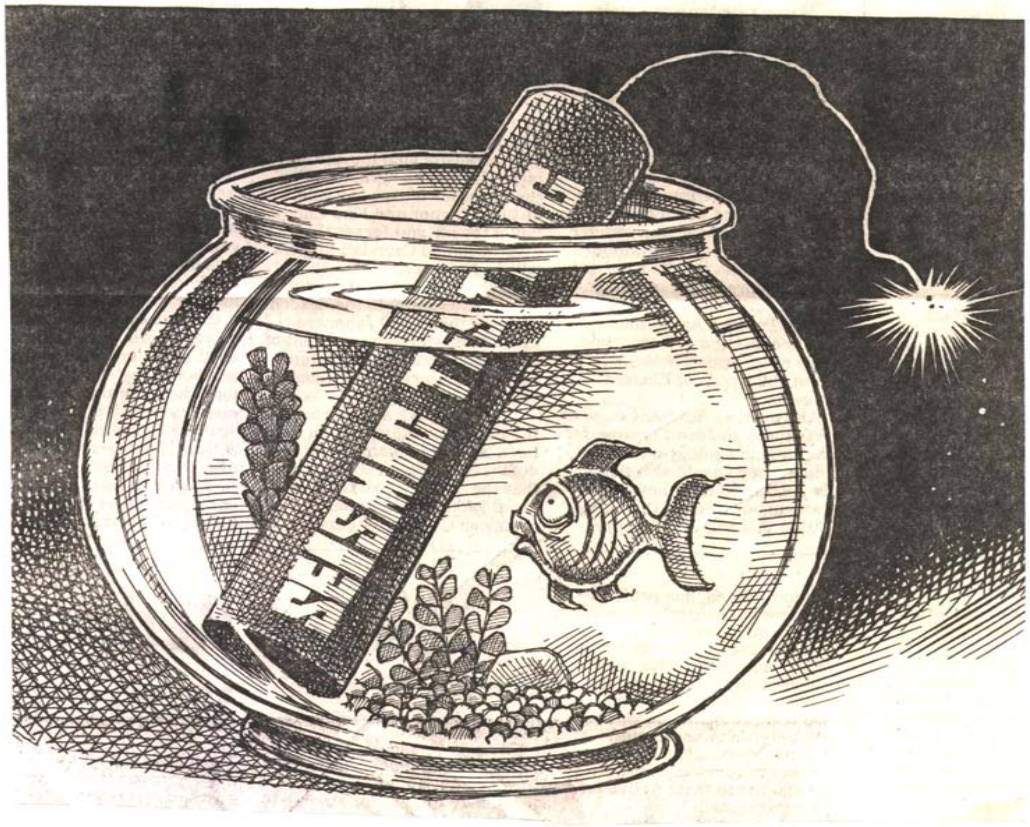
SEISMIC EXPLORATION

POTENTIAL IMPACTS ON FINFISH AND INVERTEBRATE SPECIES

LGL LIMITED
environmental research associates


CHEF

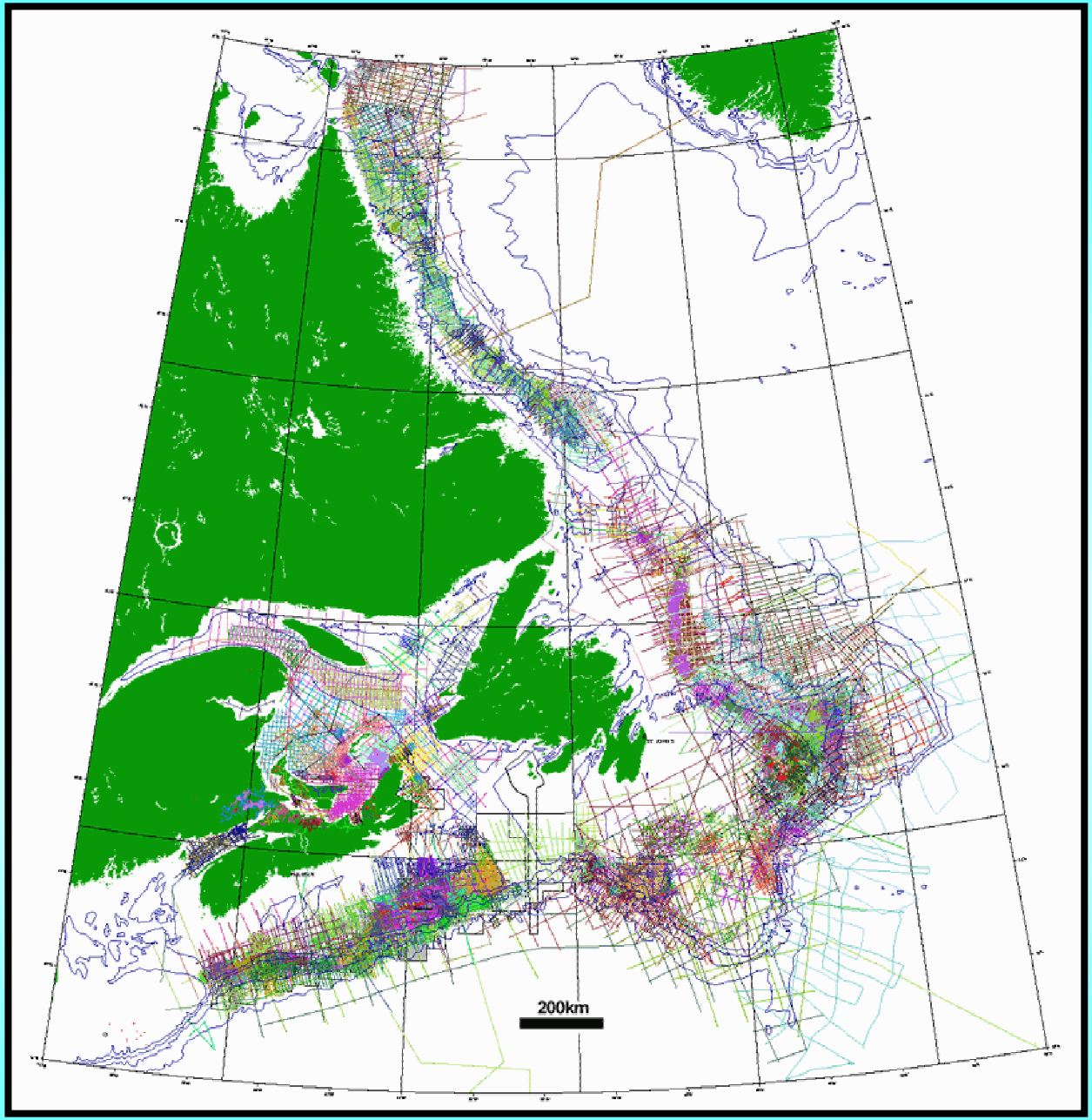
The amount of marine seismic shot in British Columbia waters during the last 40 years has been minimal compared to that in Eastern Canadian waters.

Between 1964 and 2002, more than 1,350,000 km of seismic was acquired in the Newfoundland and Labrador offshore.

~ 735,000 km 2-D seismic

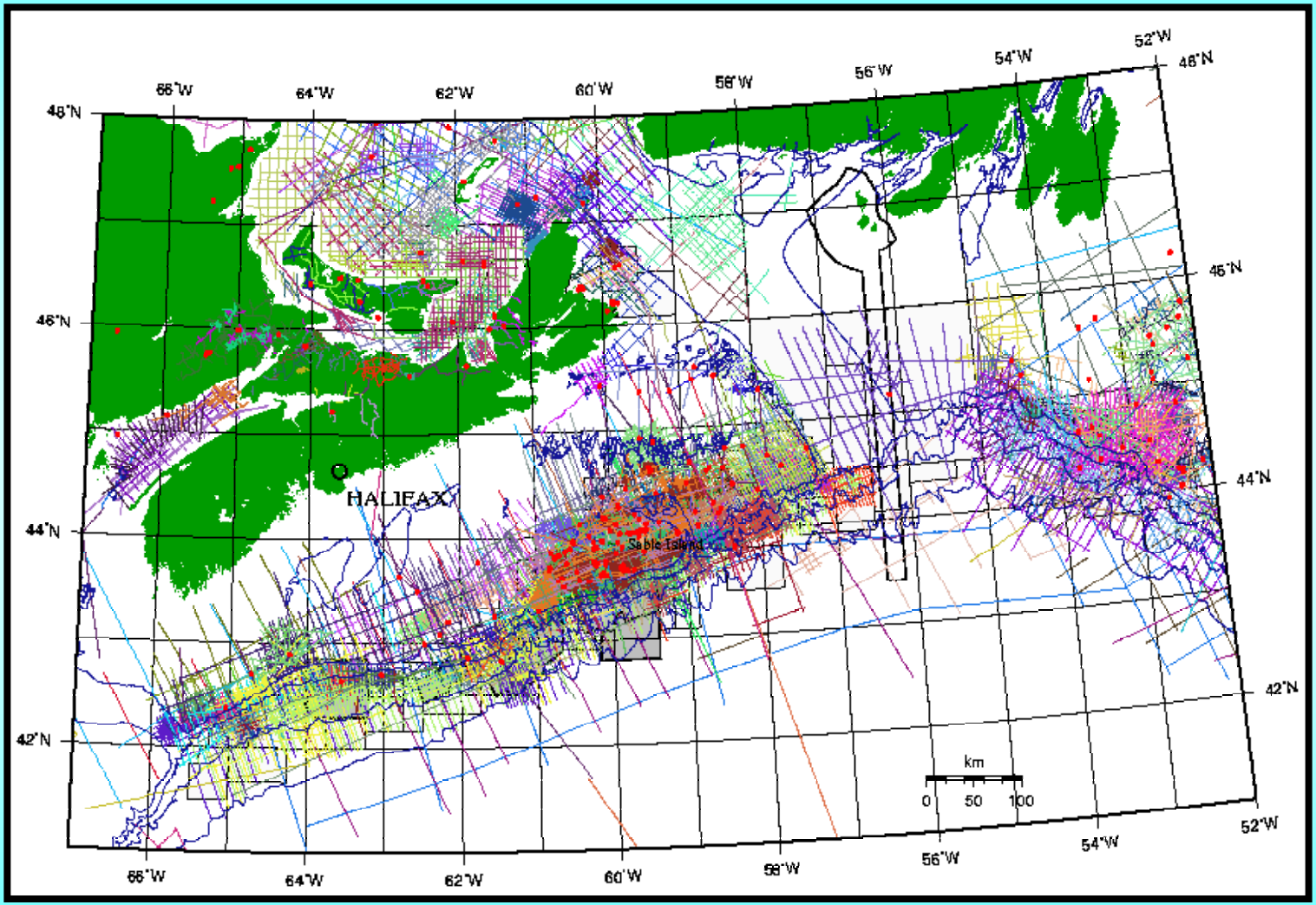
~ 615,000 km 3-D seismic
(90% between 1995 and 2002)

Eastern Canadian Seismic Transects



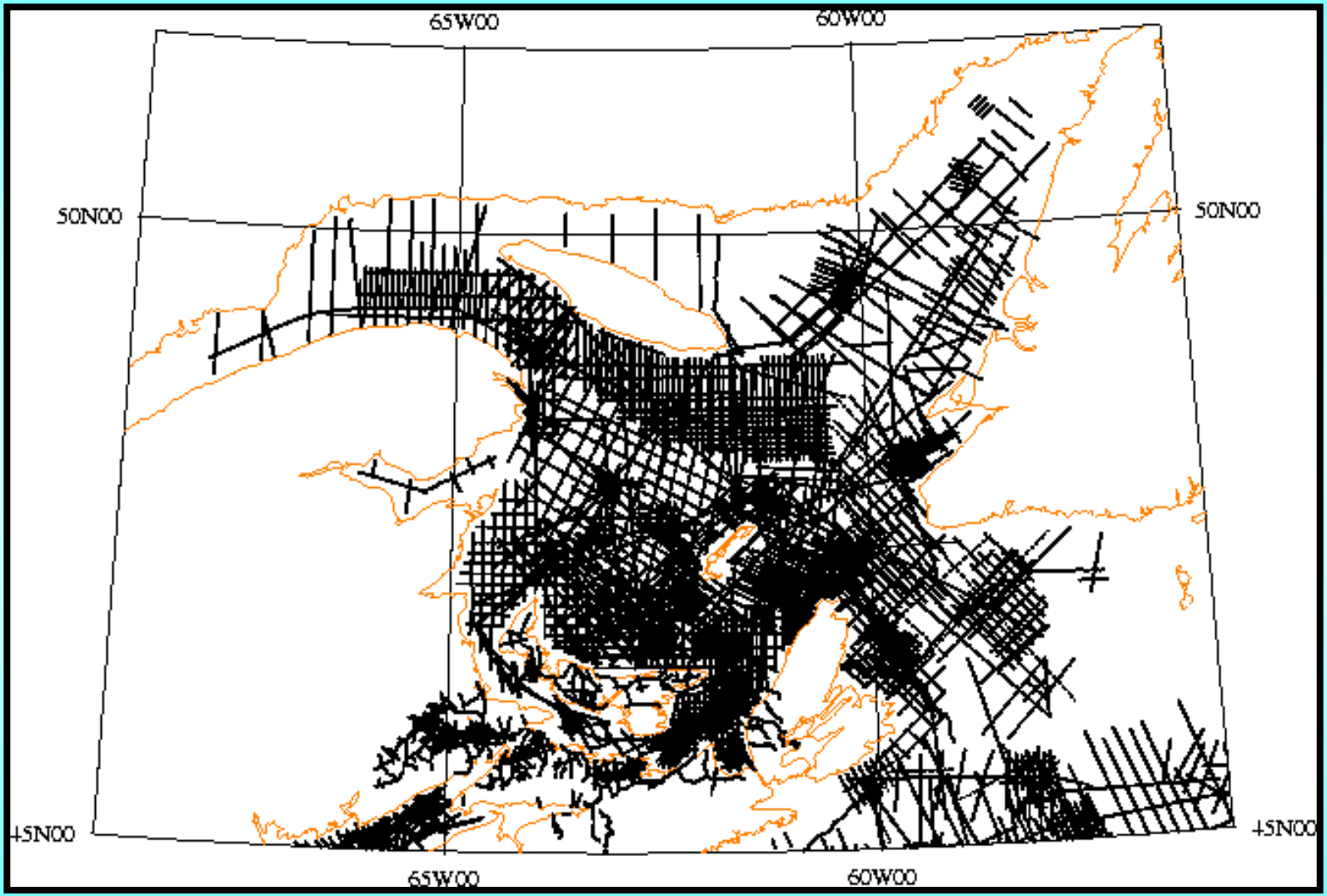
Source: Natural Resources Canada BASIN Database

Scotian Shelf Seismic Transects



Source: Natural Resources Canada BASIN Database

Gulf of St. Lawrence Seismic Transects

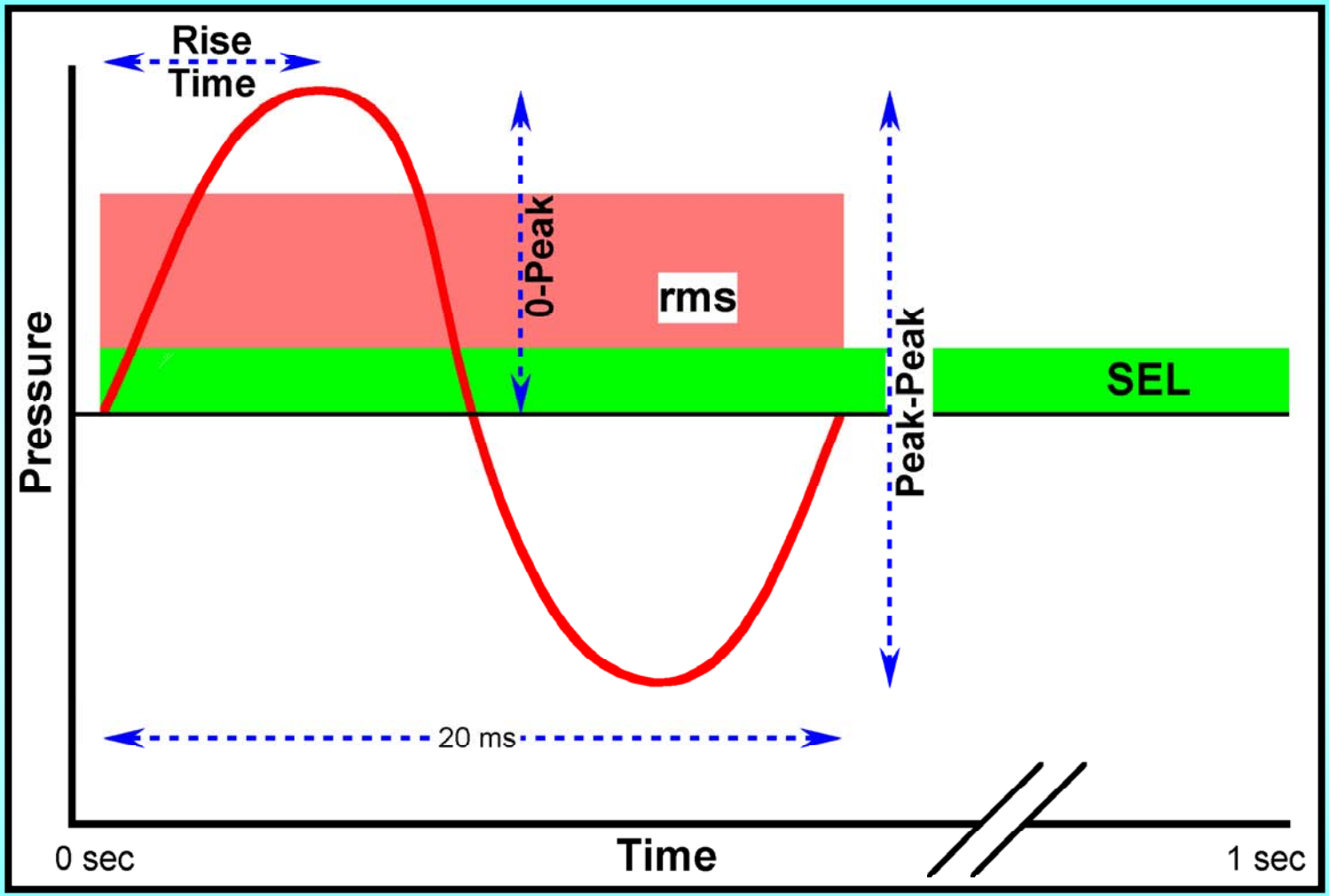


Source: Natural Resources Canada BASIN Database

Explosives vs Airguns

Underwater explosions are characterized by higher peak pressure levels and by shorter ‘rise’ and ‘decay’ times than underwater airgun signals. Airgun seismic has less potential impact than the older method of using explosives.

Expressions of Sound Pressure Level



(1) 0-Peak
(2) Peak-Peak
(3) rms
(4) SEL

DETERMINATION OF APPARENT LOUDNESS OF A NOISE

(1) Source level

(2) Propagation efficiency

(3) Ambient noise

(4) Hearing sensitivity of animal

Ambient Noise

The intensity of naturally-occurring ambient or background underwater noise varies depending on the environmental conditions. The calmer the conditions, the less intense the noise.

Typically, naturally-occurring ambient noise intensity ranges between approximately 50 to 100 dB.

Receiver Hearing Sensitivity

Fish such as cod, salmon, herring and plaice have peak hearing sensitivity at frequencies between 80 and 200 Hz, and a sensitivity threshold at 80 to 100 dB. Fish have air-filled spaces in their ears, and some in their swim bladders.

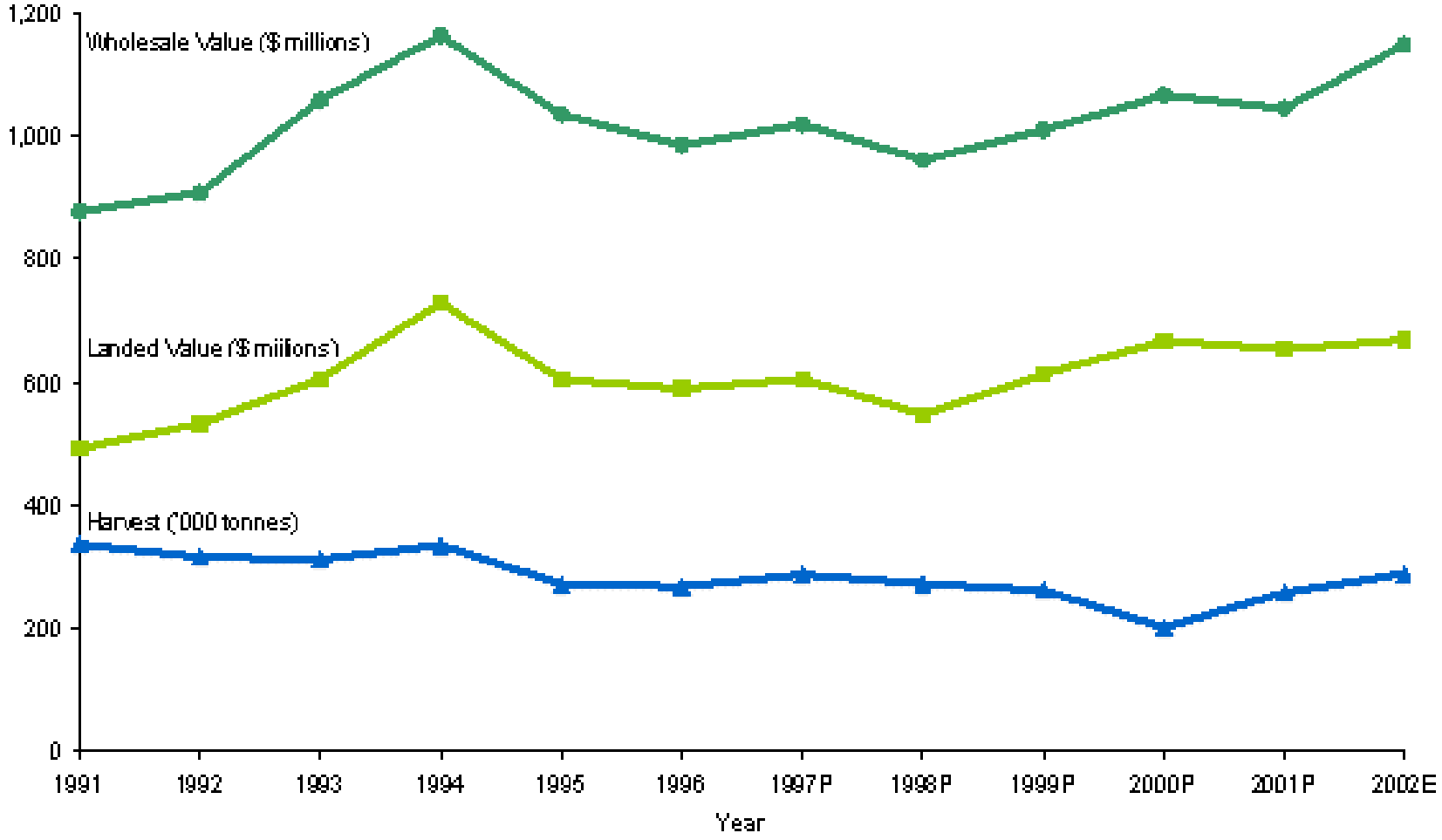
Generally, invertebrates do not 'hear' in the sense that fish do. They do sense water borne and/or substrate borne vibrations. They do not have air-filled spaces but instead detect vibration and water particle movement with external and internal sensory structures (e.g., hairs, statocyst)

Overview of British Columbia

Commercial Fishery and Aquaculture

Industries During Recent Years

BC Seafood Production, 1991-2002



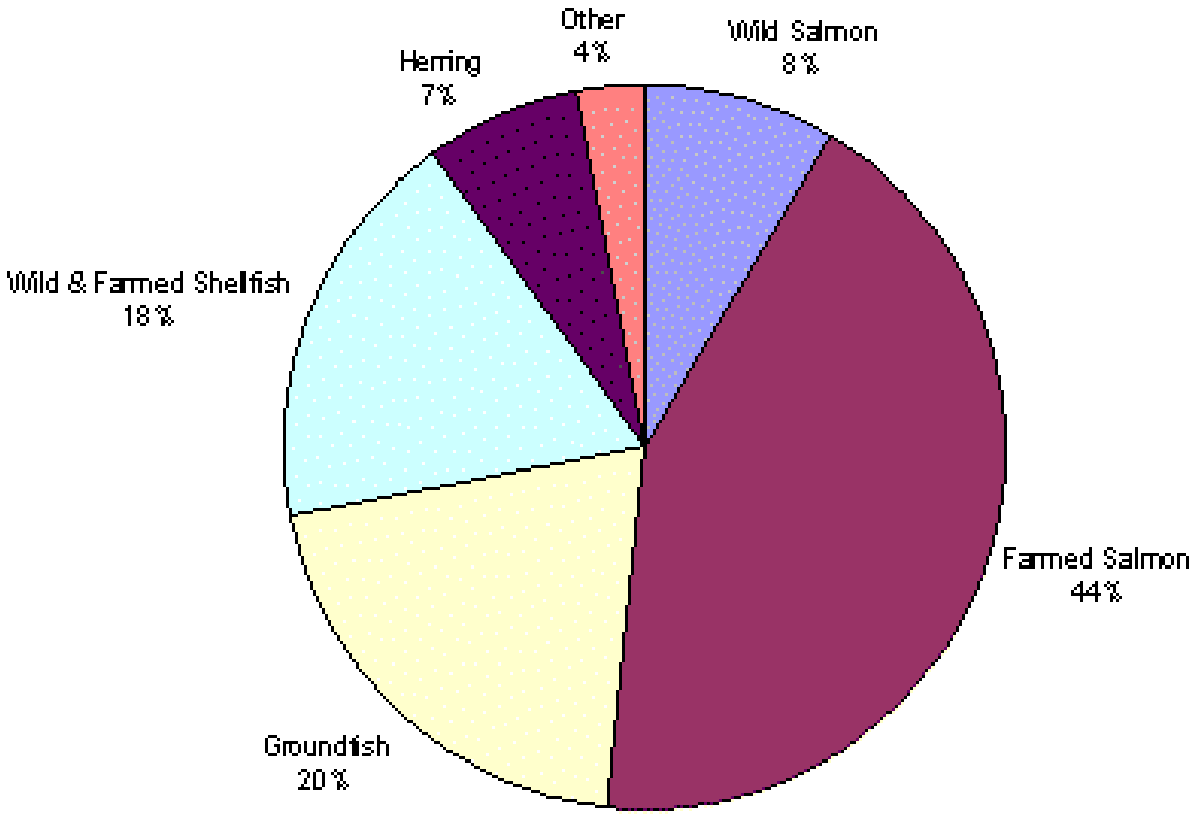
Source: BC Ministry of Agriculture, Food and Fisheries

Percentages of BC Total Landed Values, 2000-2002, Accounted for by Various Species Groups

	2000	2001	2002
Total Landed Value ($ million)	666.5	653.3	668.3
Farmed Salmon	42.3%	41.5%	43.2%
Groundfish	20.5%	19.0%	20.1%
Wild Shellfish	17.7%	20.7%	16.0%
Wild Salmon	7.6%	5.1%	8.5%
Herring	7.5%	6.8%	7.0%
Tuna	2.4%	4.0%	2.8%
Farmed Shellfish	1.8%	2.6%	2.2%
Other (including farmed trout)	0.2%	0.3%	0.2%

Source: The 2002 BC Seafood Industry Year in Review

2002 BC Total Landed Value ($668 million) by Species Group



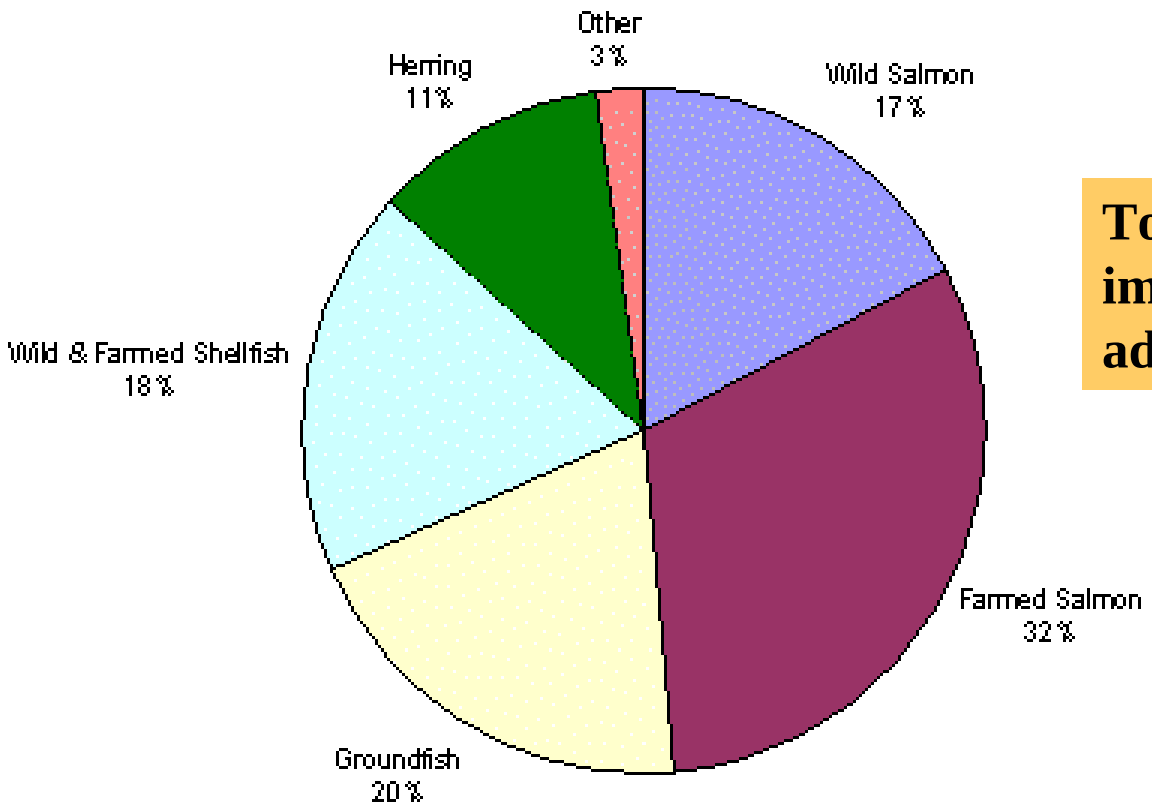
Source: BC Ministry of Agriculture, Food and Fisheries

Percentages of BC Total Wholesale Values, 2000-2002, Accounted for by Various Species Groups

	2000	2001	2002
Total Wholesale Value ($ million)	1,065.5	1,044.1	1,147.9
Farmed Salmon	30.6%	30.9%	31.3%
Groundfish	18.3%	19.1%	19.7%
Wild Salmon	18.8%	15.4%	17.3%
Wild Shellfish	15.9%	18.1%	15.7%
Herring	12.1%	10.8%	11.1%
Farmed Shellfish	2.1%	2.4%	2.5%
Tuna	2.0%	3.0%	2.0%
Other (including farmed trout)	0.2%	0.3%	0.4%

Source: The 2002 BC Seafood Industry Year in Review

2002 BC Total Wholesale Value ($1.147 billion) by Species Group



Total includes fish imported for value added processing

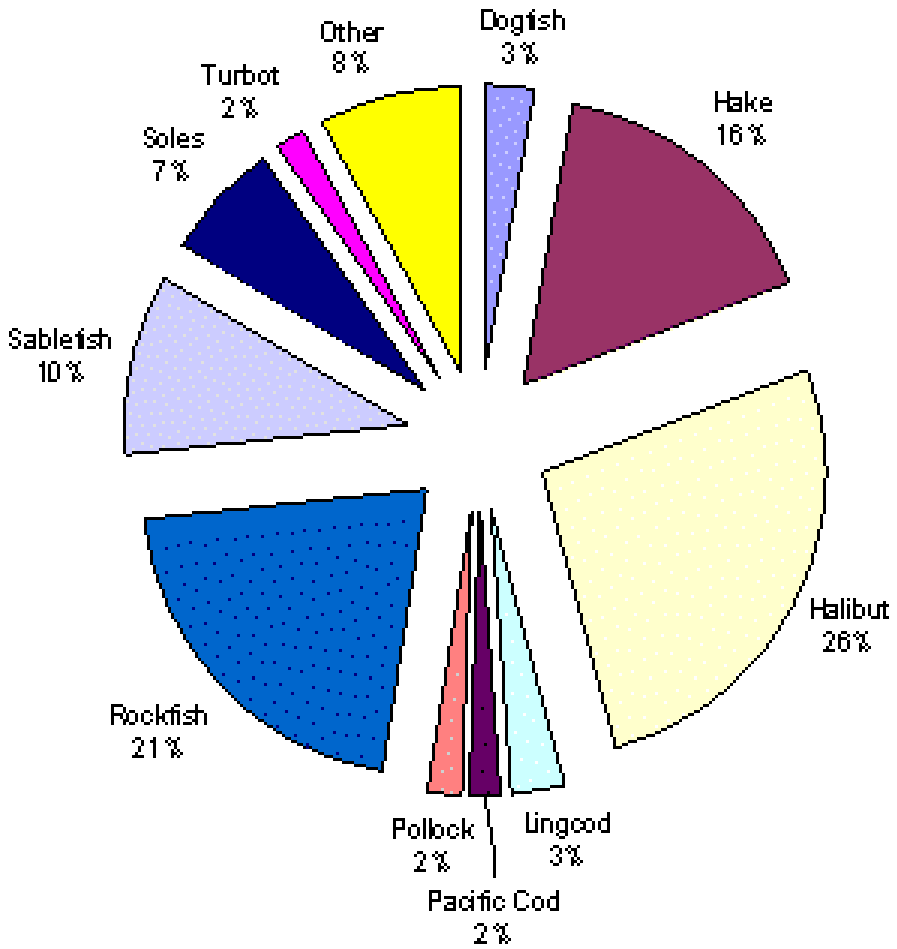
Source: BC Ministry of Agriculture, Food and Fisheries

20 MOST VALUABLE BRITISH COLUMBIA COMMERCIAL FISHERY AND AQUACULTURE SPECIES/SPECIES GROUPS, 2000-2002

SPECIES	VERTICAL DISTRIBUTION	WILD/FARMED	LANDED VALUE ($ millions)	WHOLESALE VALUE ($ millions)
Atlantic salmon	Pelagic	Farmed	690	827
Pacific herring	Pelagic	Wild	141	370
Sockeye salmon	Pelagic	Wild	100	291
Pacific halibut	Demersal	Wild	128	172
Chinook salmon	Pelagic	Farmed and wild	135	168
Geoduck	Benthic	Wild	124	161
Rockfish	Demersal	Wild	99	140
Dungeness crab	Benthic	Wild	85	137
Chum salmon	Pelagic	Wild	15	103
Pink salmon	Pelagic	Wild	12	112
Prawns	Pelagic/demersal	Wild	85	111
Sablefish	Pelagic/demersal	Wild	73	86
Pacific hake	Pelagic/demersal	Wild	36	76
Tuna	Pelagic	Wild	60	76
Clams	Benthic	Farmed and wild	38	58
Red sea urchins	Benthic	Wild	25	57
Oysters	Benthic	Farmed	21	42
Soles	Demersal	Wild	21	38
Shrimp	Pelagic/demersal	Wild	13	23
Coho salmon	Pelagic	Wild	1	22

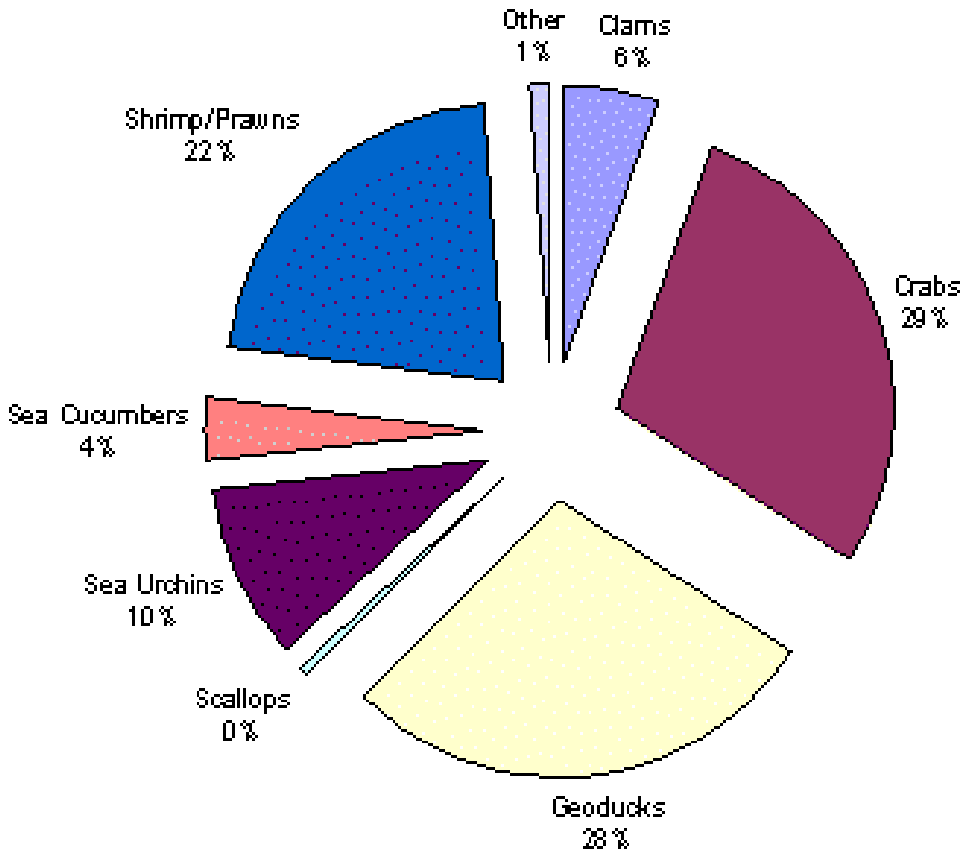
Source: The 2002 BC Seafood Industry in Review

2002 BC Groundfish Wholesale Value ($226.5 million) by Species Group



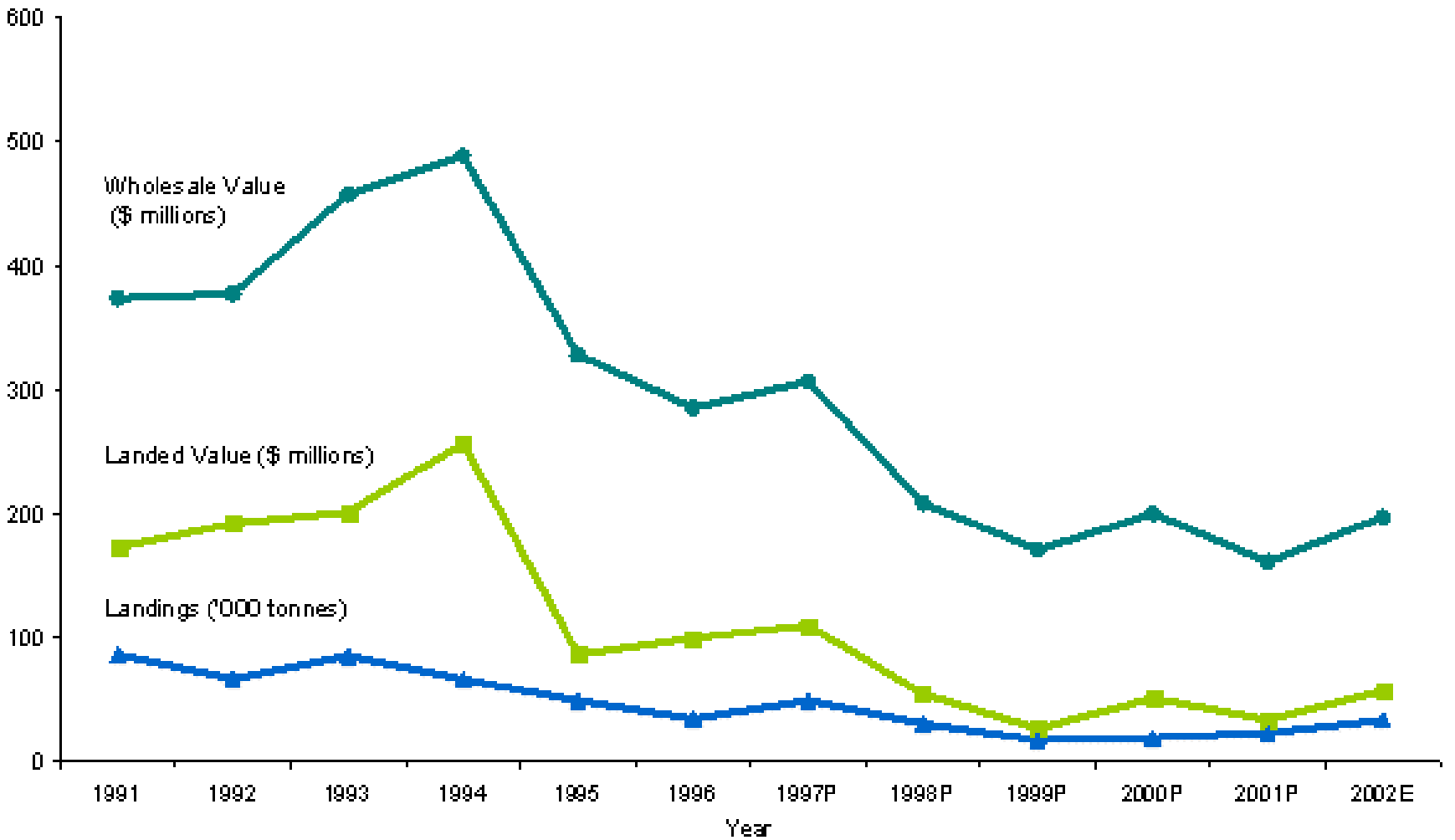
Source: BC Ministry of Agriculture, Food and Fisheries

2002 BC Wild Shellfish Wholesale Value ($180.5 million) by Species Group



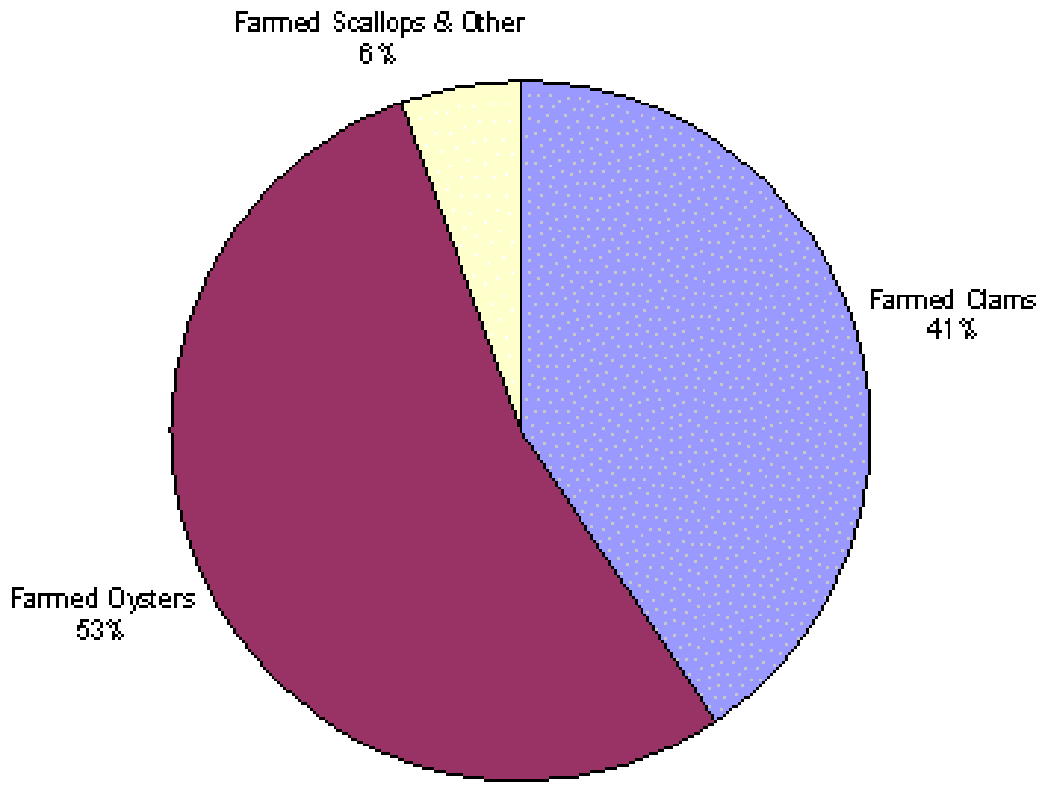
Source: BC Ministry of Agriculture, Food and Fisheries

BC Wild Salmon Production, 1991-2002



Source: BC Ministry of Agriculture, Food and Fisheries

2002 BC Farmed Shellfish Wholesale Value ($29 million) by Species Group



Source: BC Ministry of Agriculture, Food and Fisheries

Percentages of BC Wild and Farmed Landed Values Accounted for by Finfish and Invertebrates, 2000-2002

	2000		2001		2002	
	Fish	Invertebrate	Fish	Invertebrate	Fish	Invertebrate
Wild	68.2%	31.8%	62.8%	37.2%	70.6%	29.4%
Farmed	95.9%	4.1%	94.0%	6.0%	95.1%	4.9%

Source: BC Ministry of Agriculture, Food and Fisheries

Comparison of BC and Atlantic Canadian Commercial Fisheries, 2002

British Columbia

TLV: $342 million

Groundfish: $125M (37%)
halibut, rockfish, hake

Shellfish: $103M (30%)
clams/quahaugs, crabs, shrimp

Pelagics: $102M (30%)
salmon, herring, tuna

Atlantic Canada

TLV: $1.8 billion

Groundfish: $163M (9%)
cod, haddock, flatfish, hake, turbot, halibut

Shellfish: $1.5B (85%)
lobster, snow crab, shrimp, scallops

Pelagics: $83M (5%)
herring, mackerel, tuna

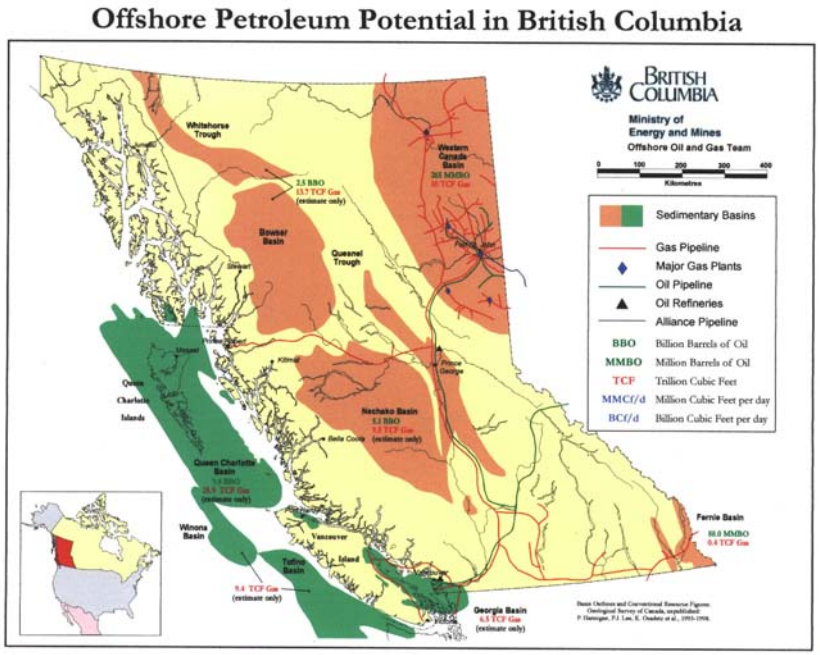
Source: DFO Website

Comparison of BC and Atlantic Canadian Aquaculture, 2002

British Columbia	Atlantic Canada
TLV: $322 million	TLV: $272 million
Finfish: $308M (96%) Atlantic salmon	Finfish: $231M (85%) Atlantic salmon, trout, steelhead
Shellfish: $14M (4%) clams, oysters	Shellfish: $41M (15%) mussels

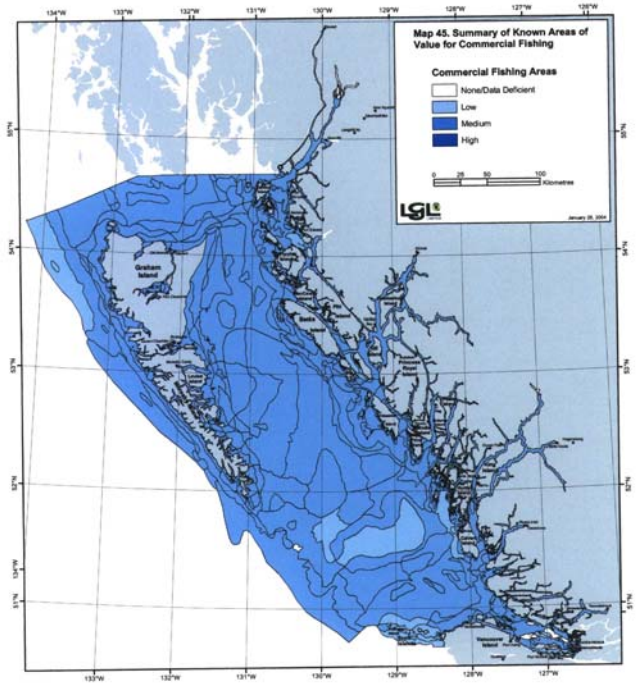
Source: DFO Website

OFFSHORE PETROLEUM POTENTIAL IN BRITISH COLUMBIA



BC OFFSHORE OIL AND GAS TEAM

SUMMARY OF KNOWN AREAS OF VALUE FOR COMMERCIAL FISHING



LGL SIDNEY

POTENTIAL EFFECTS OF SEISMIC ENERGY ON FINFISH AND INVERTEBRATE SPECIES

Pathological: acute mortality, sub-lethal physical damage (e.g., inner ear damage in fish, swim bladder rupture, hemmorrhaging, eye damage)

Physiological: stress-induced biochemical responses

Behavioural: avoidance, startle response, downward movement, masking of natural sounds

PATHOLOGICAL: FISH

McCauley et al. (2003)

- Caged pink snapper
- Mobile single 20-in^3 airgun; 217 dB @ 1 m $_{0\text{-}P}$
- ~ 600 shots; 1 shot every 10 seconds
- Source-fish distance: 5 to 800-m
- Received levels: 158 to 204 dB $_{0\text{-}P}$
- Examined ear sensory epithelia for damage

RESULTS: * 18 HOUR FISH = CONTROLS (UNEXPOSED)
*** 58 DAY FISH > CONTROLS AND 18 HOUR FISH**

PATHOLOGICAL: FISH

Kostyuchenko (1973)

- Late development eggs of 16 various fish species
- Stationary single 300-in^3 airgun; 233 dB @ 1-$m_{0\text{-}P}$
- Number of shots: Not stated
- Source-eggs distance: 0.5 to 10-m
- Received levels: ~ 215 to 233+ $dB_{0\text{-}P}$
- Monitored for mortality and damage

RESULTS: * WITHIN 0.5-M: DIFFERENCES BETWEEN SPECIES
(E.G., ANCHOVY EGGS DAMAGED SIGNIFICANTLY
AND MULLET EGGS WERE NOT DAMAGED AT ALL
* MINIMAL DAMAGE AT 5-M AND 10-M
* 75% SURVIVAL AT 0.5-M, >90% SURVIVAL AT 10-M

PATHOLOGICAL: FISH

Saetre and Ona (1996)

- **Worst-case scenario of effects on fish eggs and larvae**
- **Assumed lethal radius for each airgun of 2-m**
- **Assumed distance between seismic lines of 100-m**
- **Applied mathematical modeling**

RESULTS: * PREDICTED THAT 0.3% OF LARVAL POPULATION MAY DIE DUE TO 3-D SEISMIC

*** EXPECTED DAILY MORTALITIES CAUSED BY SEISMIC SO LOW COMPARED TO NATURAL MORTALITY RATES THAT IMPACT OF SEISMIC SURVEY ON RECRUITMENT OF A FISH STOCK REGARDED AS INSIGNIFICANT**

PATHOLOGICAL: INVERTEBRATES

Christian et al. (2003)

- Caged male snow crabs
- Stationary single 40-in^3 airgun; ~ 227 dB @ 1-$m_{0\text{-}P}$
- Stationary 200-in^3 7-airgun array; ~ 233 dB @ 1-$m_{0\text{-}P}$
- Each treatment 200 shots; 1 shot every 10 seconds
- Source-crab distance (single gun): 2 to 15-m
- Source-crab distance (array): 4 to 85-m
- Received levels: 203-221 dB (single); 197-225 dB (array)
- Examined statocyst, hepatopancreas, heart for damage

RESULTS: * NO DIFFERENCES BETWEEN EXPOSED AND CONTROL CRABS IN TERMS OF PHYSICAL DAMAGE.
*** NO ACUTE OR CHRONIC MORTALITY**

PATHOLOGICAL: INVERTEBRATES

Pearson et al. (1994)

- Larvae of Dungeness crab
- 840-in^3 7-airgun array; ~244 dB @ 1-m$_{0\text{-}P}$
- Single discharges
- Source-larvae distance: 1 to 10-m
- Received levels: 222 to 234 dB$_{0\text{-}P}$
- Monitored survival and development

RESULTS: * FOR IMMEDIATE AND LONG-TERM SURVIVAL AND TIME TO MOLT, NO SIGNIFICANT EFFECTS ON LARVAE AS CLOSE AS 1-M TO THE SEISMIC SOURCE.

PATHOLOGICAL: INVERTEBRATES

Christian et al. (2003)

- Fertilized snow crab eggs (Year 2)
- Stationary single 40-in^3 airgun; ~227 dB @ 1-m$_{0\text{-}P}$
- 200 shots; 1 shot every 10 seconds
- Source-egg distance: 2-m
- Received level: ~221 dB$_{0\text{-}P}$
- Monitored development rate

RESULTS: * AT 12 WEEKS AFTER EXPOSURE, ~71% OF THE CONTROL EMBRYOS WERE AT BIG-EYED DEVELOPMENT STAGE COMPARED TO ~45% OF THE EXPOSED EMBRYOS

*** I.E., UNEXPOSED EMBRYOS DEVELOPED FASTER THAN THE EXPOSED EMBRYOS**

PHYSIOLOGICAL: FISH

Sverdrup et al. (1994)

- Farmed Atlantic salmon in tanks
- Explosive charges; ~246 dB @ 1.3-$m_{0\text{-}P}$
- 10 explosions; 1 explosion every 7 minutes
- Maximum source-fish distance: 1.5-m
- Received levels: ~ 246 $dB_{0\text{-}P}$
- Examined stress parameters

RESULTS: * ALTHOUGH NON-LETHAL, THESE UNDERWATER EXPLOSIONS APPEARED TO AFFECT SEVERAL CRITICAL PHYSIOLOGICAL PARAMETERS IN THE ATLANTIC SALMON.

PHYSIOLOGICAL: FISH

Santulli et al. (1999)

- Caged European sea bass
- Mobile 2,500-in^3 16-airgun array; 250 db+ @ 1-$m_{0\text{-}P}$
- 700+ shots; 1 shot every 10 seconds
- Source-fish distance: 180 to 6,500-m
- Received levels: ~180 to 210 $dB_{0\text{-}P}$
- Monitored biochemical responses

RESULTS: * CONFIRMED STRESS RESPONSES TO AIRGUN SHOOTING
*** BIOCHEMICAL PARAMETERS RETURNED TO NORMAL AFTER 72 HOURS**

PHYSIOLOGICAL: INVERTEBRATES

Christian et al. (2003)

- Caged male snow crabs
- Stationary single 40-in^3 airgun; ~ 227 dB @ 1-m$_{0\text{-}P}$
- Stationary 200-in^3 7-airgun array; ~ 233 dB @ 1-m$_{0\text{-}P}$
- Each treatment 200 shots; 1 shot every 10 seconds
- Source-crab distance (single gun): 2 to 15-m
- Source-crab distance (array): 4 to 85-m
- Received levels: 203-221 dB (single); 197-225 dB (array)
- Acute and chronic levels of haemolymph parameters

RESULTS: * NO SIGNIFICANT DIFFERENCES BETWEEN EXPOSED AND UNEXPOSED CRABS IN TERMS OF STRESS INDICATORS (E.G., PROTEINS, ENZYMES)

BEHAVIORAL: FISH

Engås et al. (1996)

- Cod and haddock
- Mobile 5,000-in^3 18-airgun array; ~249 dB @ 1-$m_{0\text{-}P}$
- 25,000+ shots; 1 every 10 seconds
- Survey area ~ 2.5 nm x 10 nm
- Study area 40 nm x 40 nm; water depth 250-280-m
- Acoustic mapping, trawling, longlining
- 7 days before, 5 days during, 5 days after seismic

RESULTS: * TRAWL CATCHES OF COD AND HADDOCK DECLINED, ON AVERAGE, ~ 50%
* LONGLINE CATCHES OF HADDOCK DECLINED 21%
* CATCH DECLINE LESSENED FURTHER FROM SHOOTING AREA
* ABUNDANCE AND CATCH RATES NOT BACK TO PRESHOOTING LEVELS 5 DAYS AFTER CESSATION

BEHAVIORAL: FISH

Løkkeborg (1991)

- Cod
- Mobile 160-in^3 4-airgun array; ~ 227 dB+ @ 1-$m_{0\text{-}P}$
- 11,000+ shots; 1 every 5 seconds
- Survey area ~ 2 nm x 2 nm
- Study area 20 nm x 20 nm; water depth ~185-m
- Longlining before, during and after shooting

RESULTS:
* CATCH RATE REDUCTIONS OF 55-80% WITHIN SEISMIC SURVEY AREA
* CATCH RATES REDUCTION CONTINUED FOR 24 HOURS AFTER SHOOTING CESSATION
* CATCH REDUCTIONS MOST PRONOUNCED WITHIN 5-NM OF THE SEISMIC SURVEY AREA

BEHAVIORAL: FISH

Skalski et al. (1992)

- **Rockfish (*Sebastes* spp.)**
- **Mobile single 100-in^3 airgun; 223 dB @ 1-m$_{0\text{-}P}$**
- **Shot fired every 5-m directly over aggregation**
- **Received levels: 180 to 190 dB$_{0\text{-}P}$**
- **Hook and line fishing**
- **Examined change in catch rates**

RESULTS: * AVERAGE DECLINE IN CATCH RATE OF ~52%
*** AGGREGATION HEIGHT DECREASED IN RESPONSE TO SHOOTING**

BEHAVIORAL: FISH

Schwarz and Greer (1984)

- Net-penned Pacific herring
- Exposed to sound from variety of sources
- Sources: fishing vessels, sonar, sounder
- Projected received levels: 105-112 dB
- Described behavioral responses of herring

RESULTS: * AVOIDANCE, ALARM AND STARTLE RESPONSES TO PARTICULAR SOUNDS, PARTICULARLY THOSE OF LOWER FREEQUENCY

BEHAVIORAL: INVERTEBRATES

McCauley et al. (2000)

- Caged squid
- Fixed single 20-in^3 airgun; ~217 dB @ 1-m$_{0\text{-}P}$
- ~ 600 shots; 1 shot every 10 seconds
- Received levels ~188 dB$_{0\text{-}P}$

RESULTS: * STRONG STARTLE/AVOIDANCE RESPONSE OF INK DISCHARGE AND MOVEMENT AWAY FROM SOURCE
* SQUID TENDED TO STAY NEAR SURFACE, PROBABLY DUE TO SOUND SHADOW (REDUCED LEVELS) NEAR SURFACE
* APPARENT EXPOSURE THRESHOLD TO ELICIT SQUID RESPONSE ~ 175-180 dB$_{0\text{-}P}$

BEHAVIORAL: INVERTEBRATES

Christian et al. (2003)

- Commercial-sized male snow crabs
- Stationary 200-in^3 7-airgun array; ~ 233 dB @ 1-$m_{0\text{-}P}$
- Each treatment 200 shots; 1 shot every 10 second
- Source-crab distance (array): 50 to 1,000-m
- Received levels:173-203 $dB_{0\text{-}P}$

RESULTS: * CAGED ANIMALS 50-M FROM SOURCE DID NOT EXHIBIT ANY OBVIOUS STARTLE RESPONSES
* CPUE AFTER SEISMIC SHOOTING DID NOT DECREASE AFTER SEISMIC EXPOSURE
* ACOUSTICALLY TAGGED CRABS DID NOT LEAVE THE AREA IN RESPONSE TO SEISMIC EXPOSURE

OTHER WORK OF NOTE

•**Preliminary studies at DFO, St. John's, involving exposure of various marine biota (cod, cod larvae, cunner, lobster, snow crab, blue mussels, sea cucumbers) to seismic energy from a single 10-in^3 airgun. Source levels ~ 216 dB @ 1-m$_{0\text{-}P}$**

PRELIMINARY RESULTS: CUNNER DISPLAYED ORIENTATION DIFFICULTIES AND HEMORRHAGING IN REGION OF THE SWIM BLADDER. SOME HEMORRHAGING IN COD LIVER. NO LARVAL MORTALITY. PLANS TO EXAMINE COD EARS FOR SIGNS OF DAMAGE.

•**Exposure of egg-carrying snow crabs to seismic energy during an industry survey conducted in the Gulf of St. Lawrence off the west coast of Cape Breton in December, 2003.**

NO RESULTS YET. ANALYSES BEING CONDUCTED IN NEW BRUNSWICK AND NEWFOUNDLAND BY DFO SCIENTISTS.

MITIGATIONS

MINIMIZE CLOSE INTERACTION BETWEEN SEISMIC ACTIVITY AND THE MARINE BIOTA

(1) MINIMIZE SHOOTING AT SENSITIVE TIMES OF THE YEAR (I.E., SPAWNING, MIGRATION, PEAK FISHING)

(2) MORATORIUM ON SHOOTING IN AREAS THAT ARE SENSITIVE YEAR-ROUND

(3) RAMPING UP OF AIRGUN SYSTEMS TO ALLOW ANIMALS TO AVOID AREA

(4) MORE ACOUSTIC MODELING BASED ON FIELD MEASUREMENT

(5) GOOD COMMUNICATION BETWEEN SEISMIC PROPONENTS AND FISHING INDUSTRY

POTENTIAL IMPACTS ON SCUBA DIVERS AT AQUACULTURE SITES

Recommended maximum exposure limit for SCUBA divers: Received level ~ 155 dB

Exhaust bubble noise: Received level ~ 140 dB

Boat engine noise: Received level ~ 160 dB

Sonar: Received level ~ 155-170 dB

Source: U.K. Ministry of Defence (2004)

DIVERS AND NOISE

The potential for underwater sound to physically impact a diver is related to received sound level, duration of exposure and sound frequency.

Diver hoods and suits made of closed-cell foam neoprene reduce apparent loudness of water-borne sound. This material scatters and reflects much of the sound at frequencies above 500 Hz.

Source: U.K. Ministry of Defence (2004)

CONCLUSIONS

(1) APPARENT IMPACTS ON SOME MARINE BIOTA AT HIGH EXPOSURE

(2) HIGH VARIABILITY OF IMPACT BETWEEN AND WITHIN SPECIES

(3) NEED FOR MORE COMPREHENSIVE DOSE-RESPONSE STUDIES, ESPECIALLY LONG-TERM

(4) NEED FOR STANDARDIZATION IN RECEIVED SOUND LEVEL REPORTING

(5) NEED FOR MORE OPPORTUNISTIC EXPERIMENTATION DURING INDUSTRY SEISMIC SURVEYS

(6) NEED FOR MORE KNOWLEDGE OF THE BASIC BIOLOGY OF MARINE BIOTA IN ORDER TO BETTER UNDERSTAND THE POTENTIAL INTERACTIONS BETWEEN BIOTA AND SEISMIC