Effect of Seismic Energy on Snow Crab \textit{(Chionecetes Opilio)}

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The primary responsibilities of the Torngat Wildlife and Plants Co-management Board and the Torngat Joint Fisheries Board are to establish total allowable harvests for non-migratory species of wildlife and for plants, recommend conservation and management measures for wildlife, plants, and habitat in the Labrador Inuit Settlement Area (LISA) and to make recommendations in relation to the conservation of species, stocks of fish, aquatic plants, fish habitat, and the management of fisheries in the Labrador Inuit Settlement Area.

The Secretariat is the implementation agent of the Torngat Joint Fisheries Board and the Torngat Wildlife and Plants Co-Management Board. The Secretariat is a team of professionals based in Happy Valley-Goose Bay that provide financial management, logistical, project management and analytical support to both boards.

Torngat Omajunik, Piguttunik Oganniaganillu Suliangit


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Introduction

The Torngat Wildlife, Plants & Fisheries Secretariat has an interest in evaluating the impact that seismic activity may have on commercial fish species such as snow crab (*Chionoecetes opilio*) in area 2H and 2J of the NAFO regulatory zone. The Nunatsiavut Government currently holds commercial licences for snow crab in these areas.

Seismic surveys are used in the search for undersea reserves of oil and gas. They utilize arrays of airguns to produce powerful sound waves through sudden releases of pressurized air bubbles, while “streamers” of hydrophones listen for echoes. Using sophisticated acoustic processing, these echoes can provide information about geological structures up to 40km below the sea floor.

Effects of seismic testing on marine species remain unclear and research is still being conducted to better understand if the exploration by oil and gas industry can conflict with commercial fisheries.

The information presented in this report will serve as two functions for the Torngat Joint Fisheries Board when making recommendations and disseminating information on seismic testing:

- Increasing the Board’s knowledge of past and current snow crab fishery information/research studies with respect to seismic testing in the Labrador region.
- Providing information to local fishers on seismic exploration and the potential effects, if any, on commercial fisheries

Snow Crab Management

Snow crab (*Chionoecetes opilio*) occur throughout the Northwest Atlantic from Greenland to the Gulf of Maine and over a broad range of depths. Although fished for decades, the commercial snow crab fishery increased substantially in the mid 1980’s at the same time as the collapse of groundfish resources on the Northeast coast (IFMP 2009). In 2010, the landed value of snow crab was 155 million making up 42.2% of total landed value of commercial fisheries in Newfoundland and Labrador (DFA 2010).

The Newfoundland and Labrador snow crab fishery began in Trinity Bay in the late 1960’s. The fishery in Labrador began in 1985 and expanded significantly in 1991 with commencement of fishing north of 53° 30N (Taylor et al. 2008). The Federal Department of Fisheries and Oceans is the managing body responsible for annual reviews of resource status and quotas, the current snow crab Integrated Fisheries Management Plan (IFMP) has been in effect since 2009, and primarily considers the maintenance of the reproductive potential of the resource, aiming to achieve a sustainable harvest of legal-sized crab and minimizing wastage. All fleets have designated trap limits, individual quotas (IQs), fishing areas and in many cases different seasons. The Newfoundland and Labrador snow crab resource area is divided into snow crab management areas (or CMAs) (Figure 1) for which quotas are set, however the resource is assessed by using corresponding Northwest Atlantic Fisheries Organization (NAFO) divisions (Figure 2).
Figure 1: Newfoundland and Labrador snow crab management areas
Source: DFO (2011)
Snow crab are fished with conical baited traps with a dictated mesh size (65 mm) to ensure escapement of undersized crab. The number of traps are limited to 75 standard traps or 150 Japanese traps, with the exception of harvesters using the Buddy-up system where double
the amount of traps can be used. The minimum legal size for commercial snow crab (excluding females) is 95 mm carapace width. Additional enforcement measures include, mandatory hail-outs; vessel monitoring systems (VMS) which have been mandatory since 2004; at-sea observer coverage; 100% dockside monitoring; and area closures if the occurrence of soft-shelled crab reaches 20% of catches. The release of soft-shell and adolescent crab is allowed and the live release of species under the Species at Risk Act (SARA) act is mandatory (IFMP 2009).

The Nunatsiavut Government holds 4 communal licenses for the snow crab fishery, 3 in 2J (including one for 2J North, north of 54° 40N) and one for 2H, south of 55° 50N (2011 allocations are 97.025 lbs; 97.025 lbs; 368t; 70t respectively). These fisheries currently occur offshore.

**Snow Crab Abundance/Resource Status and Trends**

The snow crab resource is assessed annually during a Regional Advisory Process (RAP), in which DFO and stakeholders (including the Government) participate. The assessment is based on trends in fishery catch per unit effort (CPUE), exploitable biomass indices, potential recruitment and mortality. Data from multi-species trawl surveys, inshore trap surveys, fishery logbooks, observers, industry collaborative surveys as well as biological sampling all input into the assessment (DFO 2011). It should be noted that logbook returns are often incomplete especially in the early years of the snow crab fishery and especially for NAFO divisions 2JH. In 2010, only 14% of logbooks for 2H were received (DFO 2011).

Overall effort has increased since the 1980's and been broadly distributed throughout the crab management areas. Landings have increased since 1988, reaching an all time high in 1999 (due to expansion to offshore areas).
Overall resource summary
The latest assessment includes data from 2010 surveys and fishery (Figure 3), total landings increased by 22% from 44,000 t in 2005 to 53,500 t in 2009, but then decreased to 52,200 t in 2010, primarily due to a decrease in Div. 3K. The exploitable biomass, which is as estimate of the biomass that can be fished, increased from 2003-2007 due to recovery in 3LNOPs while the north had decreased (2HJ3K) with no indication of change. Recruitment increased from 20032008 and has since changed little, longer recruitment potential are stated as uncertain (DFO 2011).

In 2011 all of the quota allocated to 2J North and approximately 16% of the available quota for 2H was harvested (Torngat Fisheries Secretariat 2011). Figure 4 shows the spatial distribution of snow crab fishing effort for 2007-2010 for 2J and 2H. Estimated biomass indices for 2J and 2H are shown in Figure 5.

Figure 2: Trends in snow crab landings in NAFO Divisions 2HJ
Figure 3: Spatial distribution of snow crab fishing effort for 2007-2010 for NAFO divisions 2J & 2H
2H resource summary

2H landings decreased 63% between 2007 and 2010, CPUE declined between 2006 and 2009 and remained unchanged in 2010. The exploitable biomass changed little from 2008-2010. Table 1 lists annual total allowable catch, landings and effort from 2004 to 2010 for Division 2H (DFO 2011). Recruitment estimates have decreased since 2004 and are expected to remain low over the next few years. The current assessment states that, "maintaining the current level of fishery removals would likely result in little change to the exploitation rate in 2011, but would increase the exploitation rate in future years" (DFO 2011).

Table 1: Annual Total Allowable Catch, Landings, Effort and Catch per Unit Effort for Division 2H

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TAC (t)</th>
<th>LANDINGS (t)</th>
<th>EFFORT (trap hauls)</th>
<th>VMS CPUE (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>10</td>
<td>2326</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>2007</td>
<td>193</td>
<td>16083</td>
<td>520.5</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>100</td>
<td>141</td>
<td>14242</td>
<td>405.8</td>
</tr>
<tr>
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<td>100</td>
<td>70</td>
<td>11864</td>
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2J Resource Summary

2J landings increased by 60% in 2008, but decreased by 14% in 2010. CPUE increased in 2009 by 27% and changed little in 2010. Table 2 lists annual total allowable catch, landings and effort from 2004 to 2010 for Division 2H (DFO 2011). The exploitable biomass has declined over the past number of years but has remained constant from 2009-2010. Recruitment has also declined and is expected to remain low. The current assessment states that, "maintaining the current level of fishery removals would likely have little effect on the exploitation rate in 2011." (DFO 2011)

Table 2: Annual Total Allowable Catch, Landings, Effort and Catch Per Unit Effort for Division 2J (Offshore only).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>TAC (t)</th>
<th>LANDINGS (t)</th>
<th>EFFORT (trap hauls)</th>
<th>VMS CPUE (kg/hr)</th>
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<tr>
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<td></td>
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<tr>
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<td>2510</td>
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<td></td>
</tr>
<tr>
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<td>1509</td>
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Seismic Survey Activity

Marine seismic surveys use the science of sound energy and seismology to map geological structures under the seabed. Towed arrays of airguns produce high energy/low frequency (averaging 230-240dB) sound waves through sudden releases of pressurized air bubbles that can penetrate more than 6,000m below the seabed. These sound waves travel through the water and bounce back to receivers that measure their strength. Seismic surveys can be used to study plate tectonics and sedimentation patterns that can hold clues to historic climate change patterns. More commonly, the signals that are collected from seismic surveys are analyzed and produce information on the depth, position and shape of an underground geological formation that may contain crude oil or natural gas (Acoustic Ecology).

Figure 5: Depiction of a marine seismic survey
There are two types of seismic surveys, two-dimensional (2-D) surveys use one sound source and one set of receivers and are usually conducted on a parallel grid with up to five kilometres between transect lines. The results of 2-D surveys provide a general picture of geological characteristics of an area, including type and size of structures present. In contrast, three-dimensional (3-D) surveys use two sound sources and multiple receivers and are conducted on a smaller grid than 2-D surveys. 3-D survey data give more detailed information about geological features and often follow 2-D surveys if a significant discovery of oil and/or gas is suspected based on 2-D survey data (CAPP 2005).

The Canada -Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) is the regulatory agency for the five offshore geographical areas for oil and gas for Newfoundland and Labrador (Figure 6). The board oversees operator activity for legislative and regulatory compliance in areas of safety, environmental protection, resource management as well as industrial benefits for all exploration, and production of hydrocarbons in the Newfoundland and Labrador Offshore Area. The process for geophysical exploration authorization (including seismic surveys) includes several steps. Firstly, an application is filed with the exploration department within the C-NLOPB, based on scoping of the survey project, the next step is the environmental assessment (EA) process in which a report is filed with the environmental affairs department as well as a screening review under the Canadian Environmental Assessment Act (CEAA). The EA process must include public consultation, and although the CEAA recommends public screenings, public participation is at the discretion of the C-NLOPB. The guidelines do state that proponents must consult with fishers and industry. All EA information is then posted on the C-NLOPB website for review and comment.
Figure 6: Newfoundland and Labrador Offshore Geographical Areas
An environmental assessment into a proposed seismic survey should explore potential negative environmental impacts and measures to reduce such impacts. Several mitigation measures could be proposed and/or adopted. Fish and fisheries-related measures could include: temporal avoidance (i.e. avoiding spawning/migration areas); avoidance of heavily fished areas; as well as timing and spatial avoidance to reduce conflict, for example, with DFO research surveys. In addition, a Notice to Mariners indicating areas and time of surveys will be regularly broadcasted; a fisheries liaison officer will be employed, a potential gear compensation program if fisher/industry gear is affected as well as a single point of contact for media and question/concerns regarding a specific seismic survey/activity (CNLOPB 2006).

The first recorded seismic survey in the Newfoundland and Labrador region occurred in 1964, and since then 329 seismic programs totalling 2.1 million kilometres of seismic have been recorded, and over 359 wells have been drilled (C-NLOPB 2010). Exploration activity in the offshore Labrador area began in 1965, with drilling in the 1970’s and 1980’s establishing 5 discoveries in the Hopedale Basin of natural gas. Approximately 136 000km of 2-D seismic data have been released and no 3-D data collected in the offshore Labrador area as of 2010 (Figure 7) (C-NLOPB 2010).

Figure 7: Area 5, Labrador Shelf, showing the location of released 2-D seismic data.
Nalcor Energy Oil and Gas announced in September 2011 a partnership and strategic investment in a large-scale multi-client 2D seismic survey of offshore Newfoundland and Labrador (including Area 5). The two-year seismic survey (commencing September 2011), will look to acquire up to date 2D seismic data and cover areas not previously surveyed which will lead to more exploratory wells being drilled (Nalcor 2011). It is important to note that as of 2010 there were more than 600,000km of seismic data not released due to confidentiality periods. According to the C-NLOPB, geophysical work performed in the offshore may be disclosed five years and six months following the date of completion. This time frame does not include nonexclusive surveys which may be disclosed 10 years and six months after field work is complete (C-NLOPB 2010).

Summary
It is evident from the spatial distribution of fishing effort in NAFO divisions 2JH (Figure 4) and the locations of seismic surveys conducted (Figure 7), that seismic exploration occurs in the same areas where the Nunatsiavut Government snow crab fishing takes place offshore. At this point in time data is insufficient to explore any statistically sound relationships or correlations between seismic activity and the snow crab resource (i.e. affects of seismic activity on biomass).

Seismic Effects on Snow Crab and Other Invertebrates

There has been much research in the area of seismic survey effects on marine organisms worldwide since surveying activities have been used to detect oil and gas deposits under the sea floor. Seismic surveys using air gun technology send sound pluses through the water column which can be detected by marine organisms. Research has been focused on marine mammals and finfish as they have the ability to hear and are at the greatest risk of physiological damage. Behaviour of whales and many fishes can be effected as well as their use of sound for communication (Parry and Gason 2006). Organisms with gas filled cavities, such as marine mammals and fish with swim bladders, are at great risk of physiological damage from seismic surveys (Gausland 2000). Not much work has been done on invertebrates as they do not have the ability to hear sound although they can detect pressure waves (Christian et. al. 2003). No matter the magnitude of damage done to marine animals or behavioural changes made seismic surveys can temporarily alter the ecosystem.

One of the concerns in relation to seismic surveying effects on marine organisms is the effect it can have on fisheries. At typical sound levels produced by airgun arrays fish may show startle or alarm response within 3-10 km of a seismic survey, although they can detect sounds up to 30-100 km from the survey (Engas et. al. 1996). If a fish reacts in this way they will leave the area and catches can be influenced, in addition to other damage to the fish can influence their health and reproductive potential. Some finfish species researched that are of interest to Newfoundland fisheries and seismic effects are Atlantic cod and monkfish.

Engas et. al. (1996) found that during a seismic survey in Norway trawl catch rates of Atlantic cod decreased 45-50% and haddock decreased 56-71% 18 nautical miles away from the survey. The recovery was monitored and after 5 days there was no increase in trawl catches but long line catches showed some evidence of some recovery. Lokkeborg and
Soldal (1993) also found a decrease in catch of cod by 55-85% 9 km from a seismic survey with the effects lasting 24 hours. A higher catch rate has also been observed for fishing in immediate areas to the survey track as the fish (species unknown) move closer to the sea bottom where the trawl is fishing (Gausland 2003). Andrews et al., 2007 also looked at some of the details of seismic effects on cod fish observing the fish 2 months post exposure. There were no mortalities but there was an increase in feeding 2 weeks after exposure, 95% more than control fish, and 33% more than control fish 1 month after exposure. The test fish were also observed swimming at the bottom of the tanks where control fish made use of all depths. Genomic studies also revealed that there was an alteration of gene expression in the brains of exposed fish. These affects in the wild would more than likely change the location of fish aggregations in nature and affect their catchability as well as mortality rates down the road with such drastic behavioural changes.

Monkfish were studied by Payne et al. (2009) to see if seismic exposure was detrimental to their unique reproductive strategy. If so the hatching and larval success could be compromised and create a decline in future monkfish stocks. The eggs which float to the surface in large veils were collected and newly hatched larvae were exposed to seismic airgun pulses in the lab at levels that represent survey pressures at the surface of the ocean. Results that there is no threat to eggs or near hatch embryos at the surface of the ocean.

Shellfish fisheries and their well being are also of great interest in Newfoundland as they are currently the most lucrative since the collapse of the ground fish fishery. There is less information available for these organisms and seismic effects as they do not use sound production or detection as readily as finfish or marine mammals. Very little is known about sound detection in invertebrates, however many species have mechanosensors that have resemblance to vertebrate ears (Popper 2003). In crustacean species, it is known that the main vibration receptors are in the statocysts and in the walking legs (Aicher et al. 1983). Certain species have been found to detect sound of different frequencies. There has been evidence that prawn ($Palaemon serratus$) are sensitive to sounds 100 to 3000 Hz (Lovell et al., 2005) and immature lobsters detected sounds of 20-1000 Hz and sexually mature lobsters can detect 2 distinct peaks of sound one 20 to 300 Hz and the other 1000 to 5000 Hz (Pye and Watson 2004).

Most invertebrates, including lobster, do not contain gas filled organs, and this may cause them to be less vulnerable to adjacent loud sounds/explosions than fish (Keevin and Hempen 1997) and Rulifson and Schoning (1963) hypothesized that it is possible that seismographic and seismic surveys may not cause mortality in the benthic species based on their morphological structure and absence of air bladders. But invertebrates often have a limited mobility, and may not be able to readily migrate out of survey areas (Moriyasu et al. 2004). Therefore as seismic surveys are still detectable by some invertebrates and are not suspected to cause mortality, immobile invertebrates who cannot migrate out of survey areas and those that are mobile are still at risk of chronic damage or behavioural responses. Some of the limited research on invertebrates and their responses to seismic energy has been on different life stages of snow crab, dungeness crab, shrimp, prawn, scallops and lobster.

The nature of researching the effects of seismic surveying on any marine animal is complicated as it is difficult to obtain concrete results. Much of the field research concerning
the effects of seismic surveying may not be accurate findings since there are many factors that also influence the animals that cannot be measured and in the lab there are many factors that cannot be duplicated. In the field it is also difficult to quantify all of these natural factors when seismic effects are evaluated by fishing pre and post survey. Reef dwelling species may not be easily scared in comparison to open ocean fish during seismic surveying, but there is still not much information on the recovery of these fish after the survey is complete (Skalski et. al. 1992). For invertebrates specifically, high migration activity, oceanographic conditions, moult cycle stage, life cycle stage and stage in sexual maturity can influence behaviour in their natural environment without the influence of air gun pulses, therefore fishing efforts to quantify the effects on bottom dwelling crustaceans before and after a survey cannot be directly connected to the seismic activity. Also some results are difficult to interpret considering that certain species may be attracted to the site of a blast or shooting to feed on the dead and injured animals (Trudeau 1979). This makes it difficult to determine the relationship between catch rate and abundance in these areas (Moriyasu et al. 2004).

One of the shellfish species of interest to the Newfoundland and Labrador fishery is snow crab and is the species of interest for this report. There have been questions asked regarding seismic surveying and a drop in catch rates.

There is concern by industry that catch rates for different crustacean species are lower in areas where active seismic surveying is occurring in Newfoundland waters, one of those being snow crab off the coast if Labrador in areas 2G and 2J (South of 55°50 North of 54°40).

The snow crab (Chionoecetes opilio) fishery is an important and valuable fishery in Atlantic Canada. Newfoundland and Labrador is the largest exporter of snow crab in Canada with the export of snow crab in 2008 at a value of $296 million. Snow crab are caught mainly on mud or sand-mud bottoms by baited wire or steel traps between April and July. Fisheries occur in NAFO areas 2J,2H, 3K, 3LNO, 3P's and 4R3Pn. Only market sized male crab are targeted for this fishery and female, soft shelled and juveniles must be returned to the sea if caught. Stock assessments are done annually to look at the abundance of snow crab for setting quotas (“Snow Crab” Backgrounds 2003. 6 May 2003. web. 27 Sept 2011).

The available research on snow crab and other crustaceans and their reactions to seismic surveying and air pulse technology is summarized here.

**Snow crab**

Christian et. al. (2003) looked at snow crab CPUE and physiological responses after exposure to seismic surveying in Conception Bay Newfoundland in 2002. There was a commercial fishery conducted before and after seismic shooting, and movements directly after exposure were monitored by tagging 8 individuals and tracking with hydrophones. Health was determined by sampling crab that were caged and then exposed to air gun shots, as well as experiments in the lab using ovigerous females.

Crab exposed to sound at close range in the lab reacted slightly and those caged in the field did not react to air gun array firing 50 m above them. The tagged crab did not show any large scale movement in the field after exposure. More crab were caught after the seismic
survey than before, and it was concluded that there were other factors influencing the crab in addition to the seismic exposure.

There were no significant changes to the crab health immediately after exposure with analysis of total dissolved substances in serum, serum proteins, serum enzyme level and haemocyte types.

It was found that exposing snow crab eggs to high levels of sound at close range may slow the development of eggs. It was also noted that this level of exposure would not occur during a commercial seismic survey in the field, with a large distance to the sea bottom where snow crab inhabit and eggs are better protected as they are on the underside of the female.

(Overall hypothesis of study: sounds emitted during seismic exploration do not cause a significant decrease in the catch per unit effort of snow crabs. Cannot be rejected.)

Christian et. al. (2004) followed up on the chronic effects on the same crab that were used in the previous study from 2002.

39 crab from the commercial fishery collected after seismic shooting were held for 7 months at DFO to observe for mortality and to replicate the health evaluation.

There were no significant results to prove that there were chronic effects of seismic energy on snow crab.

3 of the 39 crab died (2 from the control group and 1 from the treatment group). These mortalities were attributed to natural causes and in part due to a long holding period.

There was a significantly high serum protein level in crab exposed to the single airgun array but no significant difference for animals exposed to the seven gun array (which was expected to have more of an effect). These groups had a small sample size so results were not included as significant.

Serum enzyme analysis indicated that 3 enzymes were in higher levels in treated crab but not at a significantly different level to the control group. The enzymes of higher levels are associated with liver and pancreatic damage. Any large changes in serum enzymes can indicate tissue damage.

DFO (2004) looked at a seismic survey off the coast of Cape Breton and the potential impacts on of seismic energy on reproductive biology of female snow crab and to expand on the work of Christian et. al. (2003), by adding a comprehensive cage study design.

There were no acute or midterm mortality of crab or a change in feeding rate in the lab during holding. Larvae hatched from exposed gravid females were unaffected, and balance organs of caged crab were completely cleaned of sediment when sampled 5 months after exposure where sediment was stirred up in snow crab habitat.

Some significant findings include hepatopancreas damage in the form of bruising as well as
ovaries in female crab. Ovaries also had dilated oocytes with a detached outer membrane. One test group had a delayed embryo hatch with smaller than control larvae. There was also a different turnover rate between exposed and control crab, showing there was damage to some of the balance organs used to control animal orientation.

There were more conclusive results from this study in comparison to Christian et al. (2003, 2004) but results were speculative not definitive with different test and control sites, different site temperatures, substrate and food availability, depth and bottom type. These speculative results were further examined in Courtenay et al. (2009).

Courtenay et al. (2009) had the hepatopancreas and ovary samples from the Christian et al. (2004) study re-analyzed by a third party. They found that there was no significant damage to the organs in exposed and control crab. They did however find a correlation between organ damage and the length of caging. Crab that were caged longer had significant damage to their organs which could be associated with physical impacts and confinement stress. If any of the previously thought damage was from seismic energy it was undetectable because of this pre treatment damage probably due to length of time in cages. The small size of larvae from eggs exposed to seismic energy that were of smaller size can be attributed to lower incubation temperatures during caging in the field at the seismic site and control site, not as a result of seismic exposure. It was also mentioned that crab caged in the control area were exposed to sound pressure not much less than those in the experimental site, where a true control site should have had 0 exposure.

Bourdreau et al. (2003) quoted anecdotal evidence from a snow crab fisherman operating off of Newfoundland that catches declined in the immediate vicinity of a seismic survey but there was no decline at a distance of 50 nautical miles. A similar occurrence was reported by Thomson et al (2001b) where NAFO division 3NO crab catches dropped off sharply after seismic exploration but there were no reductions in more distant areas.

Payne (2011, Personal communication) added that it is very difficult to do seismic research especially on snow crab and lobster as there are so many factors that cannot be controlled. For example, to evaluate a soft shelled snow crab or lobster (which would be of much interest to the community) it is very hard to catch them with soft shells as they are less mobile and vulnerable to predation in the wild. There are concerns with stress if they are caught while soft shelled and if they are caught there is cannibalism risks while holding. There would also be a very long wait if animals were caught pre moult and then held till moult and then there are other tank effects and stressors that could affect the rate of moult and their subsequent reactions to seismic exposure when the time came to conduct an experiment.

There is also research being planned to do a more chronic exposure on lobster and crab in the lab. Surveys normally pass over the same area numerous times within 2 or 3 weeks and the same animals could be exposed to seismic energy for a prolonged time period. Most of the studies presented here are based on one survey pass or one exposure equivalent to one pass of the survey vessel. Using recordings of sound from a full length survey, animals will be exposed to these sounds for 2 to 3 weeks in the lab to better mimic conditions during a commercial survey and then evaluate the chronic effects seismic sounds on the animals such
as changes in metabolism, food consumption, internal organ condition and serum parameters.

**Summary**
From the information presented in this report, it can be speculated that there are no mortalities or startle response in snow crab that have been exposed to commercial level seismic survey intensities as well as no decrease in CPUE after a survey. Results of the investigation of internal organs of crab that were exposed to seismic activity seems very controversial and we cannot conclude from these studies that damage is solely a result of seismic exposure. It is also apparent from these studies that there are many different opinions on some of the findings and that there needs to be improvements on experimental design and data analysis. Other comments on problems with experimental design and low sample sizes are also reason to question many of the findings here and that there is a need for more research. It would also be of value to have follow up studies to back up the anecdotal evidence reported by fisherman.

**Other Invertebrates**

Payne et al. (2008a) looked at seismic exposure on lobster (*Homarus americanus*) caught in Newfoundland waters in the lab and the field. Low and high air gun levels were conducted in tanks and in the field. Survival, food consumption, serum parameters, turnover rate and leg loss were measured. Lobsters were exposed in cages in the field and then held in the lab for observation up to 8 months post exposure.

There were no delayed mortalities, no problems with their ability to right themselves (no damage to balance organs), or loss of appendages (stress response).

There was a significant increase in feeding which could be correlated with brain trauma, and there were also increased deposits of carbohydrates in the hepatopancrease.

Parry and Gason (2006) looked at the CPUE of rock lobster in seismic surveyed areas off the coast of Australia in Western Victoria. They used historical catch data from 1978 to 2004 to cross reference with seismic surveying. There were no significant results found and it is noted that the surveys were mostly done in deep water >50 m and most fishing occurs in 50-70m of water.

Payne et al. (2007) looked at the effects of seismic activity equivalent to survey strengths on lobster (*Homarus americanus*) in Newfoundland and evaluated a number of common reactions with exposure in the lab and in small scale field trials. There were no mortalities or damage to the balance organs after different holding periods. There was an increase in feeding in exposed animals in 4 out of the 5 trial groups several weeks post exposure, an indicator that there may have been a disturbance of metabolic rate, or could be connected to a brain injury.

Serum enzymes were not elevated indicating there was no cell rupture in the major organs but one exposure trial showed an uptake of excess water, as well as a decreased serum protein and calcium. Suggesting that there may have been an interruption in protein
synthesis, and a disturbance in osmoregulation.

Histological examination of hepatopancreas and ovaries of exposed and control female lobsters showed no structural changes to the cell structures. But there were elevated deposits of carbohydrate in the hepatopancrea suggesting that there had been damage previously and only been detectable 4 months post exposure. This suggests that there may have been a disturbance in the cellular process connected with synthesis and secretion of lipids. It was mentioned that there needed for be further investigation to determine if this reaction was in fact due to stress on the exposed lobsters.

Overall results point to the fact that there are no immediate risks to lobsters exposed to seismic surveying but there are sub-lethal effects that may be delayed of persist to different levels after exposures. The many parameters that were of interest in this study were impossible to evaluate for lobster in field trials so it is suggested that these be repeated and with less parameters of interest at one time.

Payne, J. F. and J. Christian (cited in Moriyasu et al. 2004) studied 3 shellfish species with close range exposure and observed immediate mortality within 48 hours after being exposed 1 m to an airgun. Species included were shrimp (Pandalus borealis), lobster (Homarus americanus) and scallops (Placopecen magellanicus). This intensity of exposure is not reflective of a commercial seismic survey. There was also some stunning of lobster observed by J.F. Payne (Pers. Comm. in Moriyasu et al. 2004).

Pearson et. al. (1994) looked at the effects of seismic exposure on dungeness crab (Cancer magister) larvae. Larvae were raised in the lab and then exposed in the field in specially designed containers and then returned to the lab to monitor mortality and moulting rate post exposure. The larvae were exposed to only one discharge in the near field of the test array of air guns and were at the high end of the possible range typically expected of a commercial survey.

There was no significant mortality upon returning to the lab and there were no delays or problems with moulting. When results were compared to previous studies on fish eggs and larvae this studies results suggests that the zoeal stage of dungeness crab may be more resistant to effects from energy released from air guns than are fish eggs and larvae.

Webb and Kempf (1998) Looked at the effects of seismic pulses on brown shrimp (Crangon crangon) in the Wadden Sea and found no mortality of shrimp and no evidence of reduced catch rate. They attributed the lack of an effect to the absence of gas-filled organs and a rigid exoskeleton.

Keeping in mind that there were no details given about water depth, sampling design, analytical methods, mortality or catch rates, it was also mentioned that in shallower waters they had to use different sound making methods and no mention was made to the type of sound source.

Lagardere and coligues (1980, 1981, 1982) exposed sand shrimp (Crangon crangon) to permanently high noise levels in tanks in the lab. The growth rate and reproduction rates were significantly reduced and there was an increase in aggression in the form of
cannibalism. There was also an increase in mortality and a decrease in feed uptake attributed to a stress response. An increase in metabolism was observed using water chemistry expressed within a few hours of exposure and there was no evidence of any adaptive reduction of metabolic rates over a period of 5 observation days post treatment.

The levels of exposure may have differed from those that are produced by a seismic survey, and animals would not be exposed to such consistent noise in the wild during a survey.

Steffe and Murphy (1992) compared historical data for seismic survey activity and king prawn catch rates from fisherman’s records off the coast of Newcastle Australia. They found no significant difference in catch rates before, during or after the surveying operations. Keeping in mind that there was no statistical analysis completed for the catch comparison.

Dallen (1994) in Moriyasu et al. (2004) monitored catch data from 2 shrimp trawlers fishing in the Barents Sea. One ship had a 60% increase in shrimp catches immediately after a seismic survey while the other had no changes in catch rate. They also looked at the bycatch and there were no changes in Greenland halibut but cod decreased by 80-85% in both vessels.

Brand and Wilson (1996) looked at the CPUE for the Isle of Man Queen scallop fishery. They looked at the CPUE after a seismic survey and found that a decline in scallops after the seismic survey was due to 2 years of poor recruitment of scallops prior to the seismic survey.

**Summary**

For all the above studies it can be concluded that there are some sub-lethal damage risk to some invertebrates when exposed to commercial seismic energy levels and that shrimp CPUE changes directly after a survey with an increase in catches. All other findings for mortality related to exposures were much more extreme than what would ever occur during a real survey. Many of the studies as with snow crab had problems with experimental design and influences from the field that cannot segregate just seismic effects alone.

**Ecosystems**

The following studies consider many species within the same ecosystem, including crustaceans and finfish.

La Bella et al. (1996) looked at the effect of seismic shooting on different fisheries in the Adriatic Sea off the North Eastern coast of Italy. They used different fishing methods before a seismic survey and then 1 day following.

They found no significant difference in catch rates pre and post seismic survey for trawl fishing with the most abundant species being hake, Norway lobster and squid. There was also no significant difference in mantis shrimp catches using gill nets in overnight soaks when the shrimp emerge from their burrows, as well as all other species. Clam density was also evaluated using dredging and there was no change in density or mortality after the seismic vessel passed over the bed, but there was a biochemical stress response with an increase in hydrocortisone, glucose and lactate levels in the muscle and hepatopancrease.
Captive sea bass responded initially to the seismic survey with a startle response and also had a stress response found biochemically and recovered 72 hours later.

La Bella et al. (1998) was a similar study to La Bella et al. (1996) only adding in a study for river system organisms, macroinverts living in fine sand, bivalves, gastropods and crustacean larvae and eggs using dredging and caged studies.

The same results were found for trawl experiments, captive sea bass startle response and biochemical stress response in sea bass and clams.

A second captive study on boney fish, molluscs and crustaceans resulted in no mortality from pressure wave exposure. The animals included were flounder, cuttle-fish, sardine, pilgrim’s scallop, variegated scallop, crab (*M. Crispata*) and Mediterranean mussel. However there was some internal bleeding in 2 sardine individuals and some scallops were stunned for 30 minutes.

The pelagic (predominantly sardines) biomass was evaluated before and after the survey using echosurveys and there was a decrease in the aggregation and catchability of the biomass from 24 tons/n. sq. mile to 13 tons/n. sq. mile.

The eggs and larvae of 7 species of fish, molluscs and crustaceans had no damage done to bone structure or function except for dory and squid which were affected at both stages when exposed at close distance to the airgun.

The river system fish caged experiments used goldfish, carp, catfish, sheat fish and eels, and it was found that there were no mortality or severe lesions to animals. Also the vibrations in the river banks caused by the airguns was greatly below what was expected and are not of risk to animals in that habitat.

Andriguettio-Fihlo et al. (2005) looked at the difference in catches of different shrimp species before and after a seismic survey in the shallow waters off the coast of Brazil. Species included Southern white shrimp, Southern brown shrimp and the Atlantic seabob, and were fished using a bottom trawl. They found that there was no affect on catch rates of artisanal shrimp fisheries and no internal damage to shrimp exposed to seismic surveys.

Kosheleva (1992) looked at seismic effects on a group of invertebrates at close range organisms included blue mussels, periwinkles and amphipods. The mussels and amphipods showed no discernible effects (the Periwinkle test was unsuccessful). It was mentioned in Moriyasu et al. (2004) that other authors who cited this study determined the Latin names of organisms in this study and the source sound levels were not included in this author’s abstract. This uncertainty in the details of this study should question the validity of the findings.

Wardle et al. (2001) found no evidence of reef fish or invertebrates moving away from a reef over which an array of 3 airguns was discharged at four locations over four days at a rate of 1 shot/min for up to 81 min/day. However, underwater video observations of fish behaviour up to 109 m from the airgun indicated that fish always.
Summary

Many of the mentioned above studies have similar with some catch rates declining and others not all and some organisms having behavioural changes and physiological damage after exposure to seismic air gun pulses. The addition of a river bank system is a different ecosystem that is normally included in seismic studies as it is not a traditional area for oil and gas exploration. The same issue of validity of findings is present here as well with experimental design issues and the presentation of study details.

Moriyasu et al. (2004) arranged and critiqued all available research documents in this topic of invertebrate sensitivities to seismic surveying up to 2003. All the available information on a number of organisms both of commercial value and not were analyzed and recommendations were made that we also agree with. Many of the studies didn’t include details of methods and experimental design and others made conclusions without conducting statistical analysis (in a study where there was enough data to do so).

Moriyasu et al. (2004) restated that there is not enough research done in this area and there are many factors that can discount findings. They state that there is no clear rule for defining sound levels that will inflict behavioural change, which leaves interpretation of the reports subjective. They also make recommendations to what types of research is needed to obtain more concrete results:

- Immediate and delayed behavioural and lethal effects (like seasonal movement patterns which would apply to snow crab for example) -immediate and delayed pathological effects (like hearing, sighting, growth and mating capacity)
- Cumulative effects of multiple disturbance displaced in time and space like exposure of long duration and repeated exposures over time
- Timing of seismic surveys versus timing of sensitive period of the life cycle event like moulting and when females are ovigerous in snow crab for example
- Indirect impacts of the animals exposed on seismic noise such as increased vulnerability to disease and predation.

Conclusions

Oil and gas exploration offshore Newfoundland and Labrador is on the rise, which may equate to an increase in seismic survey activity. Although there is overlap between the snow crab fishing areas off of Labrador and seismic exploration activity, at this point in time data is insufficient to draw any scientifically sound conclusions. We can conclude that there are many other avenues that need to be researched on this issue for snow crab. And that any experimental designs need to be adjusted for accuracy in comparison to the experimental designs used in the discussed studies. Similar concerns have been raised for other studies on crustaceans and the effects of seismic. It is evident and as stated by Moriyasu et al. (2004) that there is a great need for more research in order to obtain concrete evidence on the effects of seismic surveying on snow crab and other invertebrates.

In order to further investigate the effects of seismic on the snow crab resource, several things should occur. Firstly, the best possible picture of the status of the snow crab resource is
required for the most reliable estimate. Accurate logbook data is of particular importance and is lacking in 2J north and 2H with low return rates. Establishing a dedicated crab pot survey in fishing areas creates a time series of data necessary to determine the long-term effects of seismic exposure, if any, on the snow crab resource. A more transparent and user-friendly process for acquiring exploration data from the Canada-Newfoundland Offshore Petroleum Board, including shorter disclosure periods for seismic activity would allow for more up to date data input into necessary research.
References


Engas, A., S. Løkkeborg, E. Ona, and A. Soldal. 1996. Effects of seismic shooting on local abundance and catch rates of cod (Gadus Morhua) and Haddock (Melanogrammus Aeglefinus). Canadian Journal of Fisheries and Aquatic Science 53: 2238-2249.


Figure 8: Released seismic data Offshore Labrador Area with Nafo divisions 2J, 2H