in the inshore during 1998-2002 provided an opportunity to conduct tagging studies with the intent of estimating exploitation rates. After several years it became apparent that the returns of tags applied during specific tagging studies had declined very rapidly over time in Div. 3K (Brattey and Healey 2003). This trend was less dramatic in Bonavista Bay, and even less so in Trinity Bay. An exploration of the magnitude of natural mortality that would be consistent with such rapid disappearance of fish (Cadigan and

Brattey 2003) concluded that natural mortality was likely as high as 55% per year in Div. 3K and 33% in Div. 3L as a whole.

### Smith Sound Cod Population

Smith Sound is a fjord-like inlet on the western side of Trinity Bay in Div. 3L. It is about 20 km long, 1-2 km wide, and more than 200 m deep over much of its length. It has a trench depth as great as 350 m and a sill at about 155 m. It is not an estuary.

There is much evidence that cod have always overwintered in Smith Sound, but the recent winter/spring aggregations appear to be much larger than people were aware of in the past. In winter, the cod tend to be in the deep water of the sound in relatively stationary, semi-pelagic, mono-specific aggregations (Rose 2003). These aggregations are often about mid-way along the length of the sound, but they can be found further to the west or the east (Rose 2003). It has generally been assumed that the cod remain within the sound during winter and early spring, but observations during a mass mortality in April 2003 (Colbourne et al. 2003; DFO 2004) indicate that some of the cod might move out of the sound and then return before leaving on their summer feeding migration.

Numerous tagging studies (Brattey and Healey 2003) have illustrated that the cod move northward after leaving the sound. Returns have come from the north side of Trinity Bay, Bonavista Bay and Notre Dame Bay. There have been only rare returns from north of Notre Dame Bay and few fish have been recovered south of Trinity Bay. The cod return to the sound during the late autumn or early winter. Not all cod leave the sound. Some cod are found from late spring to early autumn, generally in shallower water than during winter and early spring. It is not known if the cod found during the summer are resident fish or just some individuals that happen to remain behind.

Many tags were recovered from fish that were collected from the sound during the mass mortality of April 2003. Most of these tags had been applied within Smith Sound or in Bonavista Bay. None had been applied in 3Ps. These observations support the concept that the cod within Smith Sound constitute a discrete population. This population is but one of several such populations that occur in Trinity, Bonavista and Notre Dame Bays. However, all other populations appear to be much smaller (Lilly et al. 2000). The Smith Sound population is the only one whose magnitude has been studied during winter.

Hydroacoustic studies have been conducted in Smith Sound at various times since the aggregation was discovered in spring 1995. Winter surveys have been conducted in a standard manner since 1999 by George Rose, Senior Chair of Fisheries Conservation at Memorial University of Newfoundland. Average indices of biomass increased to a peak of about 26,000 t in 2001, and then declined to about 18,000 t in 2004. The cod studied during these surveys tend to be large (about 35-120 cm in winter 2004). The location of the smaller cod is not well understood (see further discussion below).

### Monitoring of Cod in Smith Sound

In recent years, information on cod in Smith Sound has come from four main sources.

<u>Acoustic surveys</u>: George Rose, Senior Chair of Fisheries Conservation at Memorial University of Newfoundland, has conducted acoustic surveys in January/February of each year since the late 1990s. He has conducted additional surveys during other months in some years. There were additional acoustic studies from mid-April to early May of 2003 as part of a study of a mass

mortality of cod. Dr. Rose is intensifying his studies of Smith Sound. Additional studies are being conducted by Fran Mowbray of DFO in conjunction with her studies of capelin.

Sentinel survey: Sentinel surveys were initiated in 2J3KL in 1995 to provide catch rates and biological samples of cod in inshore waters during the moratorium period, and were continued when small directed commercial fisheries were reopened in the inshore in 1998-2002 (Maddock Parsons and Stead 2003). Sentinel surveys involve limited test fishing by fish harvesters in traditional areas with traditional fixed gears (mainly gillnets). One sentinel survey site is located within Smith Sound. This site is operational for several weeks of the year during the period from July to October. Most of the cod that overwinter in Smith Sound are outside the sound during the period when the sentinel survey is operational.

Tagging studies: An intensive tagging study was in operation in Smith Sound and adjacent inshore areas (especially to the north) during 1998-2002. This study has provided information on fish migration patterns and exploitation by commercial and recreational fisheries. It was also starting to provide insight into natural mortality. The tagging programme was discontinued when the commercial and recreational fisheries were closed in April 2003.

Catch rates in commercial/index fisheries: Information on catch rates during commercial fisheries are available for a few weeks during the summers and autumns of 1998-2002. This source of information ended with the re-establishment of the closure of commercial fisheries in April 2003.

**Assessing the Benefits to Cod from a SEZ in Smith Sound**

The acoustic surveys conducted by Dr. Rose are accompanied by bottom-trawling to provide size composition of the fish at the time of the study and samples of otoliths for ageing. This information enables the computation of population numbers at age in each year. From these population numbers one can calculate the mortality experienced by the population from the winter of one year to the winter of the next year, under the assumptions that the surveys are monitoring a specific overwintering population (with no exchange with other populations) and the proportion of that population being assessed remains constant from year to year. There is insufficient information to enable the total mortality to be decomposed into its constituents. These would include fishing mortality (legal by-catch and poaching) and natural mortality (predation by seals, predation by other species, death associated with cold water and/or freezing, and other causes, which might include disease and starvation). Note that mortality from each of these causes might occur both inside and outside the sound.

One goal of a SEZ program in Smith Sound might be to reduce the level of predation by seals on cod within the sound. The efficacy of the program will be difficult to assess. Most predation deduced from the examination of seal stomach contents will involve relatively small cod, perhaps mainly of sizes less than 20-25 cm, but also some individuals as long as 40 cm or more. However, very little is known about the abundance and distribution of small/young cod within Smith Sound during the period when seals may be present. In addition, there is no ongoing monitoring program for juvenile cod in the coastal waters of eastern Newfoundland. (There is beach seining for ages 0 and 1 in a very limited area of Bonavista Bay, and some sentinel surveys deploy 3¼ inch mesh gillnets that catch fish of approximately 34-44 cm. Both of these activities occur between mid-summer and mid-autumn.) Note as well that the distribution of the juveniles of the Smith Sound population is not well known. One might expect that many will reside within Smith Sound, possibly at shallower depths than the larger fish, especially during winter, but they might also occur outside the sound. Although some of the spawning of the Smith Sound population appears to occur within the sound, there may also be spawning outside the sound. The drift patterns of eggs, larvae and pelagic juveniles, and the areas of settlement, are unknown.

Another goal of a SEZ program in Smith Sound might be to reduce the likelihood that a cod-seal "event" might occur. Such an event could involve the deaths of many relatively large cod over a short time period, perhaps just a few days. An event might start with cod moving from deep water to shallow water in response to the presence of seals. Some of these cod may then die from predation by seals or by exposure to cold water, especially if ice is present. An event might also start with cod moving of their own volition from deep water to shallow water, perhaps in pursuit of prey. Once in shallow cold water, the cod may more readily be preyed upon by seals. Cod-seal events have been reported to the north in Notre Dame Bay and Bonavista Bay, but not within Smith Sound.

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NOTE: Since 1990, more than 200 peer-reviewed scientific papers and numerous research documents have discussed some aspect of the status or biology of northern cod. A list of these documents may be obtained upon request from George Lilly, Fisheries and Oceans Canada, P.O. Box 5667, St. John's, NL A1C 5X1 (tel: 709 772-0568; email lillyg@dfo-mpo.gc.ca).

### *Southern Gulf of St. Lawrence Cod Abundance and Distribution*

G.A. Chouinard, DFO, Gulf Fisheries Centre, Moncton, N.B. E1C 9B6

Southern Gulf cod have been exploited commercially since at least the 16th century (Chouinard and Fréchet 1994). The stock undergoes an extensive annual migration which is well known by fishermen. The stock is found in the southern Gulf of St. Lawrence (NAFO sub area 4T) in summer. During the fall, the population migrates to the eastern area of the southern Gulf, and can be found off the coast of western Cape Breton in late fall. The migration continues and cod from the southern Gulf are found in Sydney Bight (sub area 4Vn) in winter. The return migration occurs in spring after the ice break-up. Historically, the fishery has been targeting migrating aggregations. The migration pattern has been documented through several tagging studies conducted from the 1940s to the 1960s. The migration is thought to be linked to the oceanographic regime. The southern Gulf is covered by ice from January to March-April. Fishery data (Sinclair and Currie 1994) suggest that there are two main migration routes; a northerly route along the Laurentian Channel and a more important southerly route through the Cape Breton Trough.

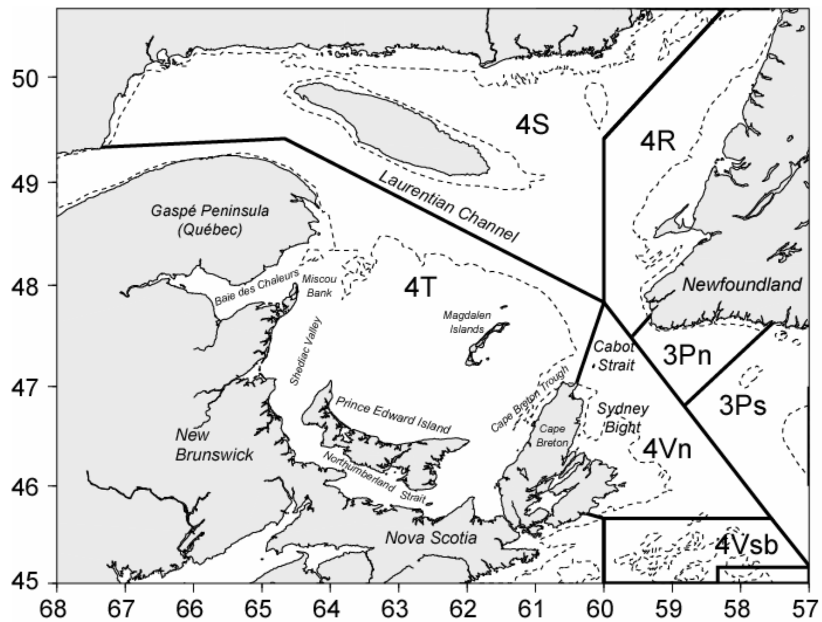


Figure 1: Chart of the Gulf of St. Lawrence showing Northwest Atlantic Fisheries organization (NAFO) areas and place names mentioned in the text.

Based on tagging studies and vertebral counts, it was concluded that there were likely several sub-stocks in the area (Templeman 1962; 1974). However, because of the extensive mixing and migration makes cod found in the southern Gulf in summer and in Sydney Bight in winter are treated as one population. There is limited mixing between the southern and northern Gulf stock however, in winter, the southern Gulf stock overwinters in the same general area as the Sydney Bight (NAFO sub area 4Vn) resident stock. The stock unit has been validated with other techniques including otolith elemental composition (Campana et al. 1999) and vertebral count studies (Swain et al. 2001).

The general distribution of cod in the southern Gulf of St. Lawrence has been examined in numerous studies (Jean 1964; Clay 1991; Tremblay and Sinclair 1985; Chouinard 1994; Benoît et al. 2003.) In addition, other studies have focused on the seasonal (Jean 1964; Hanson 1996; Swain et al. 1998: Darbyson and Benoît 2003. Benoît et al. 2003) and interannual variation in distribution (Swain 1993; Swain and Wade 1993; Swain and Kramer 1995; Swain 1999) and distribution range (Smedbol et al 2002). Migration timing has also been examined (Sinclair and Currie 1994; Comeau et al. 2002).

Data collected in the annual September research surveys (1971-2003), seasonal surveys (east – 1986-1987 and west- 1990-1991), winter (January) surveys (1994-1997) was examined to provide some indication of seasonal movements and distribution. As well, fishery logbook data in the period 1991-1993 provide relatively detailed information on seasonal movements. During that time, the fishery was not subject to opening dates and logbooks contained detailed information on fishing location. The fishery was closed from September 1993 to May 1998.

The seasonal distribution pattern from these data shows that cod are primarily found in Sydney Bight from January to March. The migration into 4T starts in April and in May most of the stock is found in the eastern southern Gulf off the west coast of Cape Breton. By June, the stock has migrated to the western southern Gulf off the coast of the Gaspé Peninsula, northern New Brunswick and northwestern Prince Edward Island. Cod concentrations are found in this area until late-September-early October when the return migration starts. The migration appears to be relatively rapid and by November cod are again found primarily off the coast of western Cape Breton and migration in 4Vn starts. By the end of the year, the only concentrations in 4T can be found along the edge of the Laurentian Channel near Sydney Bight.

The ontogenetic variation in seasonal distribution of juvenile cod has been examined by Hanson (1996). Juvenile cod exhibit the same migration pattern as adults. However, the younger juveniles (age 1, 14-20 cm) tend to be found in specific areas in summer. The areas include the Shediac Valley – western Northumberland Strait, north and east coast of Prince Edward Island and areas around the Magdalen Islands. In general, older juveniles are more widely distributed. January surveys tended to indicate that smaller cod (<43 cm) tend to be found in the northern Sydney Bight area around St. Paul's Island while older fish tend to be found to the south.

There have been significant changes in the summer distribution of cod over time. Distribution of cod during summer appears to be density–dependent (Swain 1993; Swain and Wade 1993; Swain 1999). During periods of high abundance, densities tend to be highest at intermediate depths. However, in periods of low abundance, density is either unrelated to depth or highest in shallow water. It was hypothesized that these changes in the depth preference of cod reflected a trade-off between the density-dependent benefits of greater food supplies in warm, shallow waters and the density-independent benefits of lower metabolic costs in the colder waters at intermediate depths. A higher proportion of cod were predicted to occupy the colder waters at intermediate depths during periods of high abundance as a way of reducing metabolic costs when ration was low. Swain and Kramer (1995) found support for the hypothesis as cod occupied colder waters both in absolute and relative terms during periods of high density.

Sinclair and Currie (1994) found that migration in 4Vn occurs well before the end of the year, as a result, the management unit for this stock includes all of 4T and catches in 4Vn during November-April. In some years, significant catches in 4Vs in January-April are also attributed to this stock (Hanson 1995). Recent analyses (Comeau et al. 2002) indicate that the migration timing into 4Vn was in early December in the 1970's but is now in late October-early November. In recent years, the population is highly concentrated in summer (Smedbol et al. 2002).

Abundance and biomass of the stock have varied considerably and are currently at the lowest levels observed (Chouinard et al. 2003). Landings began to increase to a peak of over 100,000 t in 1958 (Chouinard and Fréchet 1994). The stock declined in the mid-1970s and landings were reduced to 27, 000 t in 1977. The stock recovered in the late 1970s and early 1980s and landings averaged 58,000 t from 1980 to 1990. Abundance and biomass of the stock collapsed in the late 1980s and early 1990s and the fishery was closed in September 1993 due to low stock abundance. Despite little sign of recovery, the directed fishery was re-opened in 1998. Productivity of the stock has been low in the 1990's and natural mortality has been estimated to be about twice historical levels (Sinclair 2001). The increase in natural mortality corresponded with an increase in the abundance of grey seals in the area (Chouinard et al. 2002).

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### *Distribution and Mortality of Scotian Shelf Cod*

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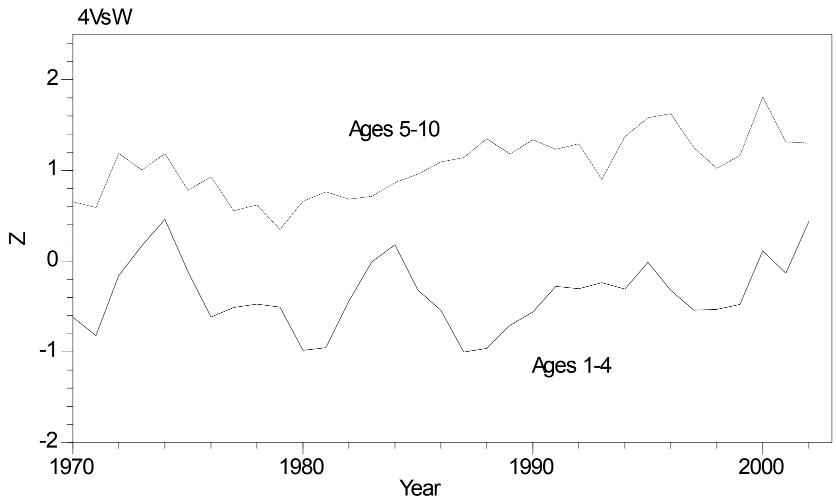
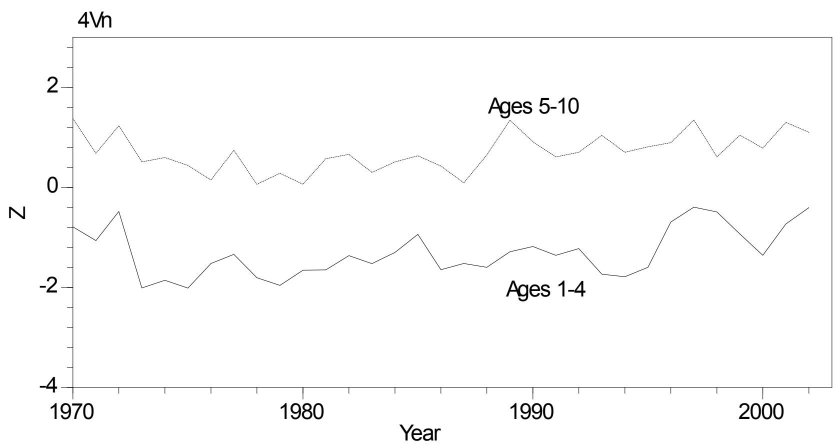
Information was summarized from research vessel surveys and commercial activity concerning the distribution of cod on the eastern Scotian Shelf (NAFO sub areas 4VsW and 4Vn May-Oct stocks). For the period during which there were three surveys (1979-1984) cod less than 40 cm were seen widely spread along the outer Shelf, in a distribution roughly coincident with that seen for grey seals derived from the satellite tag information. Although some seasonal movement was seen, the prey sizes were available throughout the year.

Total mortality (Z) for 4VsW and the summer 4Vn cod as estimated from the summer survey series were presented (Graph below) The ages 1-4 are not fished and represent the approximate size for most seal predation.




The directed fishery in both these areas was stopped in 1993. This major perturbation is not visible in the Z series. Also, over the period of observations, since 1970, the seals increased by about a factor of 30. This may correspond with the slight increase seen in the age 1-4 cod. A change caused by the removal of in a SIRZ would not be expected to be detected in a change in cod survivorship.

Predation mortality estimates for 4VsW cod from seals and from cod cannibalism were also presented. They suggest that in the 1980 cannibalism removed about 10 times as much cod as did grey seals. However, recently with the absence of large cod and the dramatic increase of seals, the relative importance has reversed.

***Summary of Presentation on Experimental Design: Designing Pinniped x Fishery Interaction Studies***

Anne York, Seattle, Washington

This talk presented a check list of some basic requirements of an experimental design and how these principles were applied to design an experiment to determine if trawl exclusion zones were beneficial for Steller sea lions in Alaska. The use of population and statistical models helped to formulate the hypothesis, do a power analysis and set up the experimental layout. The usefulness of the modelling cannot be over emphasized. In explaining the experiment to the public and stakeholders, great care must be given to explain the importance of randomization and potential harm to resources.

The critical steps in experimental design are:

*1. Define the problem:*

The western population of Steller sea lions experienced population declines of greater than 70% since the mid-1970s. The causes of the decline are/were uncertain, but data and modeling suggested that reduced survival of juvenile sea lions led to reduced recruitment. This was possibly tied to food resources for sea lions. Trawl exclusion zones around rookeries were established in the early 1990s and later extended to haul outs.

*2. Determine the question of interest and the objectives of the experiment:*

Are the trawl exclusion zones "beneficial" for Steller sea lions?

*3. Determine the response variable and null hypothesis:*

Following the recommendations of a blue ribbon panel, the response variable was determined to be the trend in population of either number of pups born or non-pups on the rookeries and haulouts inside the given zone. The panel recommended that the null hypothesis be that fishing has no effect on population trends versus some effect.

In addition, we proposed another experiment, in which the response variable was a measure of health. We assumed that animals could be classified as “healthy” or not, so that for a particular sample of size n and fraction of healthy animals, p, the number of healthy animals is distributed as a binomial (n, p). The null hypothesis *for this experiment is that fishing has no effect on the proportion of healthy animals.*

*4. Select the treatments:*

Size of the Exclusion Zone: Since we were interested in assessing the effect of the fisheries exclusion zone, the size of the no-fishing zone is factor in the experiment. We proposed three levels for this factor-- 5nm, 20nm, and 60nm for the health study and 1 level for the population study -- the experiment was originally designed for the 10-20nm no-trawl zones, but any size zone could in principle be used. Preliminary power analyses (below) suggested that it will be difficult to detect effects with great certainty with even a simple design.

Time: Since it will take several years to detect potential effects of the fishing, and since populations may increase or decrease with or without the exclusion zones, time is a factor which could likely confound results.

Spatial effects: The pattern of decline of the Steller sea lion population has also varied spatially. The panel has recommended that both the control and experimental sites be spread (stratified in some way) over broad geographical areas.

*5. Select the experimental designs:*

To deal with the potential confounding of fishing, time, and random variation and the very difficult problem of detecting effects in the short term, the panel recommended a crossover design for the population study, in which some yet to be prescribed number of sites are treated and the same number kept as controls. After a few years, the treatment and controls are switched. For the health study, we recommend designing the experiment so that effects can be detected within the first cross over period. If desired, the experiment could be continued through the second crossover period.

*6. Select the experimental units and number of replications:*

This cannot be reasonably done until a power analysis is completed. Our power analysis was a simulation for a few simple scenarios with a crossover design with 2 crossover periods of 5 years and the desire to detect a 5% change in growth rate of population. The simulations indicated that this required 8 censuses per year. The inputs to the power analysis were information on the variability of the rate estimates of non-pup counts on rookeries and haulouts.

This experiment was never conducted, so no details are provided under the remaining steps in experimental design:
*7. Ensure proper randomization and layout*
*8. Ensure proper means of data collection*
*9. Outline the statistical analysis before doing the experiment*
*10. Conduct the experiment*
*11. Analyze the data and interpret the results*
*12. Prepare complete report*

Post-mortem: The experiment was never performed-- for several reasons:
1. Political factors -- There were objections to randomization in some quarters of the fishing industry and objections to opening protected areas to fishing in the environmental community.
2. The length of time estimated to complete the experiment was at least 10 years. This was thought to be too long by many.
3. Costs -- Eight censuses per year are expensive and risky.