Appendix B: Presentations


BOEM
Effects of Noise on Fish, Fisheries, and Invertebrates
A BOEM Workshop on Data Gaps and Research Needs
March 20-22, 2012
San Diego, CA
Bureau of Ocean Energy Management
ENVIRONMENTAL STUDIES PROGRAM | Applied Science for Informed Decisions on Ocean Energy
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


BOEM
Acknowledgements
Concept: Ms. Kim Skrupky, BOEM
Driving Forces: Dr. Arthur N. Popper, UMD
Dr. Anthony Hawkins, Loughine
Science Review Panel: Dr. Christopher Glass, UNH
Dr. David Mann, USF
Dr. Jennifer Miksis-Olds, Penn State
Dr. Roberto Racca, JASCO
Logistics: Ms. Christine Denny, Normandeau
Ms. Alexis Hampton, Normandeau
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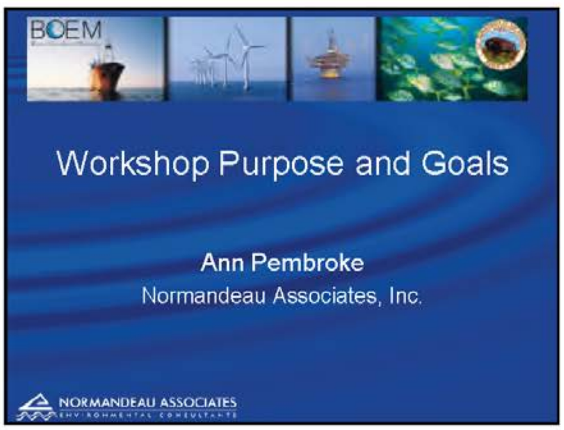
BOEM
Workshop Purpose and Goals
Ann Pembroke
Normandeau Associates, Inc.
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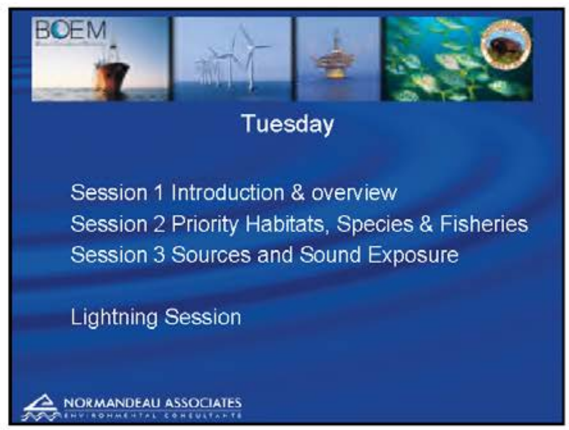
BOEM
Tuesday
Session 1 Introduction & overview
Session 2 Priority Habitats, Species & Fisheries
Session 3 Sources and Sound Exposure
Lightning Session
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BOEM
Session 1
Establish an understanding of policies & procedures BOEM must follow to implement its missions
Summarize the current understanding of the science as described in the Literature Synthesis
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BOEM
Session 2
Define the organisms of concern to regulators, managers, and the fishing community
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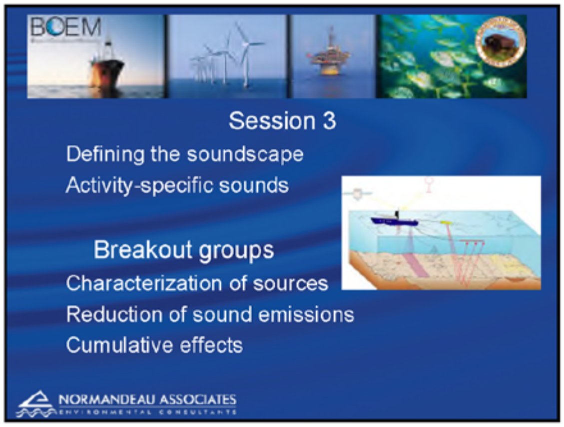
BOEM
Session 3
Defining the soundscape
Activity-specific sounds
Breakout groups
Characterization of sources
Reduction of sound emissions
Cumulative effects
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BOEM
Session 4
Who hears? Who speaks?
How are they affected?
Breakout groups
Implications for fishing
Behavioral responses
Injury
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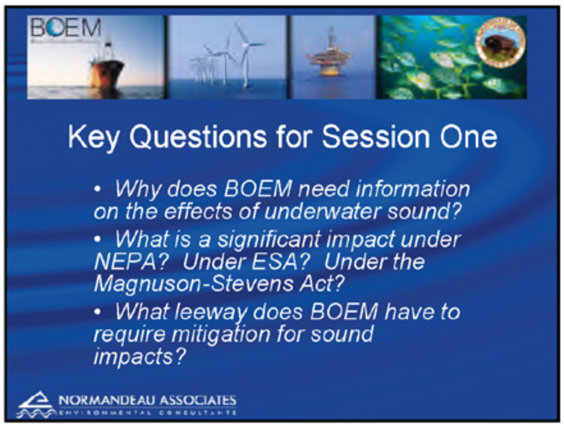
BOEM
Key Questions for Session One
• Why does BOEM need information on the effects of underwater sound?
• What is a significant impact under NEPA? Under ESA? Under the Magnuson-Stevens Act?
• What leeway does BOEM have to require mitigation for sound impacts?
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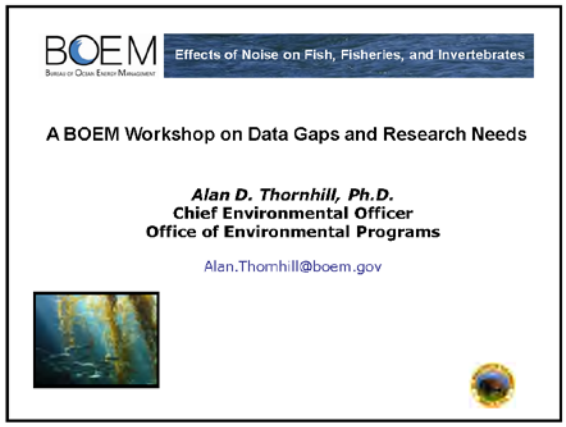
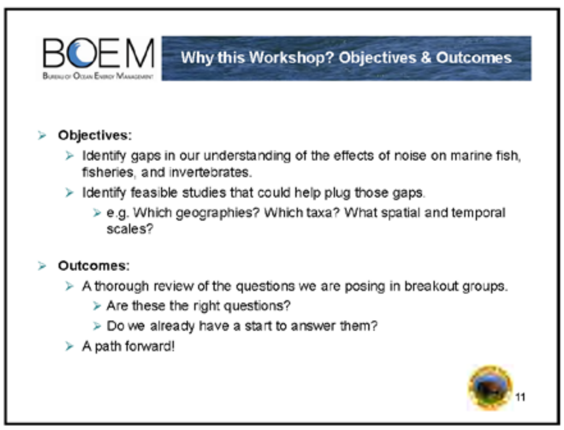
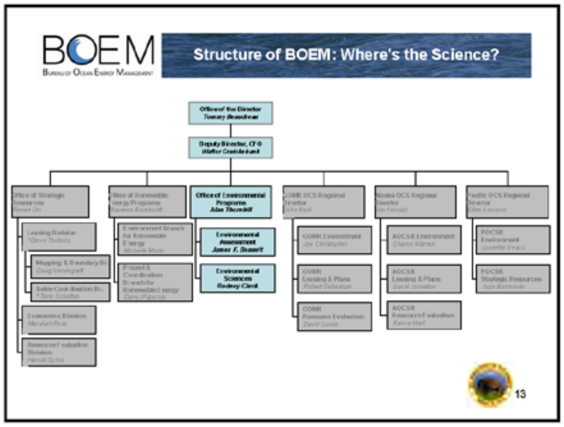
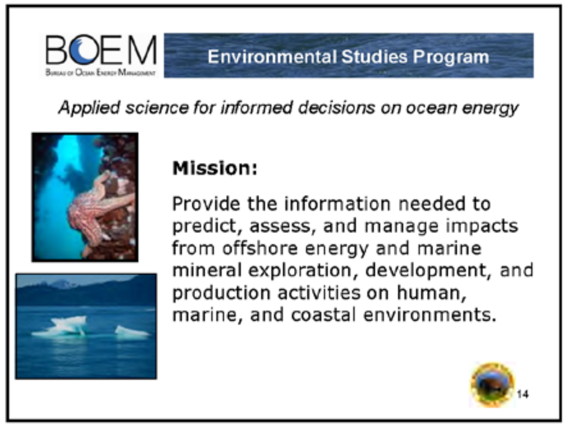
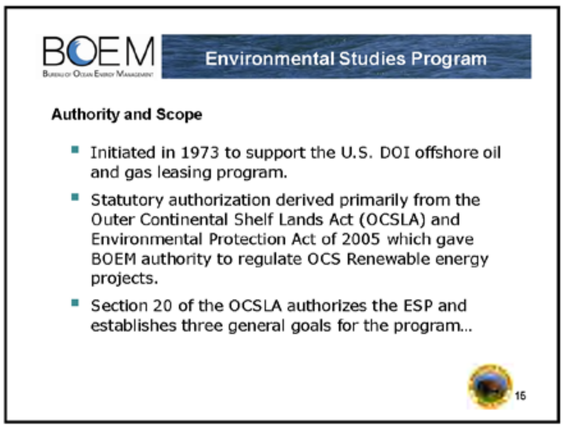

BOEM
Bureau of Ocean Energy Management
Effects of Noise on Fish, Fisheries, and Invertebrates
A BOEM Workshop on Data Gaps and Research Needs
Alan D. Thornhill, Ph.D.
Chief Environmental Officer
Office of Environmental Programs
Alan.Thornhill@boem.gov

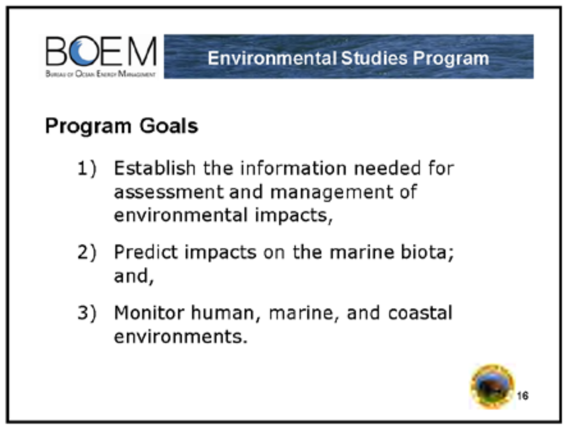

BOEM
Bureau of Ocean Energy Management
Why this Workshop? Objectives & Outcomes
Objectives:
Identify gaps in our understanding of the effects of noise on marine fish, fisheries, and invertebrates.
Identify feasible studies that could help plug those gaps.
e.g. Which geographies? Which taxa? What spatial and temporal scales?
Outcomes:
A thorough review of the questions we are posing in breakout groups.
Are these the right questions?
Do we already have a start to answer them?
A path forward!
11

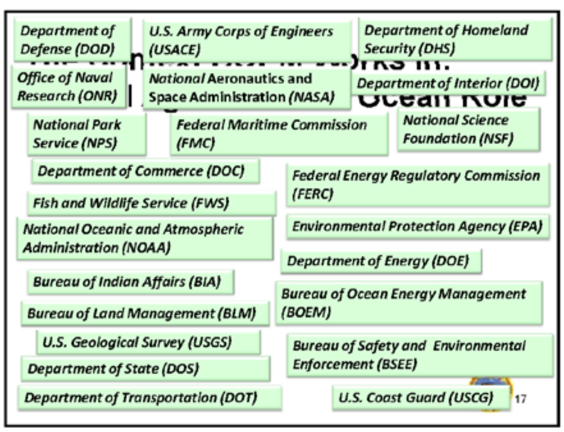

BOEM
Bureau of Ocean Energy Management
Our Organization(s)
BOEM
Bureau of Ocean Energy Management
BOEM manages development of the nation's offshore resources in an environmentally and economically responsible way.
BSEE develops and enforces safety and environmental regulations.
BSEE
Bureau of Safety and Environmental Enforcement
12

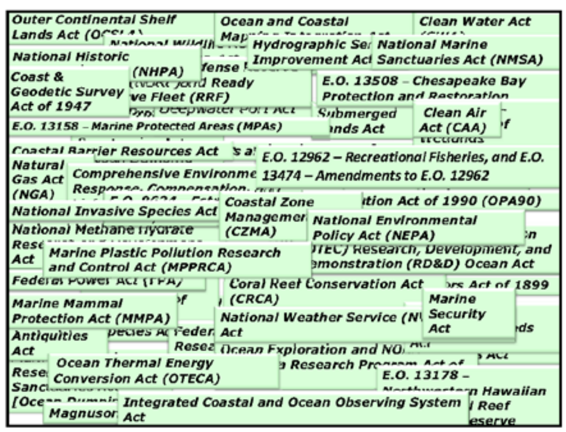

BOEM
Bureau of Ocean Energy Management
Structure of BOEM: Where's the Science?
Office of the Director
Deputy Director, CFO
Office of Environmental Programs
Environmental Assessment
James F. Bennett
Environmental Sciences
Rodney Cluck
13

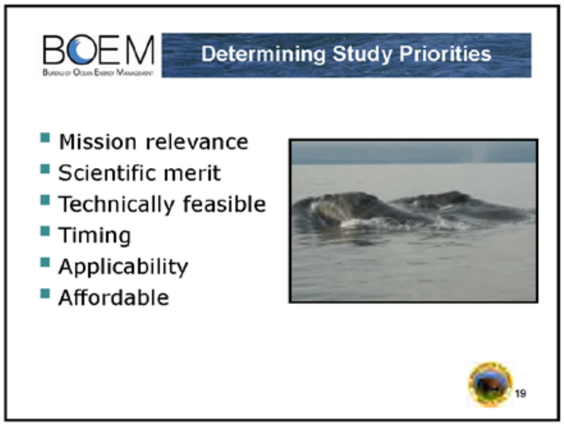

BOEM
Bureau of Ocean Energy Management
Environmental Studies Program
Applied science for informed decisions on ocean energy
Mission:
Provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.
14

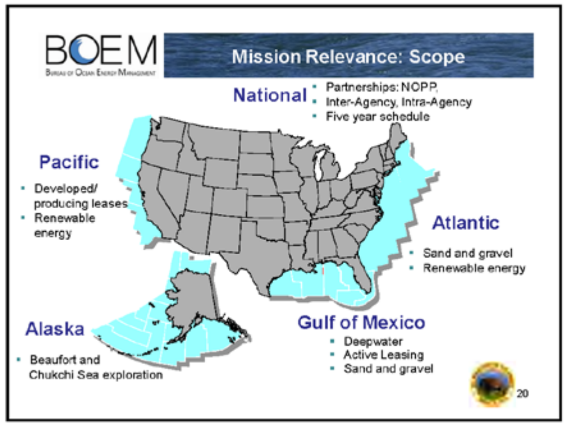

BOEM
Bureau of Ocean Energy Management
Environmental Studies Program
Authority and Scope
Initiated in 1973 to support the U.S. DOI offshore oil and gas leasing program.
Statutory authorization derived primarily from the Outer Continental Shelf Lands Act (OCSLA) and Environmental Protection Act of 2005 which gave BOEM authority to regulate OCS Renewable energy projects.
Section 20 of the OCSLA authorizes the ESP and establishes three general goals for the program…
15

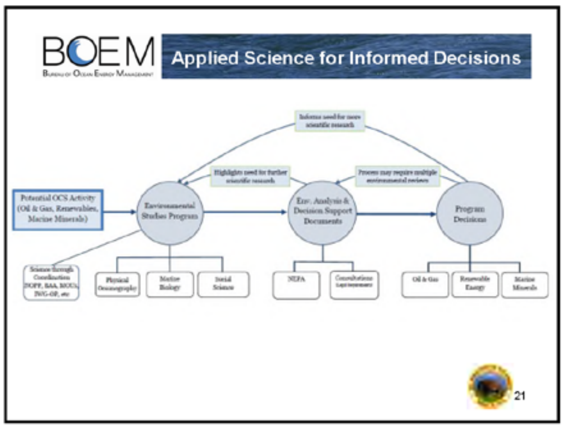

BOEM
Bureau of Ocean Energy Management
Environmental Studies Program
Program Goals
1) Establish the information needed for assessment and management of environmental impacts,
2) Predict impacts on the marine biota; and,
3) Monitor human, marine, and coastal environments.
16

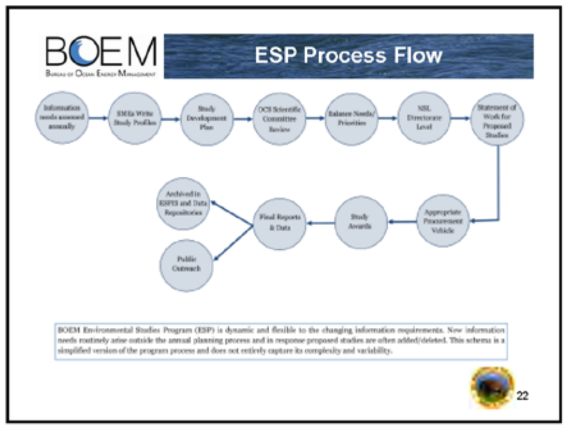

Department of Defense (DOD)
U.S. Army Corps of Engineers (USACE)
Department of Homeland Security (DHS)
Office of Naval Research (ONR)
National Aeronautics and Space Administration (NASA)
Department of Interior (DOI)
National Park Service (NPS)
Federal Maritime Commission (FMC)
National Science Foundation (NSF)
Department of Commerce (DOC)
Federal Energy Regulatory Commission (FERC)
Fish and Wildlife Service (FWS)
National Oceanic and Atmospheric Administration (NOAA)
Environmental Protection Agency (EPA)
Department of Energy (DOE)
Bureau of Indian Affairs (BIA)
Bureau of Ocean Energy Management (BOEM)
Bureau of Land Management (BLM)
U.S. Geological Survey (USGS)
Bureau of Safety and Environmental Enforcement (BSEE)
Department of State (DOS)
Department of Transportation (DOT)
U.S. Coast Guard (USCG)
17

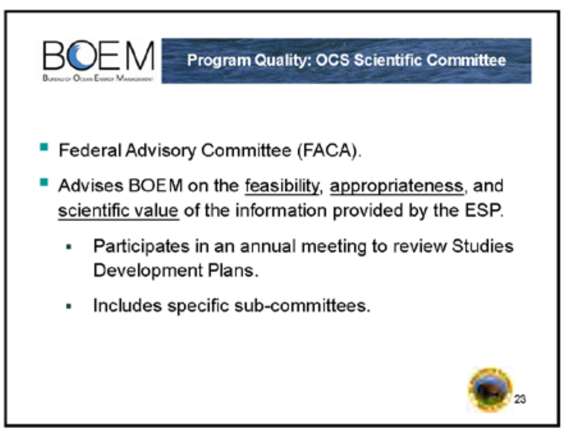

Outer Continental Shelf
Ocean and Coastal
Clean Water Act
National Historic
(NHPA)
Hydrographic Se
National Marine Sanctuaries Act (NMSA)
Coast & Geodetic Survey Act of 1947
E.O. 13508 – Chesapeake Bay
Submerged
Clean Air Act (CAA)
E.O. 13158 – Marine Protected Areas (MPAs)
Coastal Barrier Resources Act
E.O. 12962 – Recreational Fisheries, and E.O. 13474 – Amendments to E.O. 12962
Natural Gas Act (NGA)
Comprehensive Environme
Coastal Zone Managemen (CZMA)
National Invasive Species Act
National Environmental Policy Act (NEPA)
Marine Plastic Pollution Research and Control Act (MPPRCA)
Coral Reef Conservation Act (CRCA)
Marine Mammal Protection Act (MMPA)
Marine Security Act
Antiquities Act
Ocean Thermal Energy Conversion Act (OTECA)
E.O. 13178 –
Integrated Coastal and Ocean Observing System Act


BOEM
Determining Study Priorities
Mission relevance
Scientific merit
Technically feasible
Timing
Applicability
Affordable
19

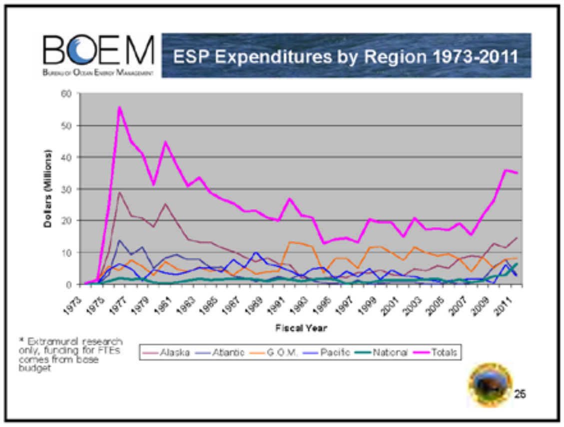

BOEM
Mission Relevance: Scope
National
Partnerships: NOPP,
Inter-Agency, Intra-Agency
Five year schedule
Pacific
Developed/
producing leases
Renewable
energy
Atlantic
Sand and gravel
Renewable energy
Alaska
Beaufort and
Chukchi Sea exploration
Gulf of Mexico
Deepwater
Active Leasing
Sand and gravel
20

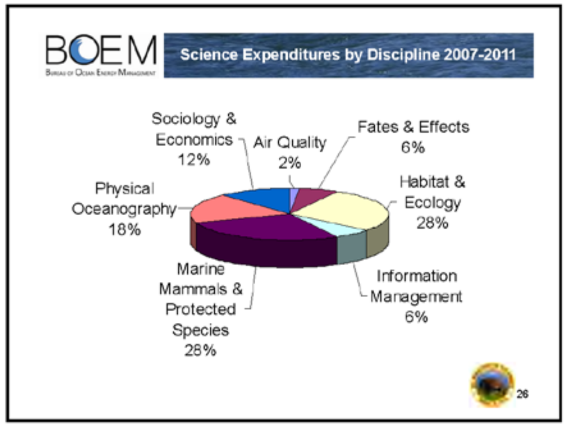

BOEM
Applied Science for Informed Decisions
Environmental Studies Program
Program Decisions
21

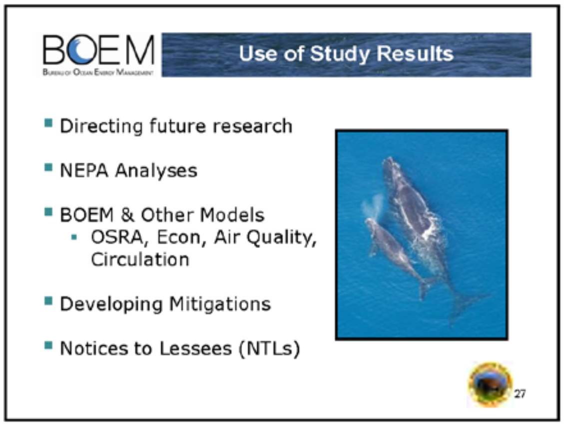

BOEM
ESP Process Flow
22

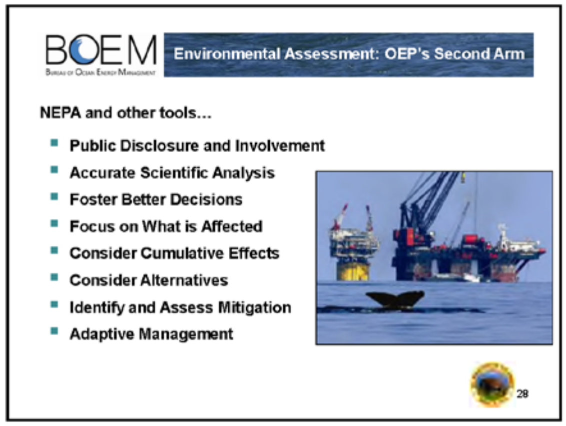

BOEM
Program Quality: OCS Scientific Committee
Federal Advisory Committee (FACA).
Advises BOEM on the feasibility, appropriateness, and scientific value of the information provided by the ESP.
Participates in an annual meeting to review Studies Development Plans.
Includes specific sub-committees.
23

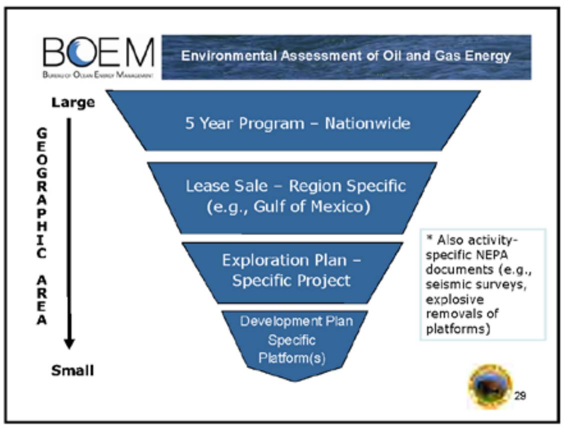

BOEM
Program Funds Research Through...
Competitive Contracts
Inter-Agency Agreements
Partnering NOPP; NOAA; ONR; NASA; NSF; USGS; FWS; NPS; DOE; etc.
Cooperative Agreements
Coastal Marine Institutes (CMI)
Cooperative Ecosystem Studies Units (CESU)
24

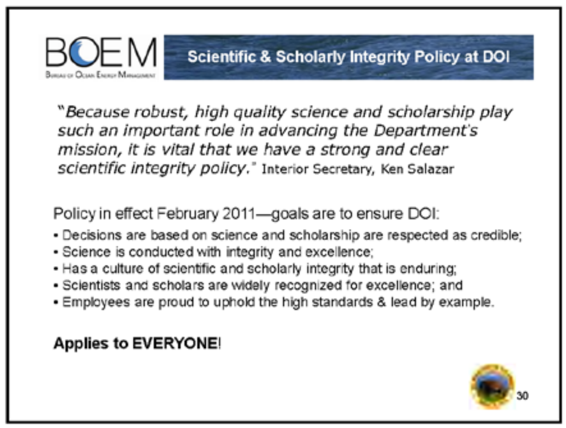

BOEM
Bureau of Ocean Energy Management
ESP Expenditures by Region 1973-2011
Dollars (Millions)
60
50
40
30
20
10
0
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Fiscal Year
* Extramural research only, funding for FTEs comes from base budget
Alaska
Atlantic
G.O.M.
Pacific
National
Totals
25

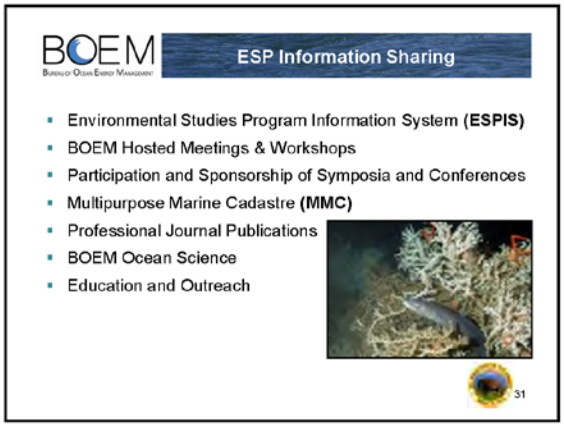

BOEM
Bureau of Ocean Energy Management
Science Expenditures by Discipline 2007-2011
Sociology & Economics 12%
Air Quality 2%
Fates & Effects 6%
Habitat & Ecology 28%
Physical Oceanography 18%
Information Management 6%
Marine Mammals & Protected Species 28%
26

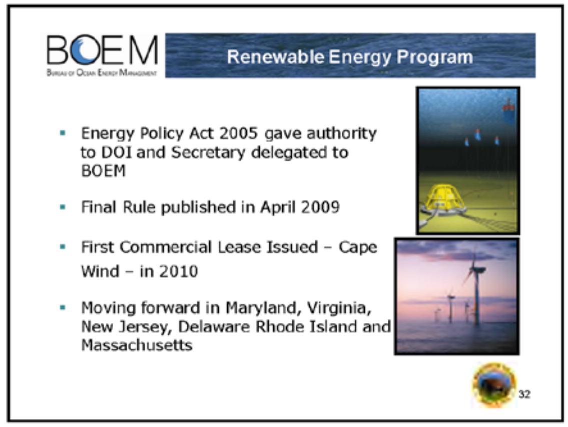

BOEM
Bureau of Ocean Energy Management
Use of Study Results
Directing future research
NEPA Analyses
BOEM & Other Models
OSRA, Econ, Air Quality, Circulation
Developing Mitigations
Notices to Lessees (NTLs)
27


BOEM
Bureau of Ocean Energy Management
Environmental Assessment: OEP's Second Arm
NEPA and other tools…
Public Disclosure and Involvement
Accurate Scientific Analysis
Foster Better Decisions
Focus on What is Affected
Consider Cumulative Effects
Consider Alternatives
Identify and Assess Mitigation
Adaptive Management
28

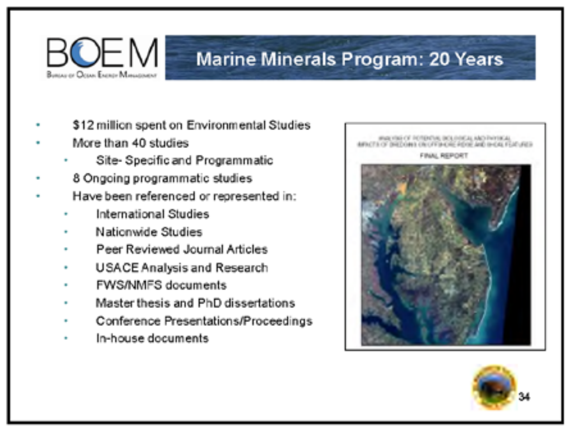

BOEM
Bureau of Ocean Energy Management
Environmental Assessment of Oil and Gas Energy
Large
GEOGRAPHIC AREA
Small
5 Year Program – Nationwide
Lease Sale – Region Specific (e.g., Gulf of Mexico)
Exploration Plan – Specific Project
Development Plan Specific Platform(s)
* Also activity-specific NEPA documents (e.g., seismic surveys, explosive removals of platforms)
29

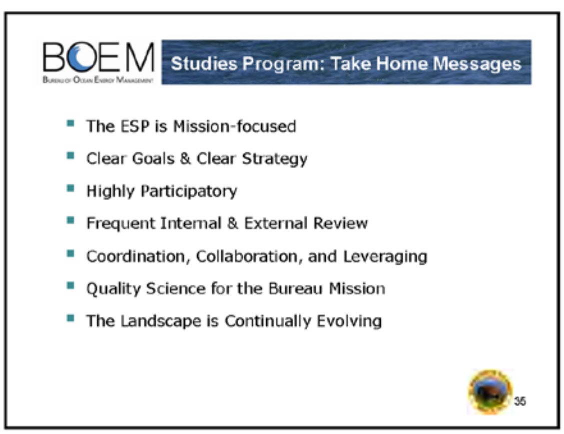

BOEM
Bureau of Ocean Energy Management
Scientific & Scholarly Integrity Policy at DOI
"Because robust, high quality science and scholarship play such an important role in advancing the Department's mission, it is vital that we have a strong and clear scientific integrity policy." Interior Secretary, Ken Salazar
Policy in effect February 2011—goals are to ensure DOI:
• Decisions are based on science and scholarship are respected as credible;
• Science is conducted with integrity and excellence;
• Has a culture of scientific and scholarly integrity that is enduring;
• Scientists and scholars are widely recognized for excellence; and
• Employees are proud to uphold the high standards & lead by example.
Applies to EVERYONE!
30

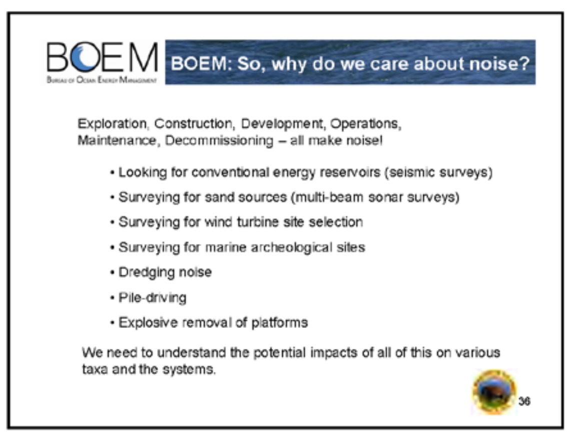

BOEM
ESP Information Sharing
Environmental Studies Program Information System (ESPIS)
BOEM Hosted Meetings & Workshops
Participation and Sponsorship of Symposia and Conferences
Multipurpose Marine Cadastre (MMC)
Professional Journal Publications
BOEM Ocean Science
Education and Outreach
31

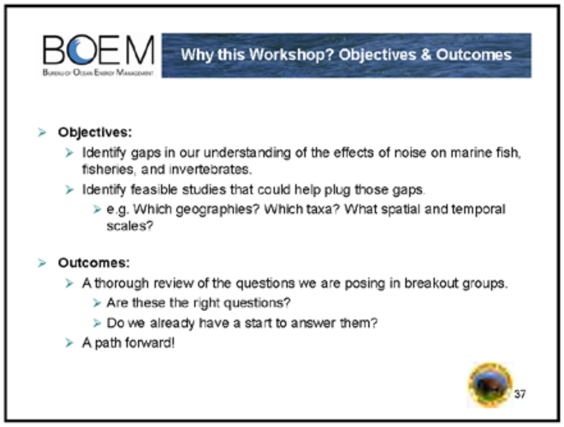

BOEM
Renewable Energy Program
Energy Policy Act 2005 gave authority to DOI and Secretary delegated to BOEM
Final Rule published in April 2009
First Commercial Lease Issued – Cape Wind – in 2010
Moving forward in Maryland, Virginia, New Jersey, Delaware Rhode Island and Massachusetts
32


BOEM
Marine Minerals Program
58 million cubic yards of OCS sand conveyed through 31 negotiated noncompetitive agreements
Projects completed in Florida, Louisiana, Maryland, South Carolina and Virginia
180 miles of the Nation's shoreline have been replenished/restored
33


BOEM
Marine Minerals Program: 20 Years
$12 million spent on Environmental Studies
More than 40 studies
Site- Specific and Programmatic
8 Ongoing programmatic studies
Have been referenced or represented in:
International Studies
Nationwide Studies
Peer Reviewed Journal Articles
USACE Analysis and Research
FWS/NMFS documents
Master thesis and PhD dissertations
Conference Presentations/Proceedings
In-house documents
FINAL REPORT
34


BOEM
Studies Program: Take Home Messages
The ESP is Mission-focused
Clear Goals & Clear Strategy
Highly Participatory
Frequent Internal & External Review
Coordination, Collaboration, and Leveraging
Quality Science for the Bureau Mission
The Landscape is Continually Evolving
35


BOEM
BOEM: So, why do we care about noise?
Exploration, Construction, Development, Operations, Maintenance, Decommissioning – all make noise!
• Looking for conventional energy reservoirs (seismic surveys)
• Surveying for sand sources (multi-beam sonar surveys)
• Surveying for wind turbine site selection
• Surveying for marine archeological sites
• Dredging noise
• Pile-driving
• Explosive removal of platforms
We need to understand the potential impacts of all of this on various taxa and the systems.
36


BOEM
Bureau of Ocean Energy Management
Why this Workshop? Objectives & Outcomes
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Identify feasible studies that could help plug those gaps.
e.g. Which geographies? Which taxa? What spatial and temporal scales?
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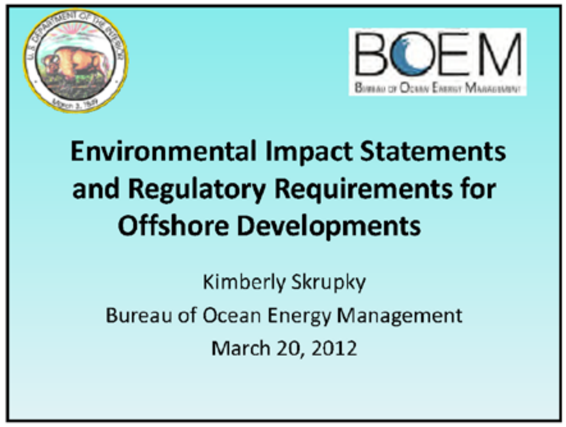
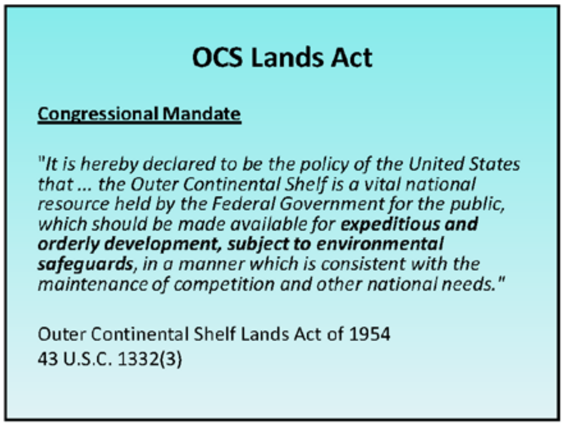
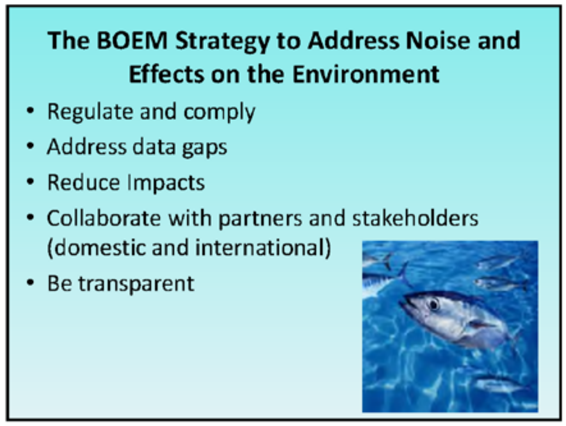
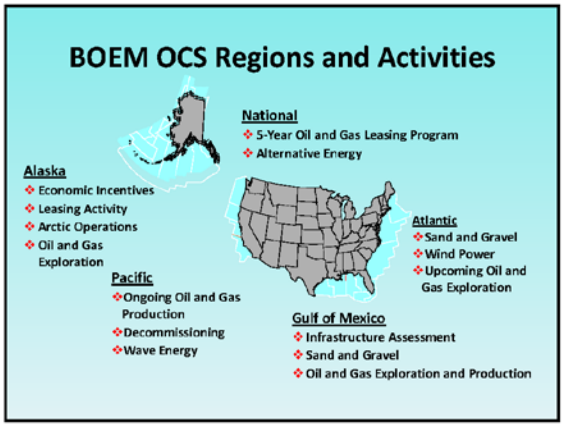
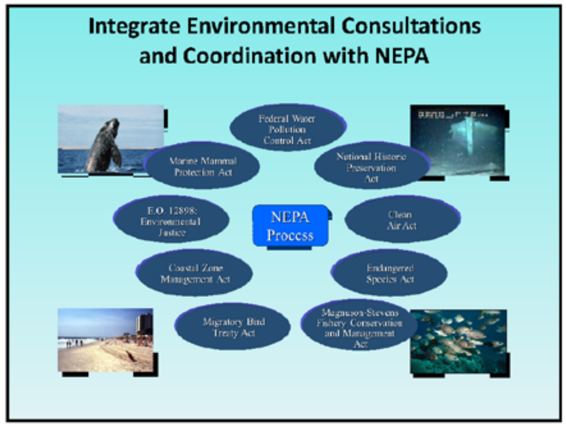
Do we already have a start to answer them?
A path forward!
37


BOEM
Bureau of Ocean Energy Management
Environmental Impact Statements and Regulatory Requirements for Offshore Developments
Kimberly Skrupky
Bureau of Ocean Energy Management
March 20, 2012

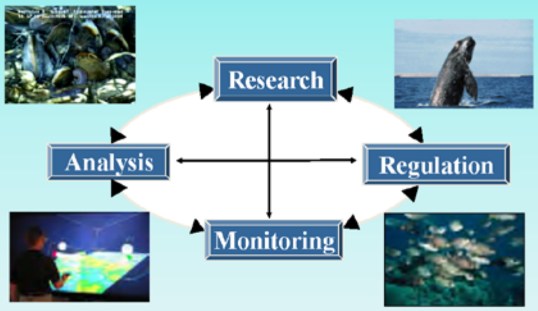

OCS Lands Act
Congressional Mandate
"It is hereby declared to be the policy of the United States that ... the Outer Continental Shelf is a vital national resource held by the Federal Government for the public, which should be made available for expeditious and orderly development, subject to environmental safeguards, in a manner which is consistent with the maintenance of competition and other national needs."
Outer Continental Shelf Lands Act of 1954
43 U.S.C. 1332(3)


The BOEM Strategy to Address Noise and Effects on the Environment
Regulate and comply
Address data gaps
Reduce Impacts
Collaborate with partners and stakeholders (domestic and international)
Be transparent


BOEM OCS Regions and Activities
National
5-Year Oil and Gas Leasing Program
Alternative Energy
Alaska
Economic Incentives
Leasing Activity
Arctic Operations
Oil and Gas Exploration
Pacific
Ongoing Oil and Gas Production
Decommissioning
Wave Energy
Atlantic
Sand and Gravel
Wind Power
Upcoming Oil and Gas Exploration
Gulf of Mexico
Infrastructure Assessment
Sand and Gravel
Oil and Gas Exploration and Production


Integrate Environmental Consultations and Coordination with NEPA
Federal Water Pollution Control Act
Marine Mammal Protection Act
National Historic Preservation Act
E.O. 12898: Environmental Justice
NEPA Process
Clean Air Act
Coastal Zone Management Act
Endangered Species Act
Migratory Bird Treaty Act
Magnuson-Stevens Fishery Conservation and Management Act

Environmental Protection – an Ongoing Integrated Process



Noise Regulated by BOEM

- Within the three program areas, noise is produced in several ways
- Geological and Geophysical sources
  - air guns, boomers, sparkers, chirpers, sub-bottom profilers, depth sounders, gravity, side-scan sonar, and magnetic/electromagnetic
- Construction, Drilling, Production and Decommissioning
  - pile driving, operational noise from rigs and platforms, vessel noise, dynamic positioning systems, explosives, dredging, ice breaking (Arctic)

Monitoring and Mitigation Measures

- Hiring Protected Species Observers to work on the vessel(s)
- Monitoring exclusion zones
- Passive Acoustic Monitoring (PAM)
- Sound Source Verification (SSV)
- Ramp-up
- Shut-down
- Time-of-Year closures
- But most of these don't work for fish!

Environmental Studies Program

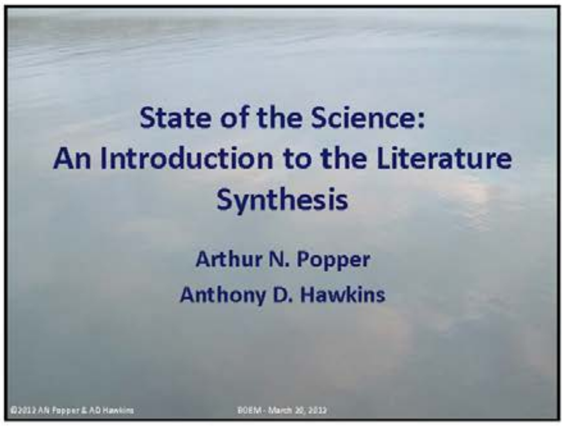
- BOEM develops, conducts and oversees world-class scientific research specifically to inform policy decisions regarding development of Outer Continental Shelf energy and mineral resources
- Research covers:
  - Physical oceanography
  - Atmospheric sciences
  - Biology
  - Protected species
  - Social sciences and economics
  - Submerged cultural resources
  - Environmental fates and effects

Funding Studies

- To provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.
- ~$30 million*
- ~$40 million on ground-breaking protected species research and acoustic issues
- ~$2 million provided annually through USGS
- ~ 50 % for ongoing
- ~ 50 % available for New starts annually
- Over 50 new projects for FY12
- Currently managing more than 300 active studies

* BOEM's FTE's not supported by ESP funds

Questions?

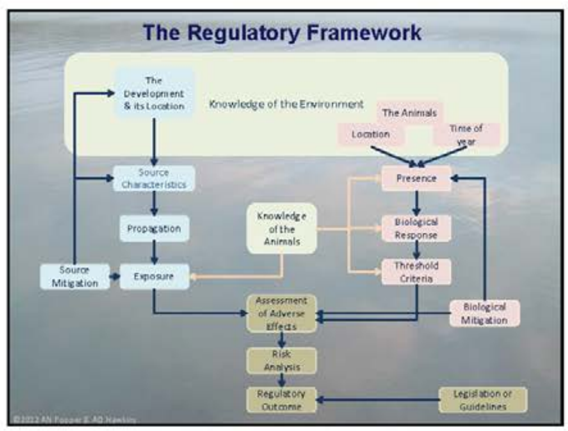

State of the Science:
An Introduction to the Literature Synthesis
Arthur N. Popper
Anthony D. Hawkins
©2012 AN Popper & AD Hawkins
BOEM - March 20, 2012


The Geographical Focus


Atlantic
United States
Mid-Atlantic Bight
Hatteras
Plain
Planning Area Boundaries
US EEZ Boundary


Arctic
Beaufort Sea
Chukchi Sea Planning Area
Beaufort Sea Planning Area
Barrow
Prudhoe Bay
Alaska
United States
Hope Basin Planning Area
Kotzebue
Arctic Circle
Russia
Canad


The Workshop Goal
To identify the most critical information needs and data gaps on the effects of various man-made sound on fish, fisheries, and invertebrates resulting from the use of sound-generating devices by the energy industry


The Regulatory Framework
The Development & its Location
Knowledge of the Environment
The Animals
Location
Time of year
Source Characteristics
Presence
Propagation
Knowledge of the Animals
Biological Response
Threshold Criteria
Source Mitigation
Exposure
Assessment of Adverse Effects
Biological Mitigation
Risk Analysis
Regulatory Outcome
Legislation or Guidelines

What do we know?

- Energy developments can generate transient high level sounds & increase overall background levels
- Many marine fish and invertebrates are sensitive to sound and use sounds in their everyday lives
- There is therefore potential for energy developments to have adverse effects upon species and habitats, and also to affect activities like fisheries

The Big Questions

- Are levels of sound in the sea changing as a result of human activities?
- Do man-made sounds have detrimental effects upon fish and invertebrates?
- Which sound-generating activities are most damaging to fish and invertebrates?
- How might the effects be reduced or mitigated?

Priority Habitats & Species

- Which species or habitats are particularly vulnerable to man-made sounds?
- Do any require protection?
- What protection can be provided?

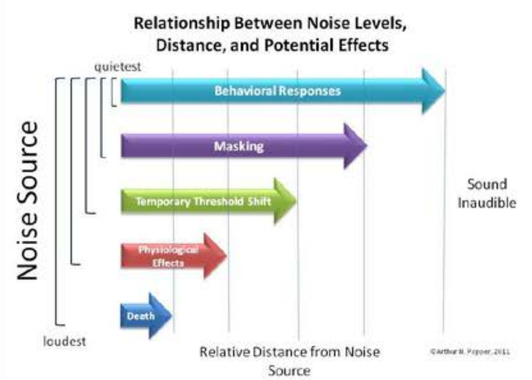
Are any fisheries likely to be affected by man-made sounds?

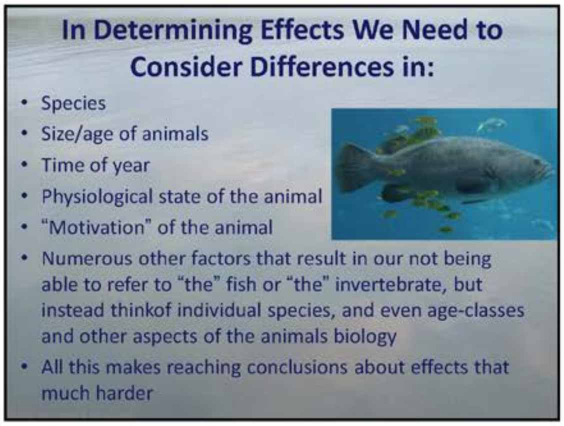
Natural Sounds

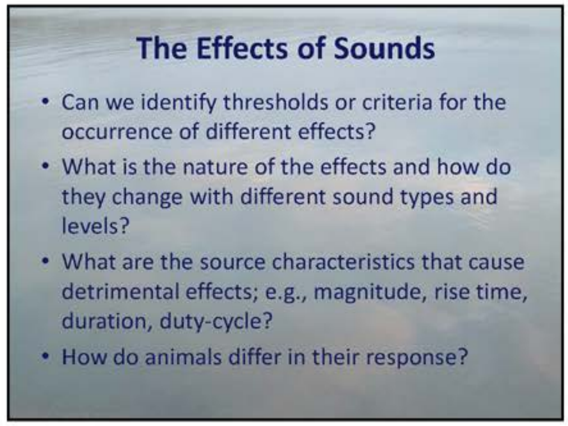
- What is the contribution to sound levels from natural sources, including biological sources?
- What physical quantities and metrics are most useful for describing ocean soundscapes?
- Are natural soundscapes at risk from man-made sounds?
- Which natural sounds will be masked by man-made sounds

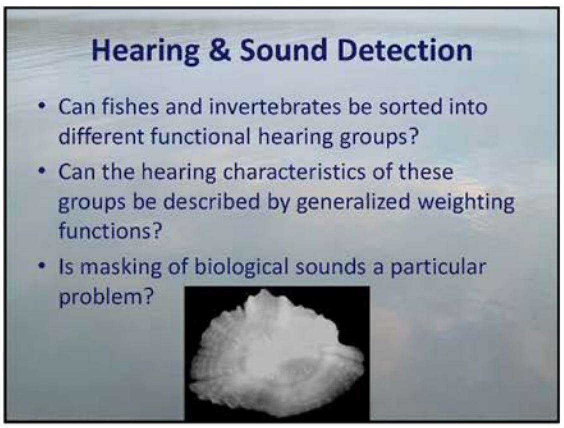
Sound Sources

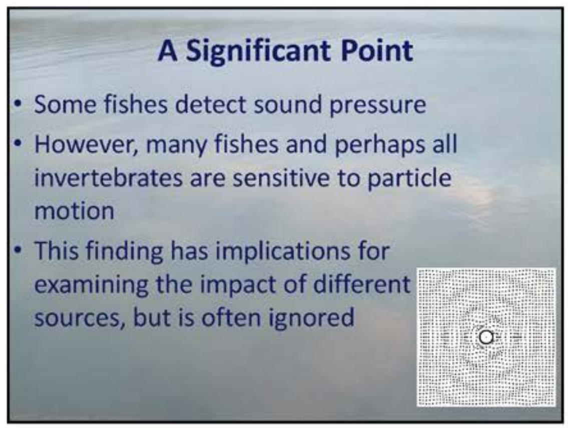
- What is the contribution to sound levels from different man-made sources?
- Which man-made sources are likely to have the greatest adverse effects?
- What are the likely future trends in sound levels?
- Do we have appropriate standards and metrics for characterizing man-made sources?

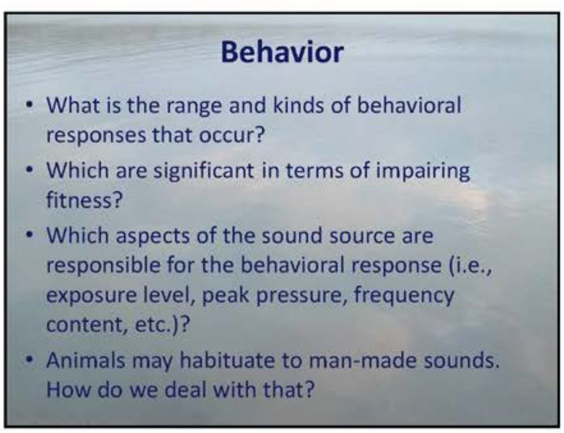


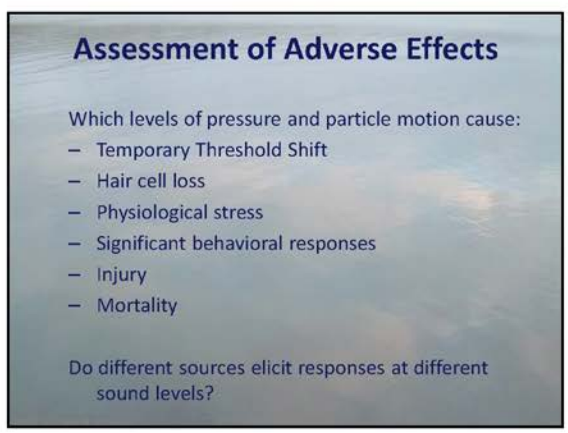

In Determining Effects We Need to Consider Differences in:
• Species
• Size/age of animals
• Time of year
• Physiological state of the animal
• "Motivation" of the animal
• Numerous other factors that result in our not being able to refer to "the" fish or "the" invertebrate, but instead thinkof individual species, and even age-classes and other aspects of the animals biology
• All this makes reaching conclusions about effects that much harder

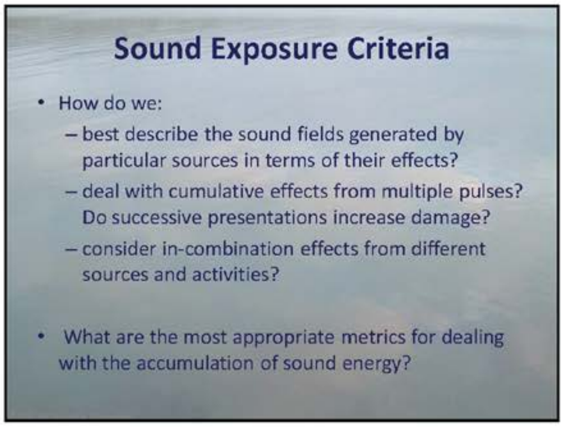

The Effects of Sounds
• Can we identify thresholds or criteria for the occurrence of different effects?
• What is the nature of the effects and how do they change with different sound types and levels?
• What are the source characteristics that cause detrimental effects; e.g., magnitude, rise time, duration, duty-cycle?
• How do animals differ in their response?


Hearing & Sound Detection
• Can fishes and invertebrates be sorted into different functional hearing groups?
• Can the hearing characteristics of these groups be described by generalized weighting functions?
• Is masking of biological sounds a particular problem?


A Significant Point
• Some fishes detect sound pressure
• However, many fishes and perhaps all invertebrates are sensitive to particle motion
• This finding has implications for examining the impact of different sources, but is often ignored


Behavior
• What is the range and kinds of behavioral responses that occur?
• Which are significant in terms of impairing fitness?
• Which aspects of the sound source are responsible for the behavioral response (i.e., exposure level, peak pressure, frequency content, etc.)?
• Animals may habituate to man-made sounds. How do we deal with that?

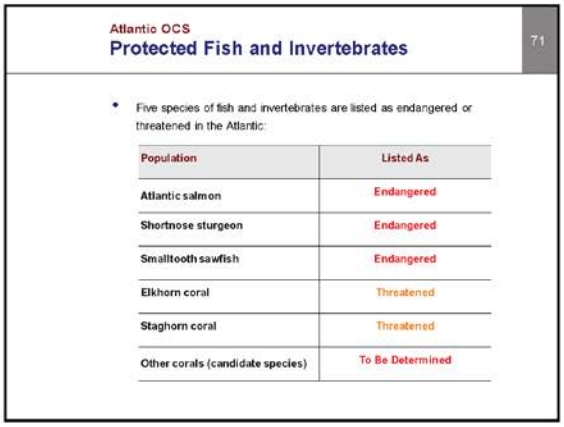

Assessment of Adverse Effects
Which levels of pressure and particle motion cause:
– Temporary Threshold Shift
– Hair cell loss
– Physiological stress
– Significant behavioral responses
– Injury
– Mortality
Do different sources elicit responses at different sound levels?

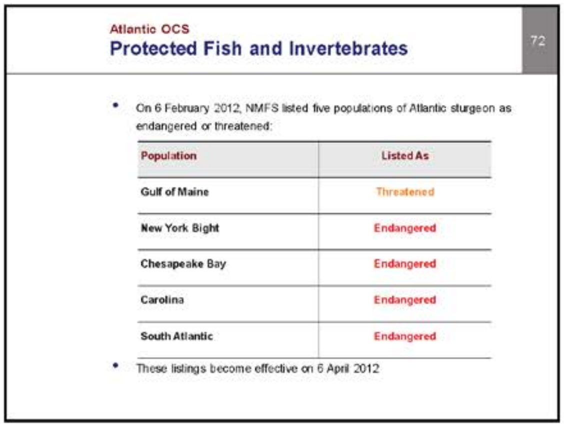

Sound Exposure Criteria
How do we:
– best describe the sound fields generated by particular sources in terms of their effects?
– deal with cumulative effects from multiple pulses? Do successive presentations increase damage?
– consider in-combination effects from different sources and activities?
What are the most appropriate metrics for dealing with the accumulation of sound energy?


Mitigation
Can we avoid using high level sources?
Are there technological alternatives?
Can sources be redesigned to make them less damaging?
Can monitoring systems detect vulnerable animals before they are exposed?


Other Mitigation Options
Do ramp-up procedures work for fish & invertebrates?
Can sound-making be restricted to times when animals are less likely to be affected by sound?


Protected Species/Habitats
San Diego | California | 20 March 2012
Craig Johnson
NOAA Fisheries
Silver Spring, Maryland


Atlantic OCS
Protected Fish and Invertebrates
71
Five species of fish and invertebrates are listed as endangered or threatened in the Atlantic:
Population | Listed As
Atlantic salmon | Endangered
Shortnose sturgeon | Endangered
Smalltooth sawfish | Endangered
Elkhorn coral | Threatened
Staghorn coral | Threatened
Other corals (candidate species) | To Be Determined


Atlantic OCS
Protected Fish and Invertebrates
72
On 6 February 2012, NMFS listed five populations of Atlantic sturgeon as endangered or threatened:
Population | Listed As
Gulf of Maine | Threatened
New York Bight | Endangered
Chesapeake Bay | Endangered
Carolina | Endangered
South Atlantic | Endangered
These listings become effective on 6 April 2012

Atlantic OCS

Protected Fish and Invertebrates

73

Atlantic OCS

Designated Critical Habitat

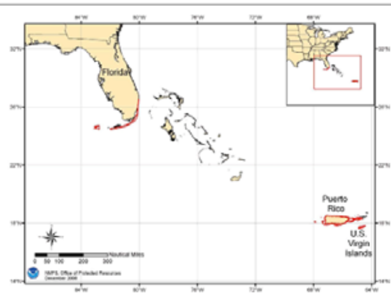
74

- Designated critical habitat for smalltooth sawfish
- We have not designated critical habitat for Atlantic sturgeon, but we are considering doing so

Atlantic OCS

Designated Critical Habitat

75



- Designated critical habitat for elkhorn and staghorn coral

Arctic OCS

Protected Fish and Invertebrates

76

- No marine, anadromous, or catadromous fish are currently listed or are proposed for listing as endangered or threatened by NMFS in the Arctic Region
- No invertebrates are currently listed or are proposed for listing as endangered or threatened by NMFS in the Arctic Region

Atlantic OCS

Potential Sources of Stressors

77

- Offshore energy development activities are associated with several physical, chemical, and biotic stressors that pose potential risks to endangered and threatened fish and invertebrates:
  - Seismic surveys
  - Underwater detonations
  - Vessel traffic
  - Pile driving
  - Coastal dredging (and other activities associated with installation of onshore infrastructure)
  - Oil spills and chemical contamination
  - Competition from native and non-native species

Atlantic OCS

Noise and Sturgeon

78

- There are some data on hearing in lake sturgeon or paddlefish, for example:
  - Meyer and Popper (2002) reported that lake sturgeon detect pure tones from 100 to 2000 Hz with best sensitivity from 100 to 400 Hz
  - Lovell *et al.* (2005) reported that lake sturgeon and paddlefish responded to sounds from 100 to 500 Hz, with lowest hearing thresholds in bandwidths between 200 and 300 Hz and higher thresholds at 100 and 500 Hz
  - Additional data on lake sturgeon from Lovell *et al.* (2006), Meyer et al. (2010), and Meyer et al. (2012)

Lovell, J.M., M.M. Findlay, R.M. Moate, J.R. Nedwell and M.A. Pegg. 2005. The inner ear morphology and hearing abilities of the Paddlefish (*Polyodon spathula*) and the Lake Sturgeon (*Acipenser fulvescens*). Comparative Biochemistry and Physiology Part A 142: 286-296.

Lovell, J.M., M.M. Findlay, G.M. Harper and R.M. Moate. 2006. The inner ear ultrastructure from the paddlefish (*Polyodon spathula*) using transmission electron microscopy. Journal of Microscopy 222(1): 36-41.

Meyer, M., and A. N. Popper. 2002. Hearing in "primitive" fish: brainstem responses to pure tone stimuli in the lake sturgeon, *Acipenser fulvescens*. Abstracts of the Association for Research in Otolaryngology 25:11-12.

Atlantic OCS

Noise and corals

79

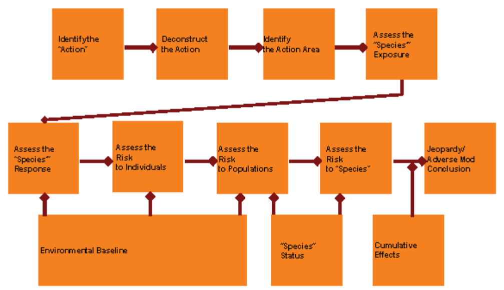
- Data on interactions between corals and sounds are the most limited, but include
  - Vermeij *et al.* (2010) reported that free-swimming larvae of tropical corals detect and use sounds as a cue for orientation
  - They did not report how these larvae detect the sounds or components of the sound field that provide the cues
  - Numerous authors have demonstrated the effects of sound on larvae of fish that are part of coral reef ecosystems

Vermeij, M.J.A., K.L. Marhaver, C.M. Huijbers, I. Nagelkerken and S.D. Simpson. 2010. Coral larvae move toward reef sounds. PLoS ONE 5(5): e10660.

ESA Consultations

A Generalized Assessment Model

80



ESA Consultations

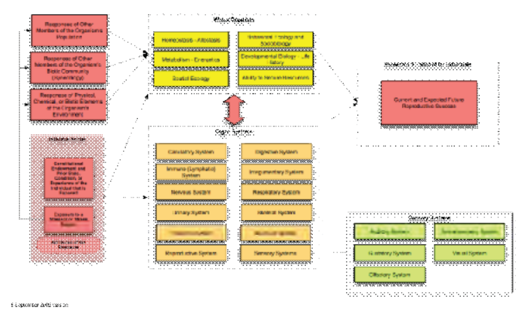
Generalized Assessment Model

81

- One of the most challenging steps of this assessment model links individual responses to individual risks
- A complete assessment of the risks of offshore energy projects must consider two risks to individuals:
  - reductions in probability of survival (increases in mortality)
  - reductions in reproductive success (which is determined by age at first reproduction, interval between reproductive events, natality, recruitment into the adult population, and age at last reproduction)
- Data on the responses of fish and marine invertebrates to noise has limited utility if we cannot somehow link those responses to one of these two assessment endpoints
- That is our largest data or knowledge gap

Sub-Model for Individual Organisms

82



ESA Consultations

Emerging Challenges

83

- Over the past five years, every assessment of noise-producing activities in the marine environment has had to deal with one constant and growing challenge: our inability to conduct rigorous cumulative impact assessments
- Challenges to our assessments have focused on
  - repeated exposures to single and multiple stressors
  - time- and space-crowded effects
  - interactions between multiple stressors (both natural and anthropogenic)
- We still lack rigorous methods for assessing these effects or the data we would need to execute such a method

Protected Species/Habitats

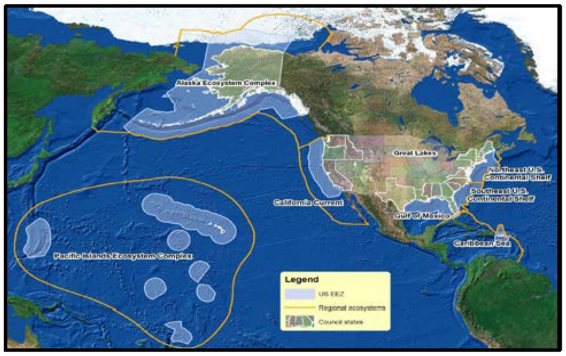
Craig Johnson, NOAA Fisheries

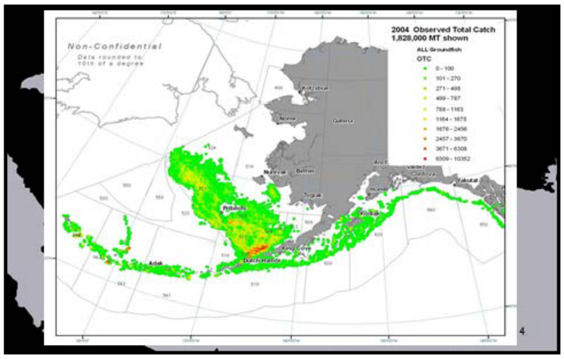
84

- Information needs
  - We need to be able to characterize how invertebrates perceive their acoustic environment and the effects of sound on their ecology
  - We need better ways of characterizing the effects of noise on the predators, competitors, symbionts, and prey of listed fish and invertebrates
  - We need to link responses to "noise" to the current and expected future reproductive success of the fish and invertebrates that are exposed to the "noise"
  - We need more rigorous methods to assess the cumulative impacts of offshore energy by itself and in combination with other human activities that co-occur with it in the marine environment

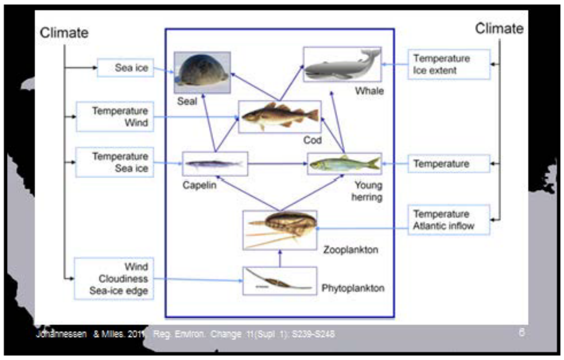

Arctic Fisheries and Habitat
Steve A. MacLean
North Pacific Fishery Management Council
Effects of Noise on Fish, Fisheries, and Invertebrates
A BOEM Workshop on Data Gaps and Research Needs
San Diego, California
19-22 March 2012
1

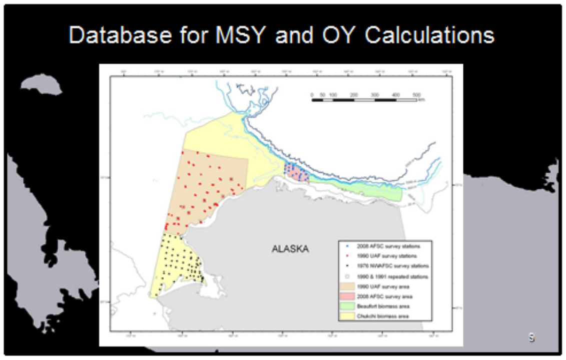

Development of the Arctic Fishery Management Plan
Current Status of Arctic fisheries
Data needs for the Arctic Fishery Management Plan
2

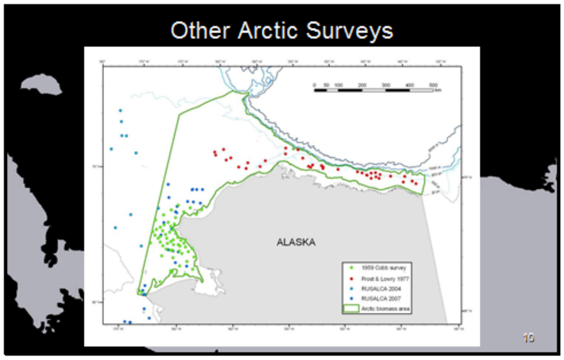

Alaska Ecosystem Complex
Great Lakes
Northeast U.S. Continental Shelf
Southeast U.S. Continental Shelf
California Current
Gulf of Mexico
Caribbean Sea
Pacific Islands Ecosystem Complex
Legend
US EEZ
Regional ecosystems
Council states

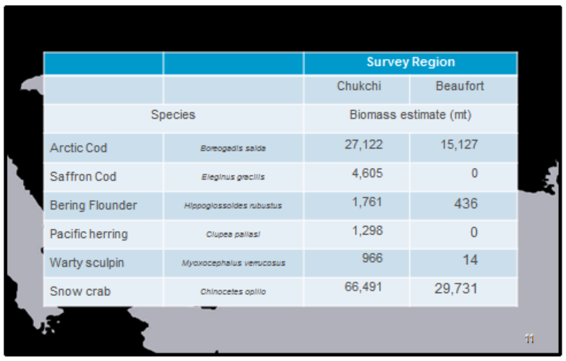

2004 Observed Total Catch
1,828,000 MT shown
ALL Groundfish
OTC
Non-Confidential
Data rounded to 10th of a degree
Adak
Dutch Harbor
Kodiak
Yakutat
4


Arctic Management Area
Alaska State Waters
Arctic Management Area
Beaufort Sea
Chukchi Sea
Russia
Canada
Alaska
Kotzebue Sound
Seward Peninsula
Norton Sound
5

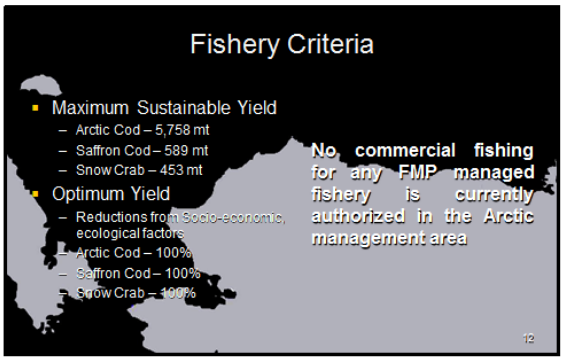

Climate
Climate
Sea ice
Temperature
Wind
Temperature
Sea ice
Wind
Cloudiness
Sea-ice edge
Seal
Whale
Cod
Capelin
Young herring
Zooplankton
Phytoplankton
Temperature
Ice extent
Temperature
Temperature
Atlantic inflow
Johannessen & Miles. 2011. Reg. Environ. Change 11(Supl 1): S239-S248
6

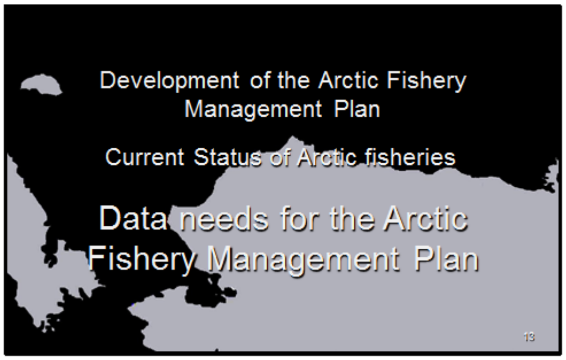


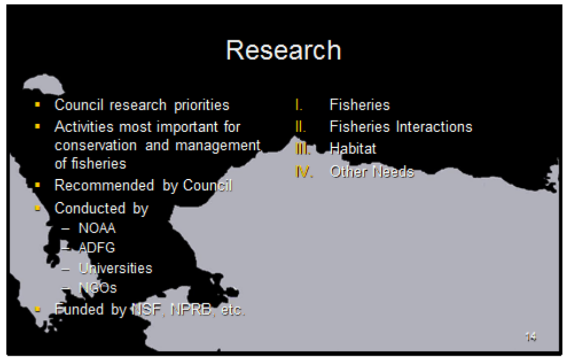


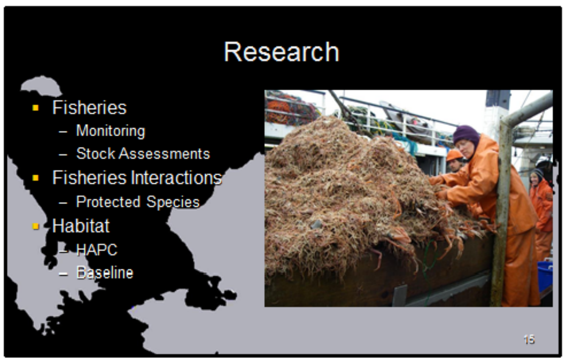


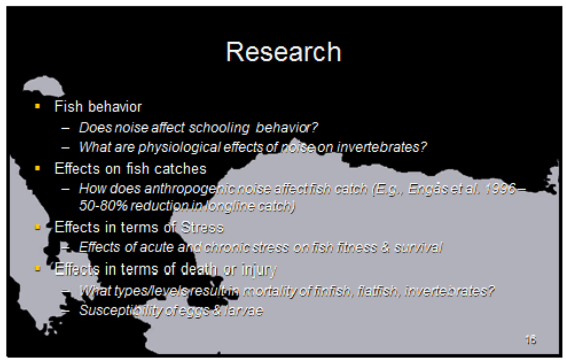
		Survey Region	
		Chukchi	Beaufort
Species		Biomass estimate (mt)	
Arctic Cod	*Boreogadis saida*	27,122	15,127
Saffron Cod	*Eleginus gracilis*	4,605	0
Bering Flounder	*Hippoglossoides rubustus*	1,761	436
Pacific herring	*Clupea pallasi*	1,298	0
Warty sculpin	*Myoxocephalus verrucosus*	966	14
Snow crab	*Chinocetes opilio*	66,491	29,731



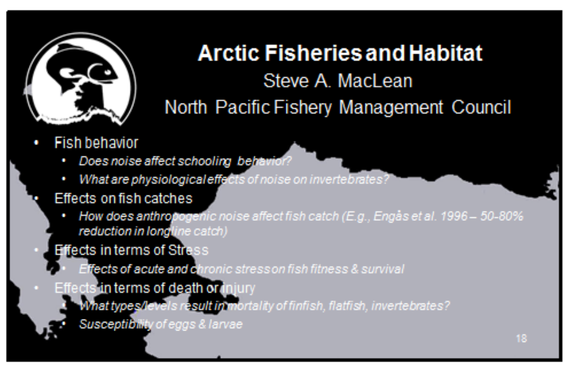

Development of the Arctic Fishery Management Plan
Current Status of Arctic fisheries
Data needs for the Arctic Fishery Management Plan
13


Research
Council research priorities
Activities most important for conservation and management of fisheries
Recommended by Council
Conducted by
– NOAA
– ADFG
– Universities
– NGOs
Funded by NSF, NPRB, etc.
I. Fisheries
II. Fisheries Interactions
III. Habitat
IV. Other Needs
14


Research
Fisheries
– Monitoring
– Stock Assessments
Fisheries Interactions
– Protected Species
Habitat
– HAPC
– Baseline
15


Research
Fish behavior
– Does noise affect schooling behavior?
– What are physiological effects of noise on invertebrates?
Effects on fish catches
– How does anthropogenic noise affect fish catch (E.g., Engås et al. 1996 – 50-80% reduction in longline catch)
Effects in terms of Stress
– Effects of acute and chronic stress on fish fitness & survival
Effects in terms of death or injury
– What types/levels result in mortality of finfish, flatfish, invertebrates?
– Susceptibility of eggs & larvae
16


Thank You
Contact:
North Pacific Fishery Management Council
605 West 4th Ave, Suite 306
Anchorage, AK 99501
907-271-2809
907-271-2817 (fax)
Steve MacLean
steve.maclean@noaa.gov
www.fakr.noaa.gov/npfmc
17


Arctic Fisheries and Habitat
Steve A. MacLean
North Pacific Fishery Management Council
Fish behavior
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Effects of acute and chronic stress on fish fitness & survival
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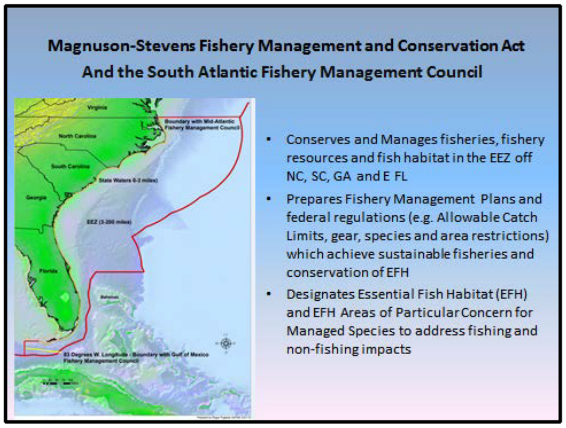
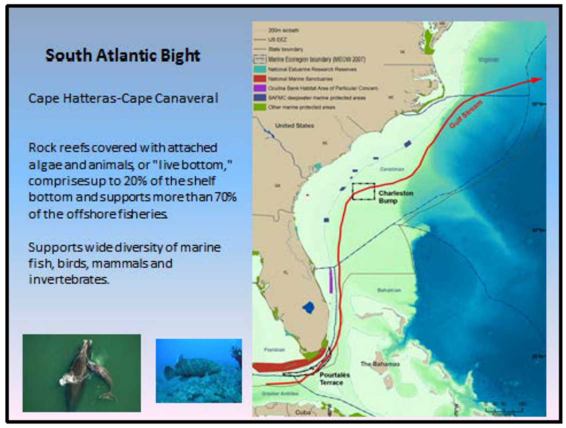
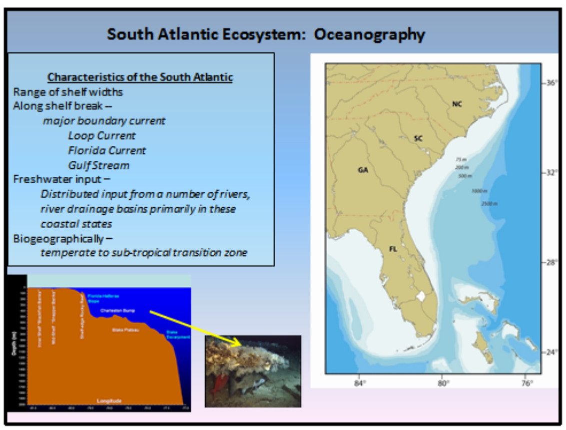
What types/levels result in mortality of finfish, flatfish, invertebrates?
Susceptibility of eggs & larvae
18


South Atlantic
Priority Habitats, Species, and Fisheries
Jaclyn Daly
NOAA's National Marine Fisheries Service
Charleston, South Carolina
Jaclyn.Daly@noaa.gov
Roger Pugliese
South Atlantic Fishery Management Council
Charleston, South Carolina
Roger.Pugliese@safmc.net


Overview
• Magnuson-Stevens Fishery Management and Conservation Act and the South Atlantic Fishery Management Council
• South Atlantic Ecosystem, Species, Fisheries
• Ecological requirements and Essential Fish Habitat
• Habitat and Ecosystem Information Systems
• Present and emerging issues/data needs


Magnuson-Stevens Fishery Management and Conservation Act
And the South Atlantic Fishery Management Council
• Conserves and Manages fisheries, fishery resources and fish habitat in the EEZ off NC, SC, GA and E FL
• Prepares Fishery Management Plans and federal regulations (e.g. Allowable Catch Limits, gear, species and area restrictions) which achieve sustainable fisheries and conservation of EFH
• Designates Essential Fish Habitat (EFH) and EFH Areas of Particular Concern for Managed Species to address fishing and non-fishing impacts

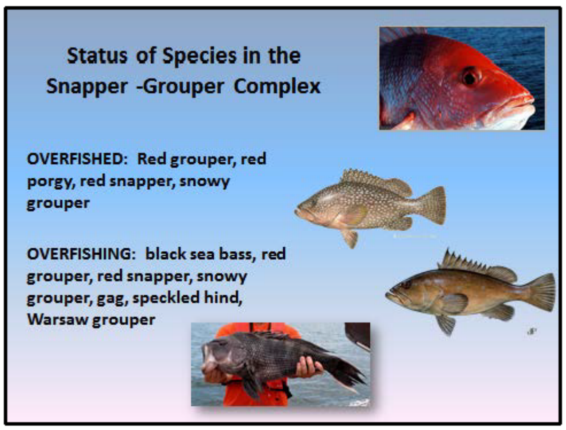

South Atlantic Bight
Cape Hatteras-Cape Canaveral
Rock reefs covered with attached algae and animals, or "live bottom," comprises up to 20% of the shelf bottom and supports more than 70% of the offshore fisheries.
Supports wide diversity of marine fish, birds, mammals and invertebrates.
Charleston Bump
Gulf Stream
Pourtalès Terrace
The Bahamas

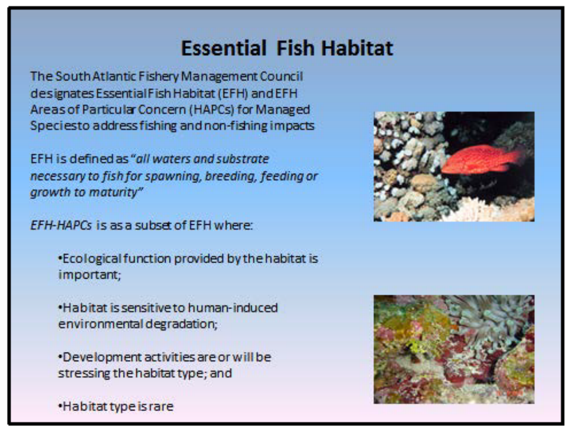

South Atlantic Ecosystem: Oceanography
Characteristics of the South Atlantic
Range of shelf widths
Along shelf break –
major boundary current
Loop Current
Florida Current
Gulf Stream
Freshwater input –
Distributed input from a number of rivers, river drainage basins primarily in these coastal states
Biogeographically –
temperate to sub-tropical transition zone
NC
SC
GA
FL

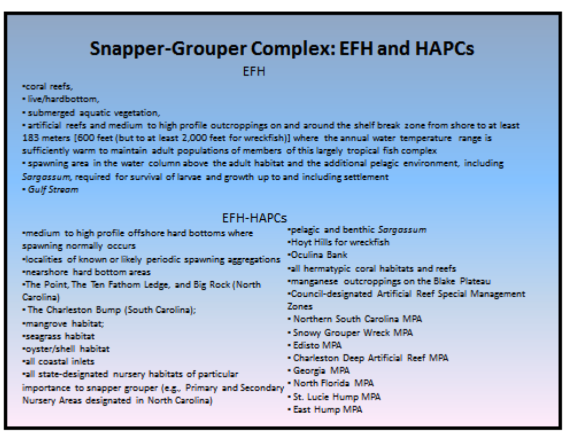

Fishery Management Plans
Shrimp Fishery Management Plan
brown shrimp - Farfantepenaeus aztecus
pink shrimp - F. duorarum
rock shrimp - Sicyonia brevirostris
royal red shrimp - Pleoticus robustus
white shrimp - Litopenaeus setiferus
Coastal Migratory Pelagics Fishery Management Plan
cobia - Rachycentron canadum
king mackerel - Scomberomorus cavalla
Spanish mackerel - S. maculatus
Cero - Scomberomorus regalis
Little tunny - Euthynnus alletteratus
Dolphin-Wahoo Fishery Management Plan
Dolphinfish - Coryphaena hippurus
Wahoo - Acanthocybium solandri
Spiny Lobster Fishery Management Plan
spiny lobster - Panulirus argus
Golden Crab Fishery Management Plan
golden crab - Chaceon fenneri

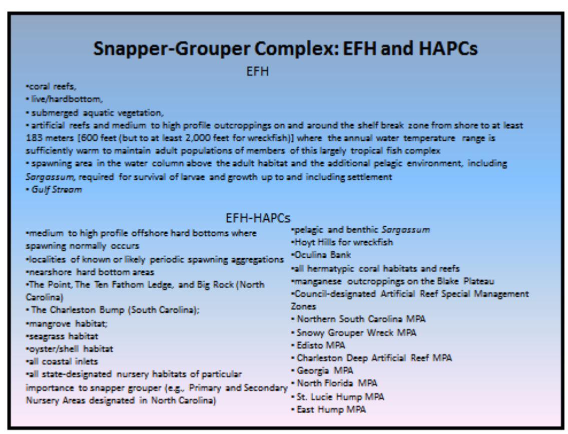

Fishery Management Plans
Snapper-Grouper Complex Fishery Management Plan
Gag - *Mycteroperca microlepis*
Red grouper - *Epinephelus morio*
Scamp - *Mycteroperca phenax*
Black grouper - *Mycteroperca bonaci*
Rock hind - *Epinephelus adcensionis*
Red hind - *Epinephelus guttatus*
Graysby - *Cephalopholis cruentata*
Yellowfin grouper - *Mycteroperca venenosa*
Coney - *Cephalopholis fulva*
Yellowmouth grouper -*Mycteroperca interstitialis*
Goliath grouper - *Epinephelus itajara*
Nassau grouper - *Epinephelus striatus*
Snowy grouper - *Epinephelus niveatus*
Yellowedge grouper - *Epinephelus flavolimbatus*
Warsaw grouper - *Epinephelus nigritus*
Speckled hind - *Epinephelus drummondhayi*
Misty grouper - *Epinephelus mystacinus*
Black sea bass - *Centropristis striata*
Bank sea bass - *Centropristis ocyurus*
Rock sea bass - *Centropristis philadelphica*
Wreckfish - *Polyprion americanus*
Queen snapper -*Etelis oculatus*
Yellowtail snapper - *Ocyurus chrysurus*
Gray snapper - *Lutjanus griseus*
Mutton snapper - *Lutjanus analis*
Lane snapper- *Lutjanus synagris*
Cubera snapper -*Lutjanus cyanopterus*
Dog snapper - *Lutjanus jocu*
Schoolmaster - *Lutjanus apodus*
Mahogany snapper - *Lutjanus mahogoni*
Vermilion snapper - *Rhomboplites aurorubens*
Red snapper - *Lutjanus campechanus*
Silk snapper -*Lutjanus vivanus*
Blackfin snapper - *Lutjanus buccanella*
Black snapper - *Apsilus dentatus*
Red porgy - *Pagrus pagrus*
Knobbed porgy - *Calamus nodosus*
Jolthead porgy - *Calamus bajonado*
Scup - *Stenotomus chrysops*
Whitebone porgy - *Calamus leucosteus*
Saucereye porgy - *Calamus calamus*
Longspine porgy - *Stenotomus caprinus*
White grunt - *Haemulon plumieri*
Margate - *Haemulon album*
Tomtate - *Haemulon aurolineatum*
Sailor's choice - *Haemulon parra*
Cottonwick - *Haemulon melanurum*
Greater amberjack - *Seriola dumerili*
Blue runner - *Caranx crysos*
Almaco jack - *Seriola rivoliana*
Banded rudderfish - *Seriola zonanta*
Bar jack - *Caranx ruber*
Lesser amberjack - *Seriola fasciata*
Tilefish - *Lopholatilus chamaeleonticeps*
Blueline tilefish - *Caulolatilus microps*
Sand tilefish- *Malacanthus plumier*
Gray triggerfish- *Balistes capriscus*
Ocean triggerfish - *Canthidermis sufflamen*
Hogfish - *Lachnolaimus maximus*
Atlantic Spadefish – *Chaetodipterus faber*


Fishery Management Plans
Habitat Based Fishery Management Plans
Coral, Coral Reef and Live Hard Bottom Habitat Fishery Management Plan
Pelagic Sargassum Habitat Fishery Management Plan
Sargassum fluitans
Sargassum natans


Status of Species in the Snapper -Grouper Complex
OVERFISHED: Red grouper, red porgy, red snapper, snowy grouper
OVERFISHING: black sea bass, red grouper, red snapper, snowy grouper, gag, speckled hind, Warsaw grouper


Essential Fish Habitat
The South Atlantic Fishery Management Council designates Essential Fish Habitat (EFH) and EFH Areas of Particular Concern (HAPCs) for Managed Species to address fishing and non-fishing impacts
EFH is defined as *"all waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity"*
EFH-HAPCs is as a subset of EFH where:
•Ecological function provided by the habitat is important;
•Habitat is sensitive to human-induced environmental degradation;
•Development activities are or will be stressing the habitat type; and
•Habitat type is rare


Snapper-Grouper Complex: EFH and HAPCs
EFH
•coral reefs,
• live/hardbottom,
• submerged aquatic vegetation,
• artificial reefs and medium to high profile outcroppings on and around the shelf break zone from shore to at least 183 meters [600 feet (but to at least 2,000 feet for wreckfish)] where the annual water temperature range is sufficiently warm to maintain adult populations of members of this largely tropical fish complex
• spawning area in the water column above the adult habitat and the additional pelagic environment, including *Sargassum*, required for survival of larvae and growth up to and including settlement
• *Gulf Stream*
EFH-HAPCs
•medium to high profile offshore hard bottoms where spawning normally occurs
•localities of known or likely periodic spawning aggregations
•nearshore hard bottom areas
•The Point, The Ten Fathom Ledge, and Big Rock (North Carolina)
• The Charleston Bump (South Carolina);
•mangrove habitat;
•seagrass habitat
•oyster/shell habitat
•all coastal inlets
•all state-designated nursery habitats of particular importance to snapper grouper (e.g., Primary and Secondary Nursery Areas designated in North Carolina)
•pelagic and benthic *Sargassum*
•Hoyt Hills for wreckfish
•Oculina Bank
•all hermatypic coral habitats and reefs
•manganese outcroppings on the Blake Plateau
•Council-designated Artificial Reef Special Management Zones
• Northern South Carolina MPA
• Snowy Grouper Wreck MPA
• Edisto MPA
• Charleston Deep Artificial Reef MPA
• Georgia MPA
• North Florida MPA
• St. Lucie Hump MPA
• East Hump MPA


Snapper-Grouper Complex: EFH and HAPCs
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• Georgia MPA
• North Florida MPA
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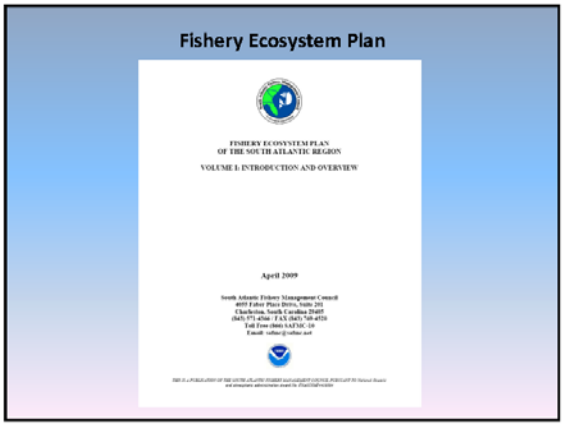
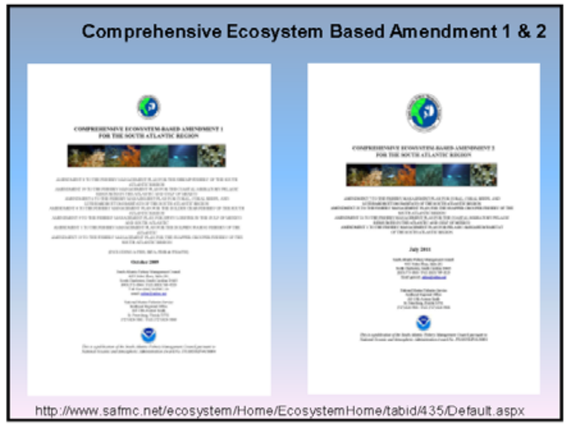
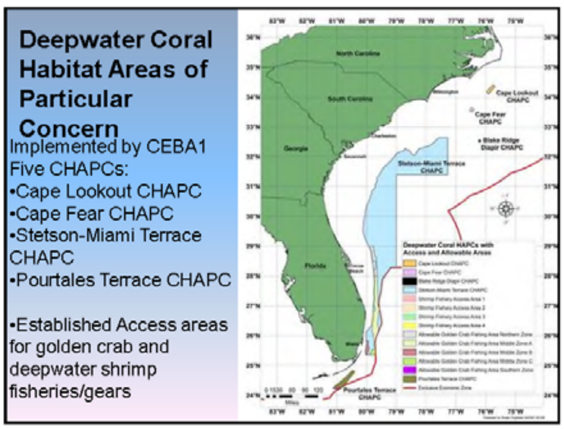
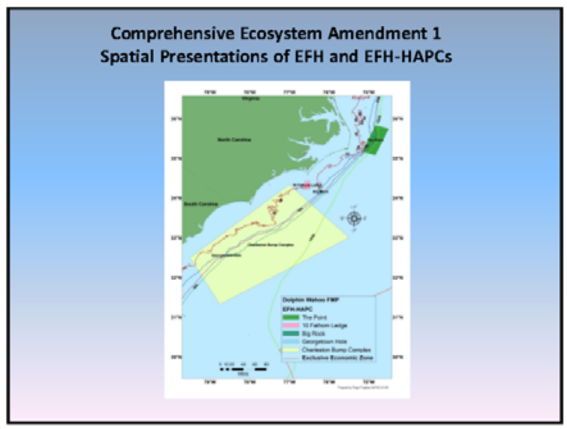
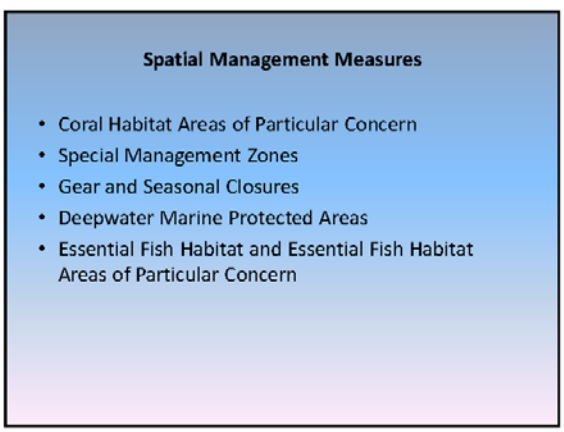
• East Hump MPA

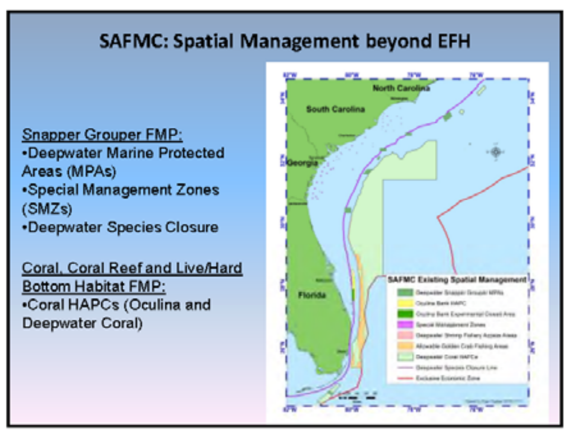

Fishery Ecosystem Plan


Comprehensive Ecosystem Based Amendment 1 & 2
http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx

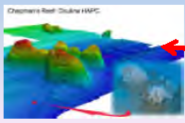

Deepwater Coral Habitat Areas of Particular Concern
Implemented by CEBA1
Five CHAPCs:
•Cape Lookout CHAPC
•Cape Fear CHAPC
•Stetson-Miami Terrace CHAPC
•Pourtales Terrace CHAPC
•Established Access areas for golden crab and deepwater shrimp fisheries/gears

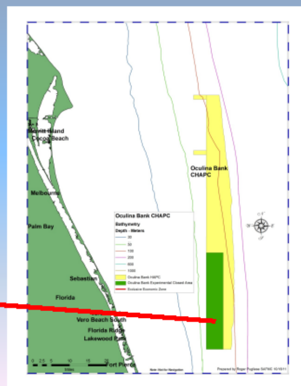

Comprehensive Ecosystem Amendment 1
Spatial Presentations of EFH and EFH-HAPCs


Spatial Management Measures
• Coral Habitat Areas of Particular Concern
• Special Management Zones
• Gear and Seasonal Closures
• Deepwater Marine Protected Areas
• Essential Fish Habitat and Essential Fish Habitat Areas of Particular Concern

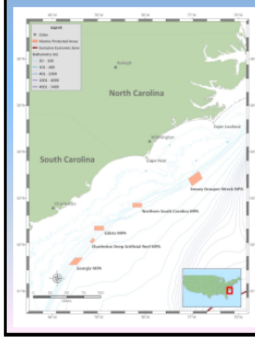

SAFMC: Spatial Management beyond EFH
Snapper Grouper FMP:
•Deepwater Marine Protected Areas (MPAs)
•Special Management Zones (SMZs)
•Deepwater Species Closure
Coral, Coral Reef and Live/Hard Bottom Habitat FMP:
•Coral HAPCs (Oculina and Deepwater Coral)

Oculina Bank Coral Habitat Area of Particular Concern





Deepwater Marine Protected Areas



Spatial presentation of EFH-HAPCs on the South Atlantic Habitat and Ecosystem Web Service

Development of Ecosystem Support Tools:

South Atlantic Habitat and Ecosystem Webpage

South Atlantic Habitat and Ecosystem Internet Map Server (IMS)

Transition to linked GIS Services for Regulations, Essential Fish Habitat, SA Fisheries, Ocean Energy and Ecospecies Data System as Part of a Digital Dashboard

- Developed in cooperation with Florida Fish and Wildlife Research Institute to support ecosystem-based resource management, habitat, species and ecosystem research, and regional collaboration
  - Web Services provide access to related GIS data
  - Ecosystem Section of the Website provides links to FEP and Digital Dashboard
  - Developing Ecospecies data system will provide online access to South Atlantic species life history data

SAFMC Habitat and Ecosystem IMS

- Since 2003, the Fish and Wildlife Research Institute (FWRI) has collaborated with SAFMC staff to compile, create and host GIS data of essential habitats in the South Atlantic ecosystem.
- The IMS was designed as a one-stop shop for managers, scientists and the public to explore marine resources of the South Atlantic region.

GIS Data Layers

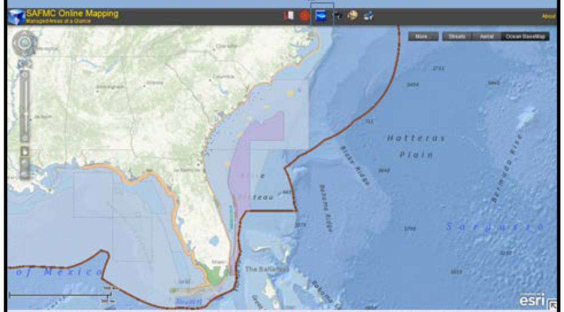
- **Base Map Layers** – Bathymetry, Marine Facilities, ATONS, Land Cover
- **Ocean Observing Systems -** National Data Buoys, SABSOON, CORMP
- **Coral Habitat Areas of Particular Concern (HAPCs)** – Oculina studies: Cleila and ROV dive tracks, multimbeam survey, proposed deep water lophelia CHAPCs
- **SAFMC Gear Restrictions –** Roller Rig Trawls, Bottom Longlines, Sargassum, Fish Traps, Black Sea Bass Pots
- **SAFMC Essential Fish Habitat and HAPCs -** Snapper Grouper, Shrimp, Red Drum, Spiny Lobster, Coastal Migratory Pelagics, Dolphin Wahoo, Coral, and Golden Crab
- **Management and Regulatory** – special management zones, marine protected areas, state waters, EEZ, sea turtle sanctuary, crab spawning sanctuary
- **Marine Sanctuaries** – habitat data for Gray's Reef and Florida Keys
- **Unique Habitats** – Right Whale Critical Habitat, Southeast US Restricted Area
- **General Habitats** – artificial reefs, fish nursery areas, seagrass, mangroves, salt marsh, tidal flats

SAFMC Map Services

- **Essential Fish Habitat (EFH)** – displays EFH and EFH-HAPCS for SAFMC managed species and NOAA Fisheries Highly Migratory Species.
- **Fisheries** - displays Marine Resources Monitoring, Assessment, and Prediction (MARMAP) and Southeast Area Monitoring and Assessment Program (SEAMAP) data .
- **Managed Areas**- displays a variety of regulatory boundaries (SAFMC and Federal) or management boundaries within SAFMC's jurisdiction.
- **Habitat*** – displays habitat data collected by SEADESC, Harbor Branch Oceanographic Institute (HBOI) and Ocean Exploration dives, as well as the SEAMAP shallow and ESDIM deepwater bottom mapping projects, multibeam imagery, and scientific cruise data.

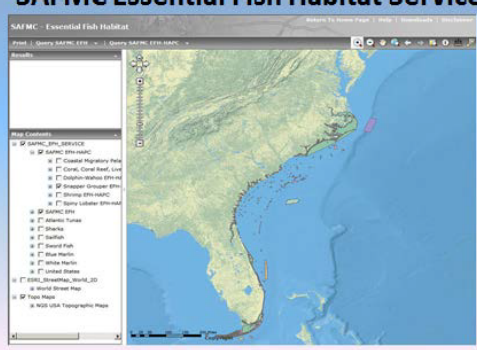
* Habitat service is forthcoming

SAFMC Managed Areas

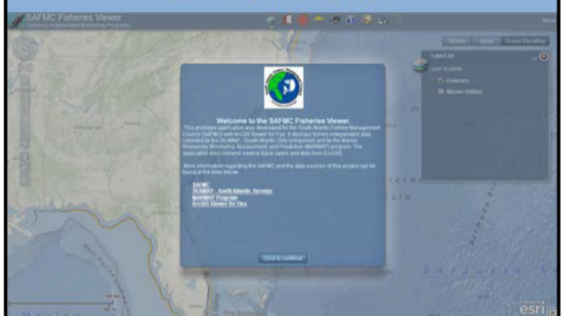


The graphic displays the initial view of the SAFMC Managed Areas viewer. Deepwater Coral HAPCs, Marine Protected Areas, Special Management Zones, and the Oculina CHAPC are visible.

SAFMC Essential Fish Habitat Service



SAFMC Fisheries



SAFMC Fisheries

- SEAMAP species data
  - Catch
  - length
- MARMAP species data
  - SAFMC Managed species
  - Other species
- MARMAP gear types
- focal species distributions
  - General area
  - Dominant area
  - Spawning area
- bathymetry
- boundaries for the continental shelf, US Federal State and US Territorial Seas.
- features custom query for SEAMAP species catch data for 2010

Prototype available at http://ocean.floridamarine.org/SA_Fisheries

South Atlantic Web Accessible Materials (SAFMC)

- Fishery Ecosystem Plan- (viewable and downloadable by Section)- http://www.safmc.net/ecosystem/Home/EcosystemHome/tabid/435/Default.aspx
- CEBA1 - http://www.safmc.net/Portals/6/Library/FMP/CE-BA1%20FINAL%20(Oct%202009).pdf
- Habitat and Ecosystem Internet Map Server - http://www.safmc.net/EcosystemManagement/EcosystemBoundaries/MappingandGISData/tabid/632/Default.aspx
- Managed Areas Web Service - http://ocean.floridamarine.org/safmc_managedareas/
- Essential Fish Habitat Web Service - http://ocean.floridamarine.org/sa_efh/
- Fisheries Web Service – http://ocean.floridamarine.org/sa_fisheries/
- Ocean Energy and Habitat Services – Under development
- Ecospecies online species life history data system- Under development
- Habitat and Ecosystem Digital Dashboard – Online June 2012

Regional Data Collection Efforts & Marine Planning Efforts: South Atlantic Alliance

Priority Issues:
- Healthy Ecosystems
- Working Waterfronts
- Clean Coastal and Ocean Waters
- Disaster-Resilient Communities
- Technical Teams Membership

Healthy Ecosystems Action Items, Sept. 2011

•Map known distributions of key estuarine/marine habitats/land use cover in each state: determine spatial extent (beach-out first), develop query template for states to capture all appropriate data elements, summarize, and identify common concerns.

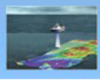
•Marine spatial plan for location of key coastal/marine resources and activities for multi-use management decisions: identify major activities (shipping lanes, artificial reefs, ocean disposal areas, sand borrow areas, military use, etc.), determine locations and what data exists, and determine common framework of mapping standards and how to bring data into portal.

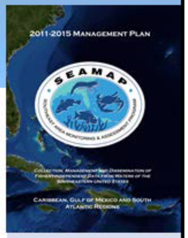
Governors' South Atlantic Alliance
North Carolina • South Carolina • Georgia • Florida

http://www.southatlanticalliance.org/

Regional Data Collection Efforts & Marine Planning Efforts:
Marine Resources Monitoring, Assessment and Prediction (MARMAP)
Southeast Area Monitoring and Assessment Program (SEAMAP)

Annual/Seasonal/Regional:
Species occurrence, species abundance, biomass
Life History
- Age and growth
- Maturity sex ratios (Diet, Genetics, toxins, etc.)
Hydrographic data
- Salinity, Temperature, Depth
- Weather and sea conditions
Fisheries Management
Stock Assessment
Genetics
-species identification
- species stock
Essential Fish Habitat
- bottom mapping
- nursery areas
Graduate student research
Systematics
Disease studies
Toxicology
Marine turtle monitoring



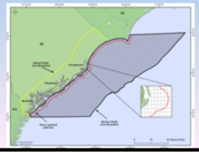


Regional Data Collection Efforts & Marine Planning Efforts:
South Carolina Roadmap to Gigawatt-Scale Coastal Clean Energy Generation: Transmission, Regulation & Demonstration.

SC Regulatory Task Force for Coastal Clean Energy Established
Geographic Information System compiled of resources and resource use from 30 miles inland to the 200 m depth contour offshore between the 32° and 34° latitudes

Resources: important fishery species, bottom fauna, sea turtle nesting and coastal juvenile distribution, bird nesting habitats and marine mammal distribution (right whales)

Resource use: military restriction zones, shipping activities and routes, sand borrow site locations, ocean disposal area locations, artificial reef zones, areas of commercial fishery activities based on landings, shipwrecks, and various jurisdictional boundaries such as (BOEMRE) lease blocks, state-federal boundary, etc.



Regional Data Collection Efforts & Marine Planning Efforts: Southeast Coastal Ocean Observing Regional Association (SECOORA)

Southeast Coastal Ocean Observing Regional Association (SECOORA) Build Out Plan

Submitted to NOAA IOOS

September 30, 2011

A Unique Region

The SECOORA region encompasses 4 states, over 42 million people and spans the coastal ocean from North Carolina to the west Coast of Florida. The region is vulnerable to hurricane hazards, potential impacts from oil drilling off Cuba and neighboring regions, and climate change because of low-lying coastal land and corals and other habitats that will be the first indicators of significant ecological impact. A regional observing system is critical to understanding risks and reducing impacts, as well as supporting the economy of the SE. SECOORA is creating customized products to address these thematic areas: Marine Operations; Coastal Hazards; Ecosystems, Water Quality, and Living Marine Resources; and Climate Change.

Figure 1 The SECOORA Footprint

The SECOORA region is linked through large-scale circulation patterns. The western boundary current (WBC) of the North Atlantic, comprised of the Loop Current/Florida Current/Gulf Stream system, interacts strongly with coastal waters, intimately coupling the SECOORA region to the global circulation. Changes in shelf width across the region and changes in circulation with time modulate the degree to which the deep ocean interacts with the nearshore environment but throughout the region shelf water properties reflect the WBC influence.

Data Needs

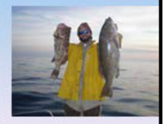
➢ Need for evaluation of competing ocean uses on fish, fish habitat (impacts on habitat, migration, spawning, foraging and on prey species) and on fishery operations and communities

➢ Need for enhanced species and oceanographic monitoring

➢ Need for pelagic/benthic habitat mapping and characterization where existing data is insufficient

➢ Focus on managed species and their prey (priority to address overfished species):
- •identify critical habitats and reproductive periods;
- •peaks in calling activity have been linked to reproductive behavior in many fish families;
- •passive acoustics as a tool to monitor fish presence and behavior

South Atlantic
Priority Habitats, Species, and Fisheries



Session Two: Priority Habitats, Species, and Fisheries: North Atlantic Fisheries and Habitat

Kevin Friedland, NMFS, Narragansett, RI

Topics that we feel would be useful to cover in this session include:

1. The status of the key fisheries in the area.
2. Status of important forage species.
3. Knowledge of ecological requirements of key fisheries and forage species; are there any (potentially) critical habitat areas?
4. Summary of issues affecting the fisheries, including emerging issues (e.g., global warming).
5. FINAL SLIDE REQUIREMENTS: In order for us to consistently collect key feedback on information gaps and data needs at the workshop, each speaker is asked to end their presentation with a slide (or slides) that includes the following:
   1. Presentation name
   2. Author and affiliation
   3. Bulleted list of information needs and data gaps related to your talk topic

Much of the information presented has not been formally disseminated by NOAA. It does not represent any final agency determination or policy. Do not cite without prior reference to the author.

1. The status of the key fisheries in the area
Stock Size and Fishing Levels for Northeast Shelf Species

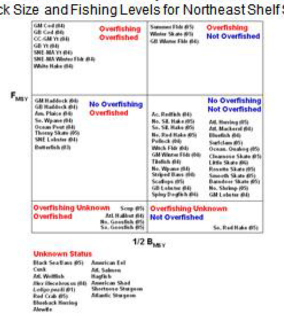
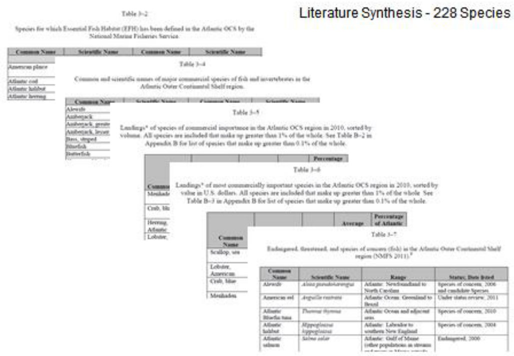
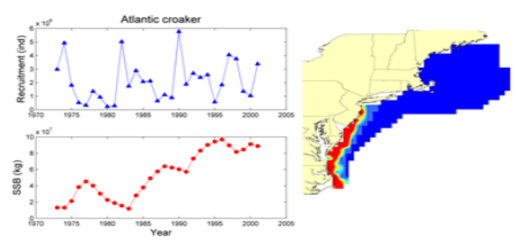


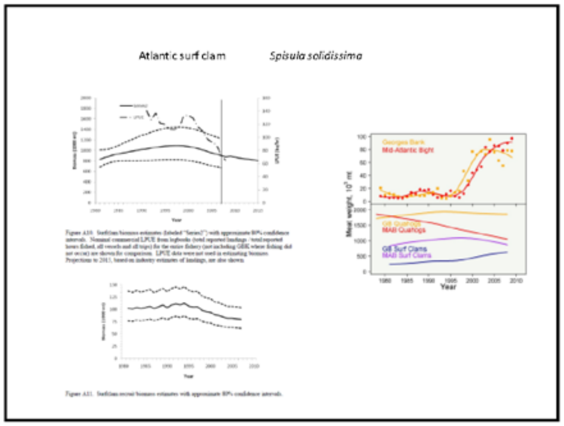
Figure 14. Summary of the status of 62 finfish and invertebrate stocks reviewed in this report. Stocks are classified by their relationship to biomass threshold (1/2 Bmsy) and fishing mortality threshold (Fmsy). The numbers in parentheses refer to the last year of data used for status determination.

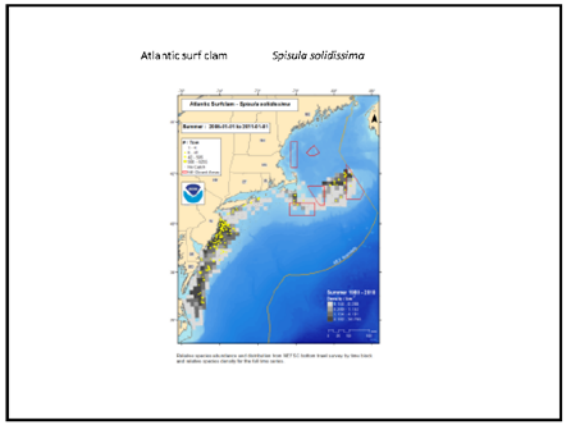


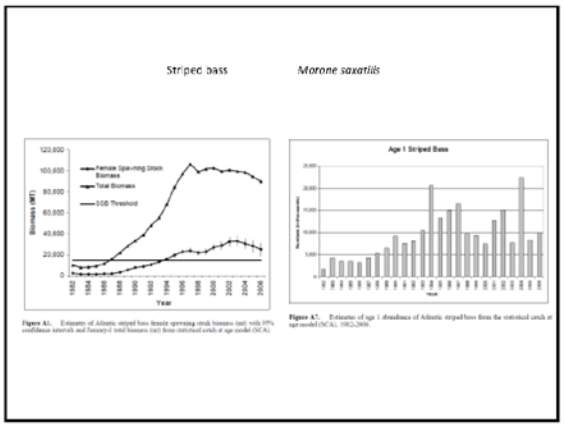
Common Name	Scientific Name	Assess	Map
American lobster	*Homarus americanus*	X	X
Atlantic cod	*Gadus morhua*	X	X
Atlantic croaker	*Micropogonias undulatus*	X	X
Atlantic herring	*Clupea harengus*	X	X
Atlantic mackerel	*Scomber scombrus*	X	X
Atlantic surf clam	*Spisula solidissima*	X	X
Blue crab	*Callinectes sapidus*	X	X
Eastern oyster	*Crassostrea virginica*	X	Des
Goosefish (monkfish)	*Lophius americanus*	X	X
Haddock	*Melanogrammus aeglefinus*	X	X
Longfin squid	*Loligo pealei*	X	X
Menhaden	*Brevoortia tyrannus*	X	X
Northern quahog	*Mercenaria mercenaria*	X	Des
Ocean quahog	*Arctica islandica*	X	X
Sea scallop	*Placopecten magellanicus*	X	X
Shortfin squid	*Ilex Illex illecebrosus*	X	X
Silver hake	*Merluccius bilinearis*	X	X
Softshell clam	*Mya arenaria*	-	Des
Striped bass	*Morone saxatilis*	X	X
Summer flounder	*Paralichthys dentatus*	X	X
White shrimp	*Litopenaeus setiferus*	-	Des

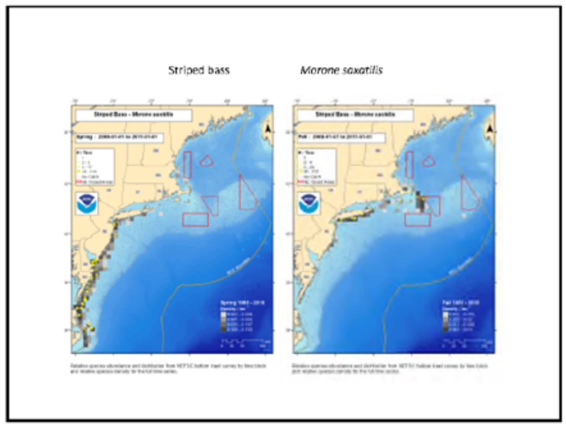
Atlantic croaker *Micropogonias undulatus*

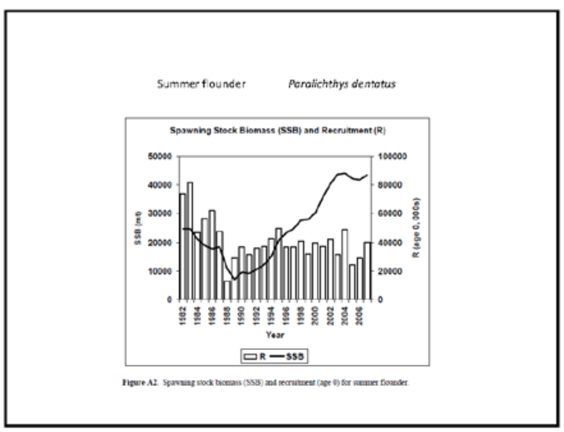


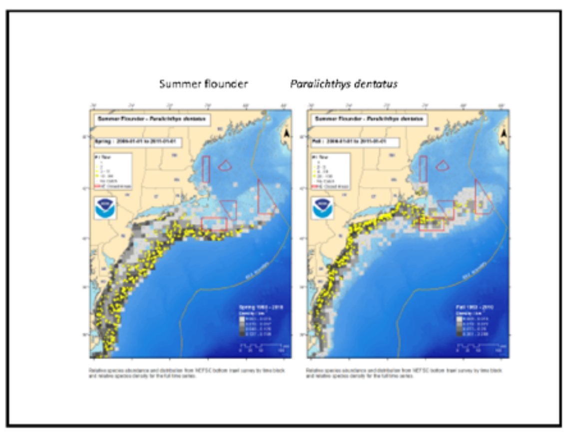

Atlantic surf clam
Spisula solidissima
Georges Bank
Mid-Atlantic Bight
GB Quahogs
MAB Quahogs
GB Surf Clams
MAB Surf Clams
Mean weight, 10³ mt
Year


Atlantic surf clam
Spisula solidissima


Striped bass
Morone saxatilis
Female Spawning Stock Biomass
Total Biomass
SSB Threshold
Biomass (MT)
Year
Age 1 Striped Bass


Striped bass
Morone saxatilis

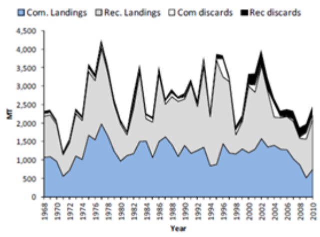

Summer flounder
Paralichthys dentatus
Spawning Stock Biomass (SSB) and Recruitment (R)
SSB (mt)
R (age 0, 000s)
Year
R
SSB
Figure A2. Spawning stock biomass (SSB) and recruitment (age 0) for summer flounder


Summer flounder
Paralichthys dentatus

Common Name	Scientific Name	Assess	Map
Acadian Redfish	*Sebastes fasciatus*		X
Alewife*	*Alosa pseudoharengus*	X	X
American Eel	*Anguilla rostrata*	X	X
American Plaice	*Hippoglossoides platessoides*	X	X
American Shad	*Alosa sapidissima*	X	X
Atlantic Hagfish	*Myxine glutinosa*	X	X
Atlantic Halibut*	*Hippoglossus hippoglossus*	X	X
Atlantic Wolffish*	*Anarhichas lupus*	X	X
Barndoor Skate	*Dipturus laevis*		X
Black Sea Bass	*Centropristis striata*	X	X
Blueback Herring*	*Alosa aestivalis*	X	X
Bluefish	*Pomatomus saltatrix*		X
Butterfish	*Peprilus triacanthus*	X	X
Clearnose Skate+	*Raja eglanteria*		X
Cusk*	*Brosme brosme*	X	X
Little Skate	*Leucoraja erinacea*		X
Northern Shrimp	*Pandalus borealis*		X
Ocean Pout+	*Macrozoarces americanus*	X	X
Offshore Hake	*Merluccius albidus*		X
Pollock	*Pollachius virens*		X
Red Deepsea Crab	*Geryon quinquedens*	X	X
Red Hake	*Urophycis chuss*		X
Rosette Skate	*Leucoraja garmani*		X
Scup	*Stenotomus chrysops*	X	X
Smooth Skate	*Malacoraja senta*		X
Spiny Dogfish	*Squalus acanthias*		X
Thorny Skate*	*Amblyraja radiata*	X	X
Tilefish	*Lopholatilus chamaeleonticeps*		X
White Hake	*Urophycis tenuis*	X	X
Windowpane+	*Scophthalmus aquosus*	X	X
Winter Flounder+	*Pseudopleuronectes americanus*	X	X
Winter Skate	*Leucoraja ocellata*		X
Witch Flounder	*Glyptocephalus cynoglossus*		X
Yellowtail Flounder	*Limanda ferruginea*	X	X

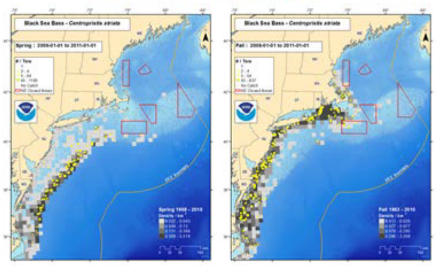
* ESA Species of concern
\+ EFH overlap

Black Sea Bass *Centropristis striata*



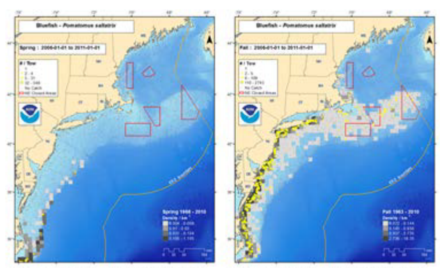
B1. Components of total black sea bass catch (mt) (Commercial and Recreational).

Black Sea Bass *Centropristis striata*



Relative species abundance and distribution from NEFSC bottom trawl survey by time block and relative species density for the full time series.

Bluefish *Pomatomus saltatrix*



Relative species abundance and distribution from NEFSC bottom trawl survey by time block and relative species density for the full time series.

Butterfish *Peprilus triacanthus*

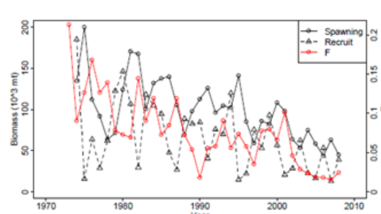
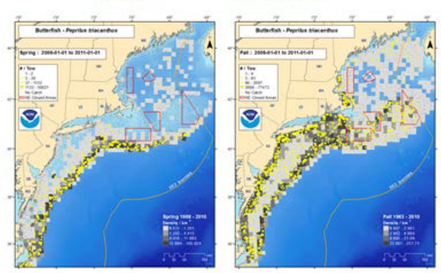
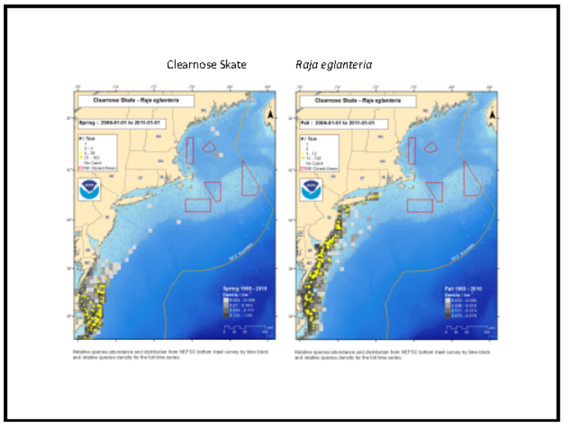


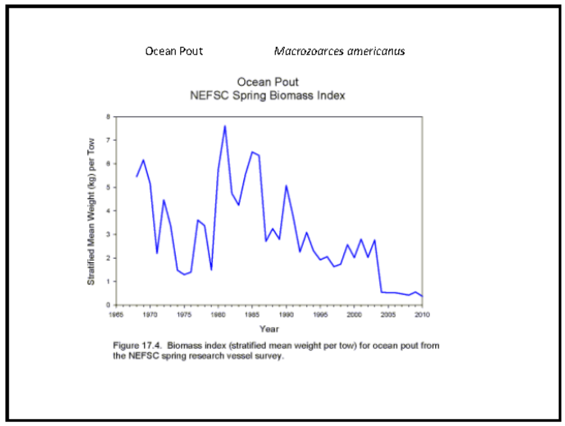
Figure B3. Butterfish spawning biomass, recruit biomass and fishing mortality estimates (KLAMZ model).

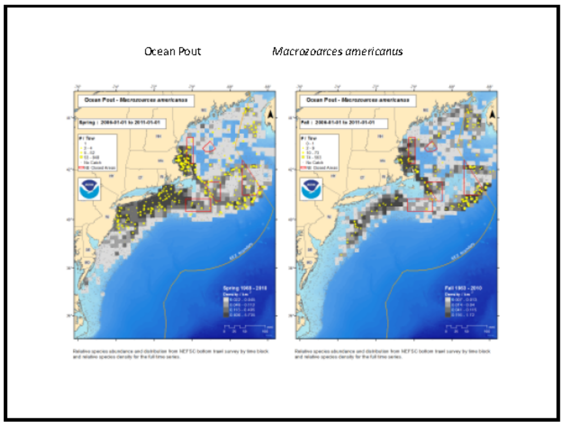
Butterfish *Peprilus triacanthus*

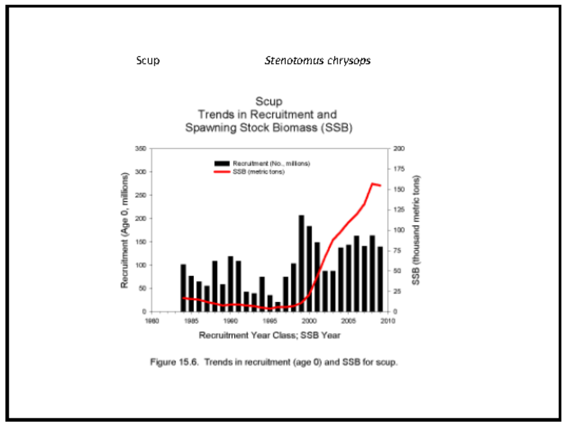


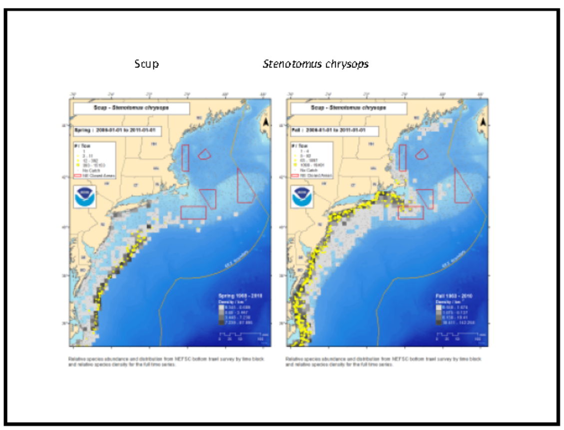
Relative species abundance and distribution from NEFSC bottom trawl survey by time block and relative species density for the full time series.

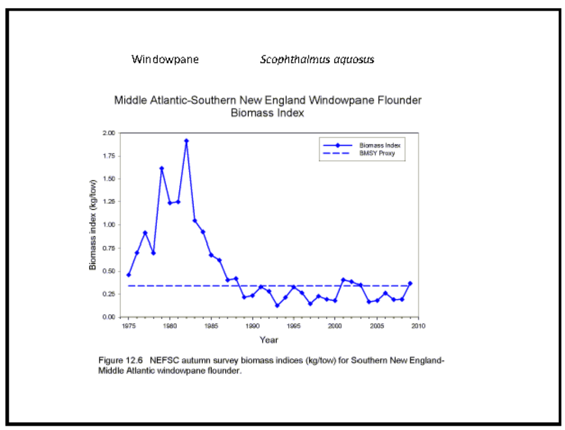

Clearnose Skate
Raja eglanteria


Ocean Pout
Macrozoarces americanus
Ocean Pout
NEFSC Spring Biomass Index
Stratified Mean Weight (kg) per Tow
Year
Figure 17.4. Biomass index (stratified mean weight per tow) for ocean pout from the NEFSC spring research vessel survey.

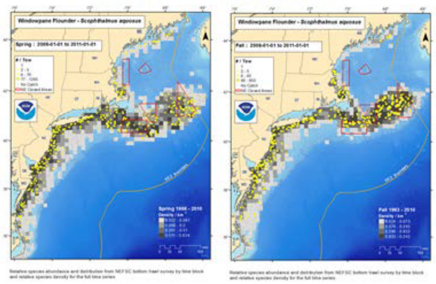

Ocean Pout
Macrozoarces americanus


Scup
Stenotomus chrysops
Scup
Trends in Recruitment and
Spawning Stock Biomass (SSB)
Recruitment (Age 0, millions)
SSB (thousand metric tons)
Recruitment Year Class; SSB Year
Figure 15.6. Trends in recruitment (age 0) and SSB for scup.


Scup
Stenotomus chrysops


Windowpane
Scophthalmus aquosus
Middle Atlantic-Southern New England Windowpane Flounder
Biomass Index
Biomass index (kg/tow)
Year
Figure 12.6 NEFSC autumn survey biomass indices (kg/tow) for Southern New England-Middle Atlantic windowpane flounder.

Windowpane *Scophthalmus aquosus*



Winter Flounder *Pseudopleuronectes americanus*

SNE-MA Winter Flounder
Trends in Recruitment and Spawning Stock Biomass

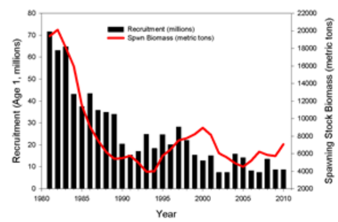
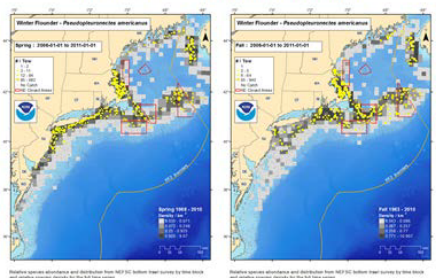


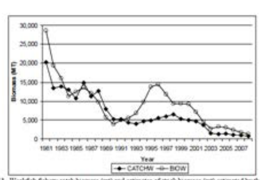
Figure 11.18. Trends in recruitment (age 1) and spawning stock biomass for SNE-MA winter flounder.

Winter Flounder *Pseudopleuronectes americanus*

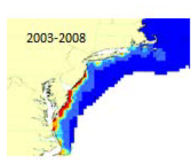


Common Name	Scientific Name	Assess	Map
Horseshoe Crab	*Limulus polyphemus*	X	Des
Red Drum	*Sciaenops ocellatus*	X	Des
Spanish Mackerel	*Scomberomorus maculatus*	X	Des
Spot	*Leiostomus xanthurus*	X	Des
Spotted Seatrout	*Cynoscion nebulosus*	X	Des
Tautog	*Tautoga onitis*	X	Des
Weakfish	*Cynoscion regalis*	X	X

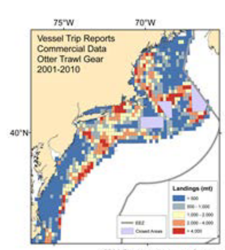
Weakfish *Cynoscion regalis*

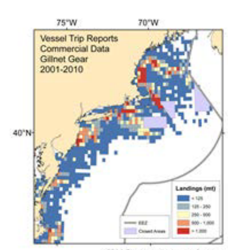


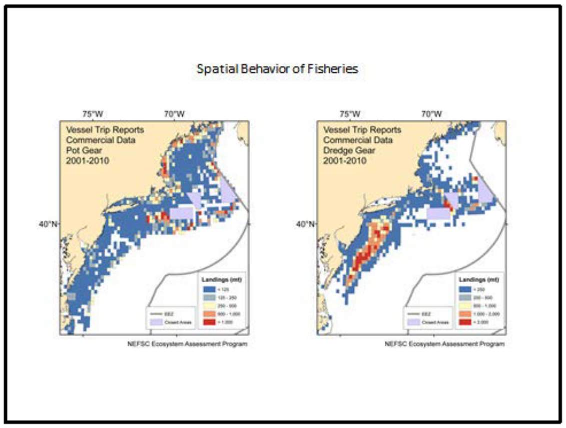
C3. Weakfish fishery catch biomass (mt) and estimates of stock biomass (mt) estimated by the SARC48 approved, 'index-based' approach. Recent biomass is well below the current estimate of SSB20% (10,179 mt) which the SARC felt could be used as an interim biomass threshold until a future assessment.

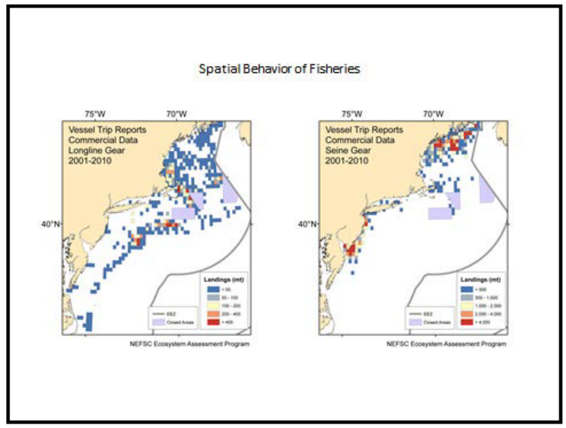


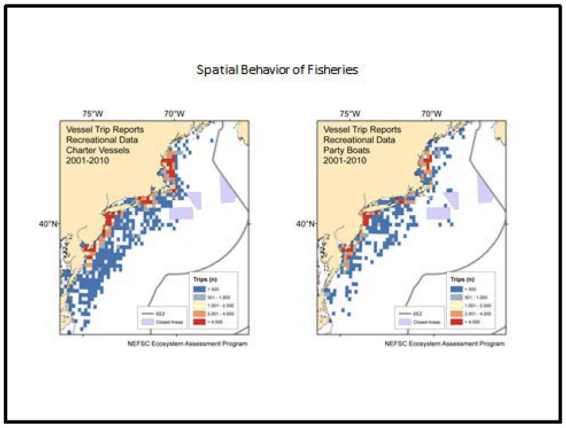
Spatial Behavior of Fisheries

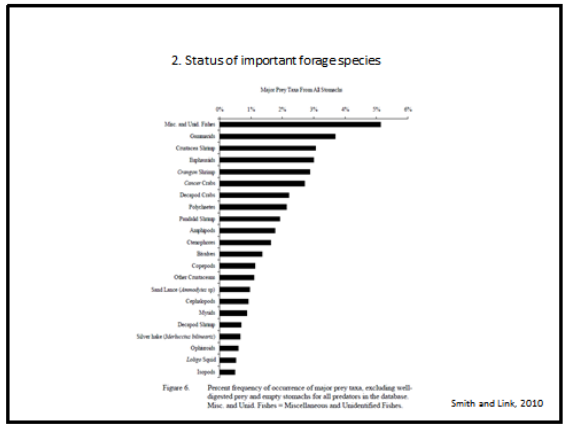


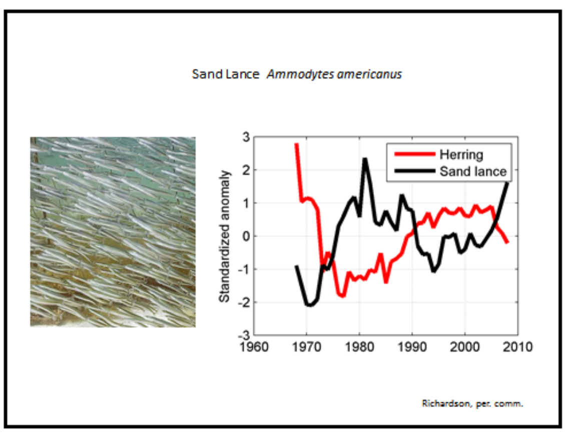


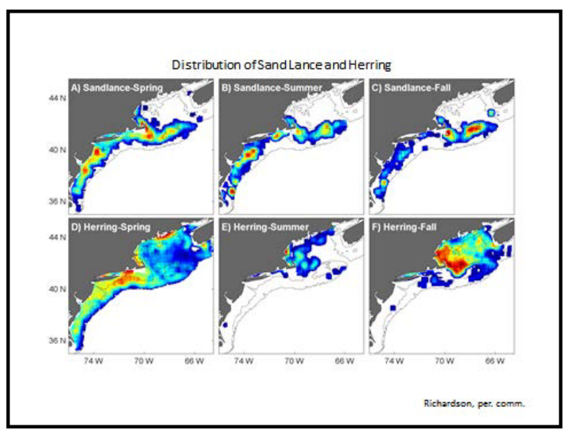

Spatial Behavior of Fisheries
Vessel Trip Reports
Commercial Data
Pot Gear
2001-2010
Vessel Trip Reports
Commercial Data
Dredge Gear
2001-2010
75°W
70°W
40°N
NEFSC Ecosystem Assessment Program

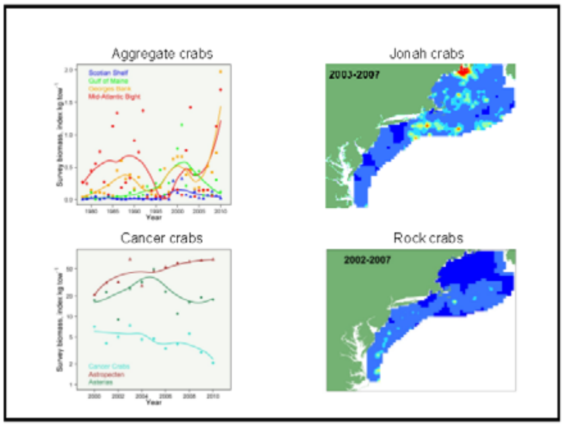

Spatial Behavior of Fisheries
Vessel Trip Reports
Commercial Data
Longline Gear
2001-2010
Vessel Trip Reports
Commercial Data
Seine Gear
2001-2010
75°W
70°W
40°N
NEFSC Ecosystem Assessment Program

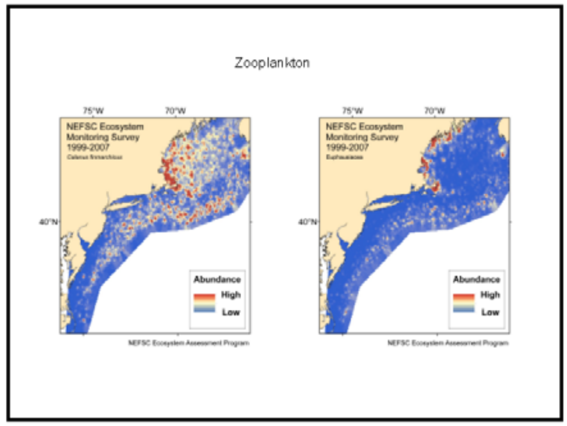

Spatial Behavior of Fisheries
Vessel Trip Reports
Recreational Data
Charter Vessels
2001-2010
Vessel Trip Reports
Recreational Data
Party Boats
2001-2010
75°W
70°W
40°N
NEFSC Ecosystem Assessment Program

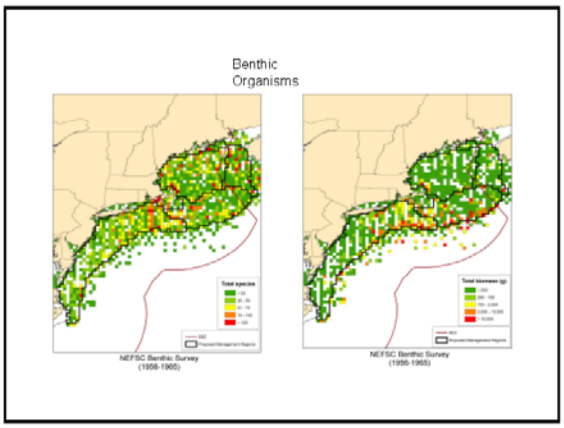

2. Status of important forage species
Smith and Link, 2010

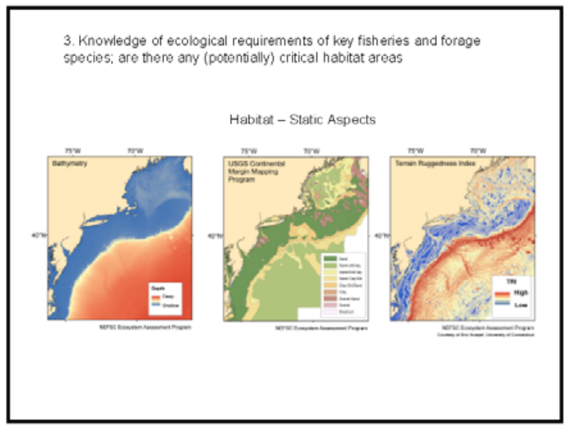

Sand Lance *Ammodytes americanus*
Herring
Sand lance
Standardized anomaly
3
2
1
0
-1
-2
-3
1960
1970
1980
1990
2000
2010
Richardson, per. comm.

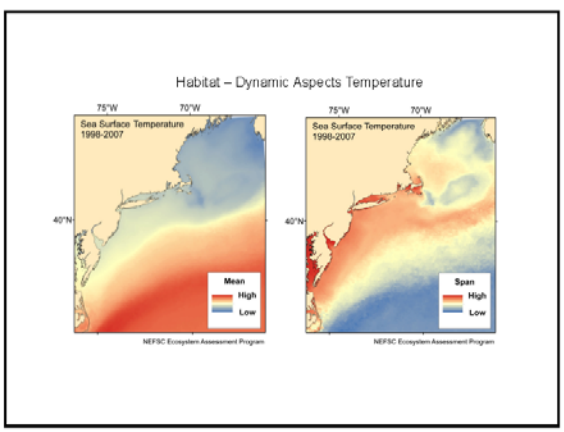

Distribution of Sand Lance and Herring
A) Sandlance-Spring
B) Sandlance-Summer
C) Sandlance-Fall
D) Herring-Spring
E) Herring-Summer
F) Herring-Fall
44 N
40 N
36 N
74 W
70 W
66 W
Richardson, per. comm.

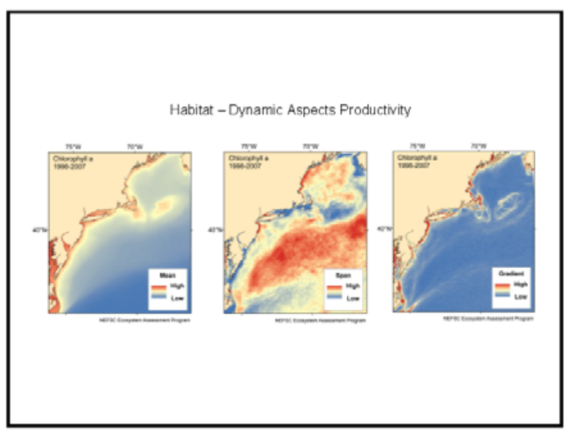

Aggregate crabs
Jonah crabs
2003-2007
Cancer crabs
Rock crabs
2002-2007


Zooplankton
NEFSC Ecosystem Monitoring Survey 1999-2007
Abundance
High
Low
NEFSC Ecosystem Assessment Program


Benthic
Organisms
NEFSC Benthic Survey
(1956-1965)


3. Knowledge of ecological requirements of key fisheries and forage species; are there any (potentially) critical habitat areas
Habitat – Static Aspects


Habitat – Dynamic Aspects Temperature
Sea Surface Temperature 1998-2007
Mean
Span
High
Low
NEFSC Ecosystem Assessment Program


Habitat – Dynamic Aspects Productivity

List of Endangered and Threatened Species under the jurisdiction of NOAA Fisheries Service Northeast Region (Maine-Virginia)

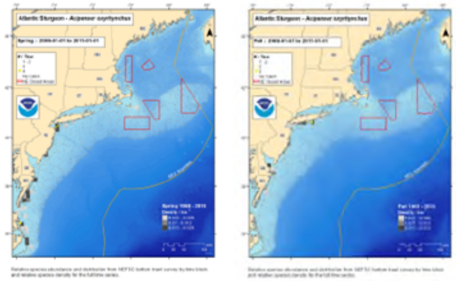
Species	Year Listed	Status
FISH		
Atlantic Salmon (*Salmo salar*) (Gulf of Maine DPS)	(2000) 2009*	E
Shortnose Sturgeon (*Acipenser brevirostrum*)	1967	E
Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*)	2012	E/T**
MARINE MAMMALS		
Fin Whale (*Balaenoptera physalus*)	1970	E
Humpback Whale (*Megaptera novaeangliae*)	1970	E
North Atlantic Right Whale (*Eubalaena glacialis*)	(1970) 2008***	E
Sei Whale (*Balaenoptera borealis*)	1970	E
MARINE TURTLES		
Green Turtle (*Chelonia mydas*)	1978	E/T****
Hawksbill Turtle (*Eretmochelys imbricata*)	1970	E
Kemp's Ridley Turtle (*Lepidochelys kempii*)	1970	E
Leatherback Turtle (*Dermochelys coriacea*)	1970	E
Loggerhead Turtle (*Caretta caretta*)	(1978) 2011	E/T*****

E – Endangered T – Threatened

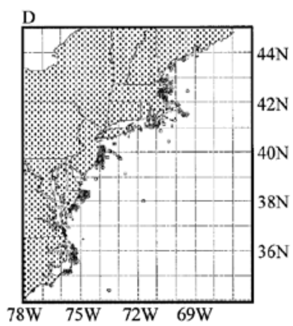
Species of Concern

Common Name	Scientific Name
Atlantic Bluefin Tuna	*Thunnus thynnus*
Dusky Shark	*Carcharhinus obscurus*
Porbeagle Shark	*Lamna nasus*
Rainbow Smelt	*Osmerus mordax*

Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus*

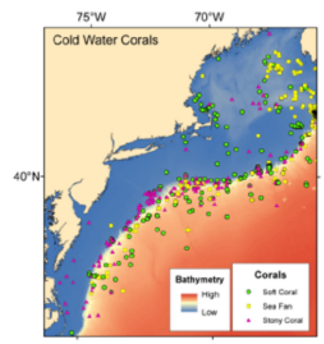


Atlantic sturgeon *Acipenser oxyrinchus oxyrinchus*



Stein et al. 2004

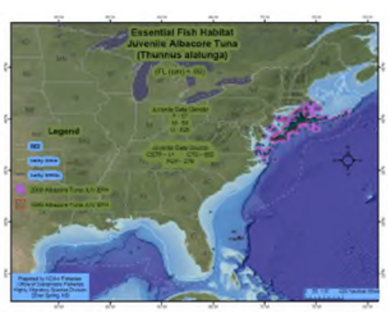
Deep Water Corals



NEFSC Ecosystem Assessment Program

Common Name	Scientific Name	EFH Overlap
Albacore tuna	*Thunnus alalunga*	X
Atlantic bluefin tuna	*Thunnus thynnus*	X
Bigeye tuna	*Thunnus obesus*	
Longbill spearfish	*Tetrapturus pfluegeri*	
Roundscale spearfish	*Tetrapturus georgii*	
Skipjack tuna	*Katsuwonus pelamis*	X
Swordfish	*Xiphias gladius*	
White Marlin	*Tetrapturus albidus*	
Yellowfin tuna	*Thunnus albacares*	

Atlantic Albacore Tuna *Thunnus alalunga*



Atlantic Bluefin Tuna *Thunnus thynnus*

Stein et al. 2004

Atlantic Skipjack Tuna *Katsuwonus pelamis*

Common Name	Scientific Name	EFH Overlap
Basking shark	*Cetorhinus maximus*	X
Bigeye thresher	*Alopias superciliosus*	
Blue shark	*Prionace glauca*	X
Common thresher	*Alopias vulpinus*	X
Dusky shark	*Carcharhinus obscurus*	X
Longfin mako shark	*Isurus paucus*	
Porbeagle	*Lamna nasus*	
Sand tiger shark	*Carcharias taurus*	X
Sandbar shark	*Carcharhinus plumbeus*	X
Scalloped hammerhead	*Sphyrna lewini*	X
Shortfin mako shark	*Isurus oxyrinchus*	
Silky shark	*Carcharhinus falciformis*	
Smooth dogfish	*Mustelus canis*	X
Tiger shark	*Galeocerdo cuvier*	X
Great white shark	*Carcharodon carcharias*	X

Sandbar Shark (coastal sharks) *Carcharhinus plumbeus*

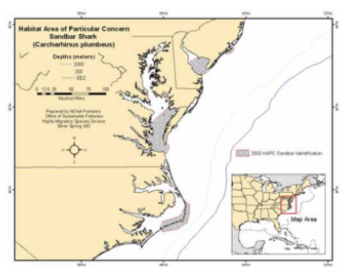


Figure 1.4.3.1.13d. Habitat Areas of Particular Concern for sandbar shark

Blue Shark (pelagic sharks) *Prionace glauca*

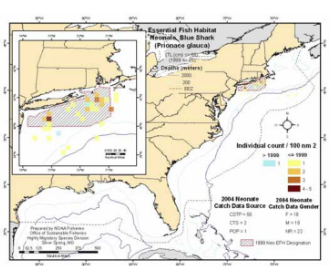
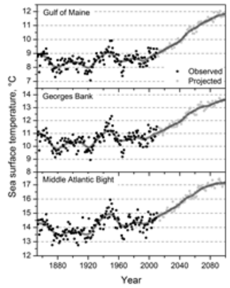


Figure 1.4.3.1.26a. Essential fish habitat for neonate blue shark

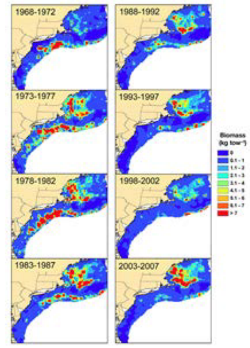
4. Summary of issues affecting the fisheries, including emerging issues (e.g., global warming).

Change in the thermal habitats
Plankton community shift
Habitat impacts of fishing
Eutrophication
Sea level rise
Wind
Precipitation
Phenological Effects
Extreme Weather Events
Thermohaline Circulation
Carbon Dioxide Concentration

Time series of sea surface temperatures in eco-regions of the Northeast Shelf Large Marine Ecosystem with projected temperature based on an ensemble of climate projection models.

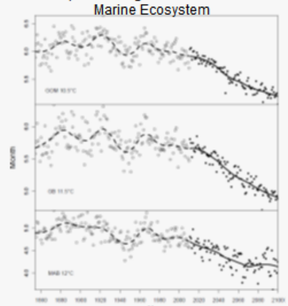


Change in Distribution – Red Hake



Nye et al. 2009

Date of arrival spring transition sea surface temperature (in fractional months) for eco-regions of the Northeast Shelf Large Marine Ecosystem



FINAL SLIDE

1. Presentation name: **North Atlantic Fisheries and Habitat**
2. Kevin Friedland, NMFS, Narragansett, RI
3. Bulleted list of information needs and data gaps:

- NEFSC data serving outside the firewall for maintained datasets.
- Continuation of ECOMON cruises providing a platform for mammal and bird surveys.
- Refinement of essential fish habitat definition and information on fine scale movements of pelagic/coastal species.
- Assessment of community change with the addition of fixed structures.

Acknowledgements: C. Keith, J. Nye, S. Lucey, R. Gamble, M. Fogarty, N. Kohler, C. McCandless, J. Hoey, R. Langton, D. Packer

Resources:

NEFSC Fish and Fisheries information
http://www.nefsc.noaa.gov/rcb/fish/

NEFSC Data Web-serving and Google Ocean Interface Developmental

Essential Fish Habitat Mapper
http://sharpfin.nmfs.noaa.gov/website/EFH_Mapper/map.aspx

Atlantic Highly Migratory Species
http://www.nmfs.noaa.gov/sfa/hms/EFH/index.htm

TNO innovation for life

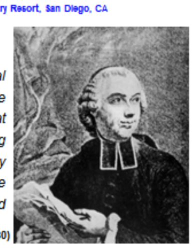
Terminology for Underwater Sound

M A Ainslie

Effects of Noise on Fish, Fisheries, and Invertebrates: A BOEM Workshop on Data Gaps and Research Needs, 20-22 March 2012, Town and Country Resort, San Diego, CA

Every science requires a special language because every science has its own ideas. It seems that one ought to begin by composing this language, but people begin by speaking and writing and the language remains to be composed

Étienne Bonnot de Condillac (1715-1780)



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Overview

- Objective and examples
- Properties of sound
  - Fundamental properties
  - Terminology of underwater sound
  - Logarithmic measures
  - Terminology of radiated sound (source properties)
- Summary and conclusion
- 'Information Needs and Data Gaps'

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Objective

- To introduce, explain and demystify terminology of underwater sound, with particular attention to sound radiated by air guns, shipping vessels, chemical explosions and impact pile driving

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Some acoustical terminology used in regulation

- Fisheries Hydroacoustic Working Group (FHWG) 2008
  - Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities
  - "The agreed upon criteria identify sound pressure levels of 206 dB peak and 187 dB accumulated sound exposure level (SEL) for all listed fish except those that are less than 2 grams. In that case, the criteria for the accumulated SEL will be 183 dB"

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Some acoustical terminology used in a "randomly chosen" publication*

Ambient noise, p4	Peak source level, p43
Background noise, p4	Peak SPL, p85
Mean peak level, p68	Sound exposure level, p51, 69
Mean sound pressure, p80	Sound pressure, p48
Particle acceleration, p48	Sound pressure level, p45
Particle displacement, p48	Source level, p37, 47, 67
Particle velocity, p48	Source peak-to-peak sound pressure level, p37
Peak level, p69	
Peak pressure, p44, 81	

*Normandeau Associates, Inc. 2012. Effects of Noise on Fish, Fisheries, and Invertebrates in the U.S. Atlantic and Arctic from Energy Industry Sound-Generating Activities. A Literature Synthesis for the U.S. Dept. of the Interior, Bureau of Ocean Energy Management.

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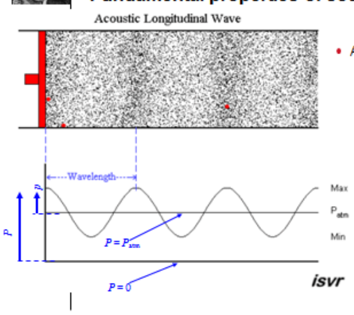
Fundamental properties of sound



- Acoustic particles

- Sound pressure $p(t)$
  - $p(t) = P(t) - P_{atm}$
  - Main focus
- Acoustic particle motion:
  - Displacement $\mathbf{x}$
  - Velocity $\mathbf{u} = d\mathbf{x}/dt$
  - Acceleration $\mathbf{a} = d\mathbf{u}/dt$

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Terminology of underwater sound

- Sound exposure E

$$E(T) \equiv \int_0^T p(t)^2 dt$$

T = integration time

- Mean square sound pressure Q

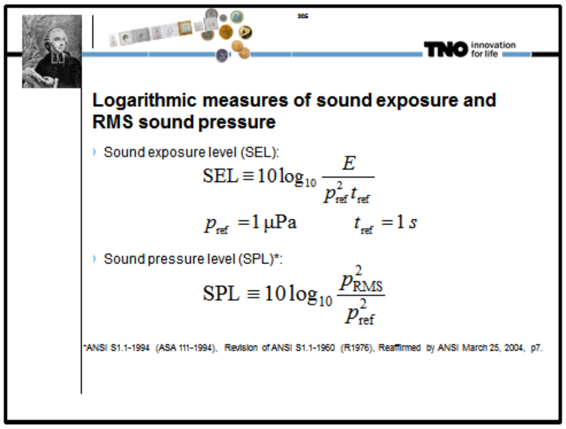
$$Q \equiv \frac{E(T)}{T} = \frac{1}{T}\int_0^T p(t)^2 dt$$

T = averaging time

- Root mean square (RMS) sound pressure p_{RMS}

$$p_{RMS} \equiv \sqrt{Q} = \sqrt{\frac{1}{T}\int_0^T p(t)^2 dt}$$

T = averaging time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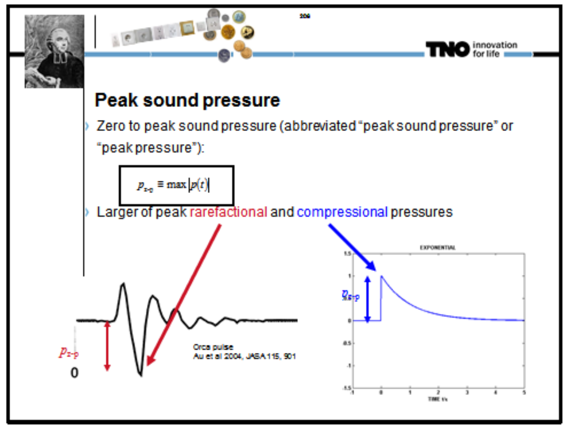
Logarithmic measures of sound exposure and RMS sound pressure
Sound exposure level (SEL):
$\mathrm{SEL} \equiv 10\log_{10}\frac{E}{p_{\mathrm{ref}}^2 t_{\mathrm{ref}}}$
$p_{\mathrm{ref}} = 1\,\mu\mathrm{Pa}$ $t_{\mathrm{ref}} = 1\,s$
Sound pressure level (SPL)*:
$\mathrm{SPL} \equiv 10\log_{10}\frac{p_{\mathrm{RMS}}^2}{p_{\mathrm{ref}}^2}$
*ANSI S1.1-1994 (ASA 111-1994), Revision of ANSI S1.1-1960 (R1976), Reaffirmed by ANSI March 25, 2004, p7.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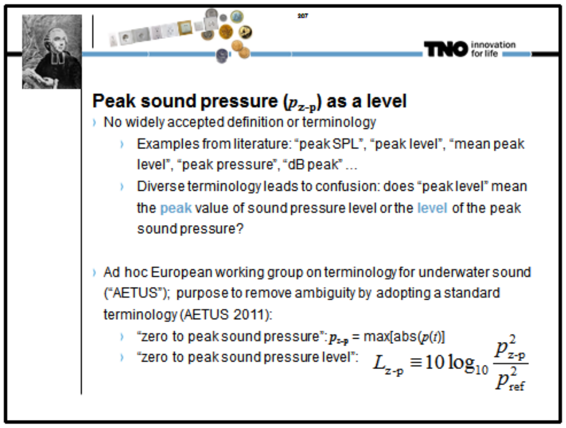
Peak sound pressure
Zero to peak sound pressure (abbreviated "peak sound pressure" or "peak pressure"):
$p_{z\text{-}p} \equiv \max|p(t)|$
Larger of peak rarefactional and compressional pressures
$p_{z\text{-}p}$
0
Orca pulse
Au et al 2004, JASA 115, 901
EXPONENTIAL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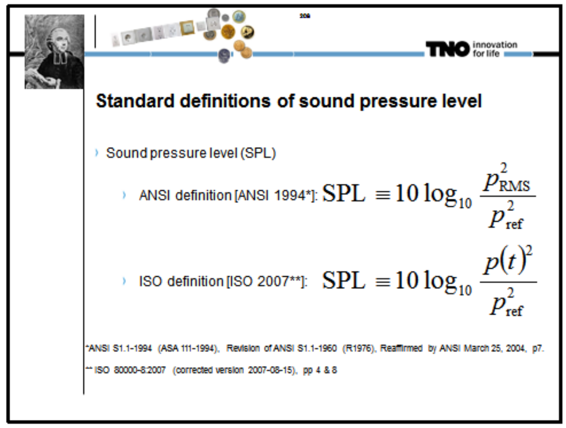
Peak sound pressure ($p_{z\text{-}p}$) as a level
No widely accepted definition or terminology
Examples from literature: "peak SPL", "peak level", "mean peak level", "peak pressure", "dB peak" ...
Diverse terminology leads to confusion: does "peak level" mean the peak value of sound pressure level or the level of the peak sound pressure?
Ad hoc European working group on terminology for underwater sound ("AETUS"); purpose to remove ambiguity by adopting a standard terminology (AETUS 2011):
"zero to peak sound pressure": $p_{z\text{-}p}$ = max[abs($p(t)$)]
"zero to peak sound pressure level": $L_{z\text{-}p} \equiv 10\log_{10}\frac{p_{z\text{-}p}^2}{p_{\mathrm{ref}}^2}$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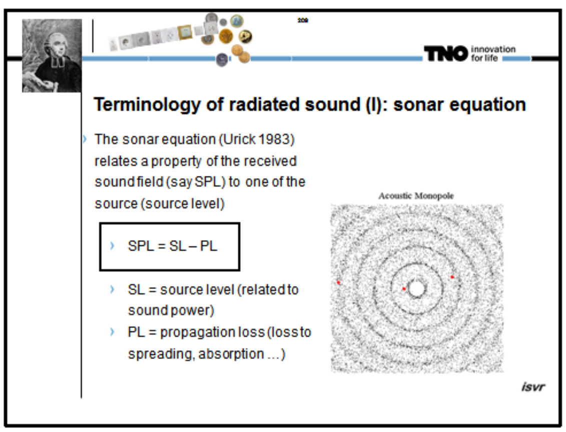
Standard definitions of sound pressure level
Sound pressure level (SPL)
ANSI definition [ANSI 1994*]: $\mathrm{SPL} \equiv 10\log_{10}\frac{p_{\mathrm{RMS}}^2}{p_{\mathrm{ref}}^2}$
ISO definition [ISO 2007**]: $\mathrm{SPL} \equiv 10\log_{10}\frac{\overline{p(t)^2}}{p_{\mathrm{ref}}^2}$
*ANSI S1.1-1994 (ASA 111-1994), Revision of ANSI S1.1-1960 (R1976), Reaffirmed by ANSI March 25, 2004, p7.
** ISO 80000-8:2007 (corrected version 2007-08-15), pp 4 & 8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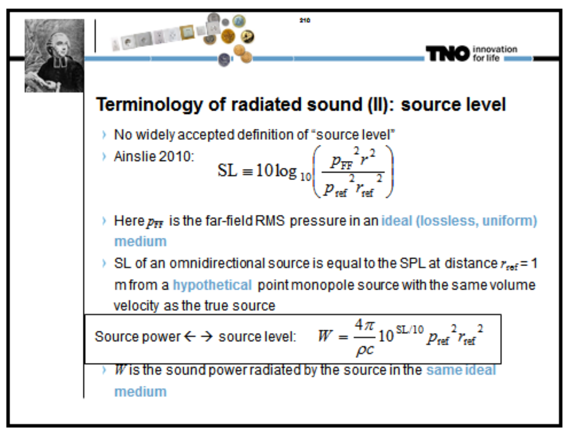
Terminology of radiated sound (I): sonar equation
The sonar equation (Urick 1983) relates a property of the received sound field (say SPL) to one of the source (source level)
SPL = SL – PL
SL = source level (related to sound power)
PL = propagation loss (loss to spreading, absorption ...)
Acoustic Monopole
isvr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Terminology of radiated sound (II): source level
No widely accepted definition of "source level"
Ainslie 2010: $\mathrm{SL} \equiv 10\log_{10}\left(\frac{p_{\mathrm{FF}}^2 r^2}{p_{\mathrm{ref}}^2 r_{\mathrm{ref}}^2}\right)$
Here p_{FF} is the far-field RMS pressure in an ideal (lossless, uniform) medium
SL of an omnidirectional source is equal to the SPL at distance r_{ref} = 1 m from a hypothetical point monopole source with the same volume velocity as the true source
Source power ←→ source level: $W = \frac{4\pi}{\rho c}10^{\mathrm{SL}/10} p_{\mathrm{ref}}^2 r_{\mathrm{ref}}^2$
W is the sound power radiated by the source in the same ideal medium

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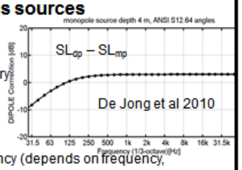
Source level (I): continuous sources

- Monopole source level (SL_{mp})
  - Source alone; far from boundary
- Dipole source level (SL_{dp})
  - Source + image
  - 3 dB higher at high frequency
  - Lower than SL_{mp} at low frequency (depends on frequency, source depth and elevation angle) [de Jong et al 2010]
- Radiated noise level: RNL(R) ≡ SPL(R) – 20 $\log_{10}(R)$
  - Similar to SL_{dp} at low frequency
  - Up to 5 dB lower than SL_{dp} at high frequency
  - Widely used (referred to in 'Literature Synthesis' as "source level")



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Source level (II): impulsive sources

- Energy source level: SL_E
  - Measure of energy
- Zero to peak source level: $SL_{z\text{-}p}$
  - Measure of zero to peak sound pressure in far field

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Source level (III): application to selected sources

- Impulsive sources
  - Explosives (non-linear source): monopole (energy) SL_E
  - Air guns: zero to peak source level (dipole, in vertical beam) $SL_{dp,z\text{-}p}$
  - Pile drivers: no definition available
- Continuous sources
  - Ships: SL_{mp} or SL_{dp}; or RNL
  - Wind turbines: no definition available

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Standard definitions of source level

- ANSI S1.1 (1994) R2004 "sonar source level"

  > *the sound pressure level on the axis of the sound projector at a reference distance of 1 meter from [a specified point associated with] the projector*

  ☒
- No mention of
  - Far field
  - Required scaling to reference distance
- ISO 9875:2000 "source level"

  > *maximum root mean square (r.m.s.) sound pressure level at a point on the principal axis of the transducer, as measured in the far field but referred to the distance of 1 m*

  ☑
- Correct (consistent with Urick 1983, Ainslie 2010), but vague
  - What is meant by "referred to … 1 m"?

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FHWG Agreement in Principle revisited

- Lack of terminology standard creates ambiguities in interpretation:
  - What is meant by "sound pressure levels of 206 dB peak"?
  - Proposed interpretation: "zero to peak sound pressure level of 206 dB re 1 µPa"
- Acceptance of this proposal would imply:

  > The agreed upon criteria identify risk thresholds of zero to peak sound pressure level equal to 206 dB re 1 µPa and cumulative unweighted sound exposure level (SEL) equal to 187 dB re 1 µPa² s for all listed fish except those that are less than 2 grams. In that case, the threshold for the cumulative SEL will be 183 dB

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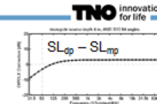
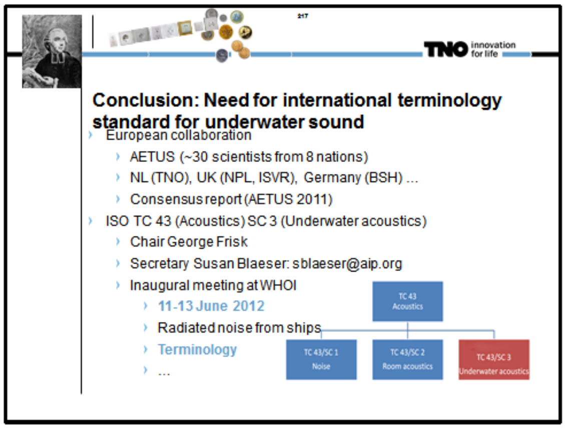
Summary



- Absence of widely accepted terminology leads to risk of confusion
  - Source level (apples and pears), for example:
    - Surface ships: difference between SL_{mp} and SL_{dp} up to 9 dB at 30 Hz (4 m depth)
    - Conceptual difference between source level and SPL @ 1 m
  - Sound pressure level
    - Inconsistency between ANSI (RMS) and ISO (inst.)
  - Peak sound pressure:
    - Positive (compressional) peak or negative (rarefactional) peak?
    - How to express in decibels?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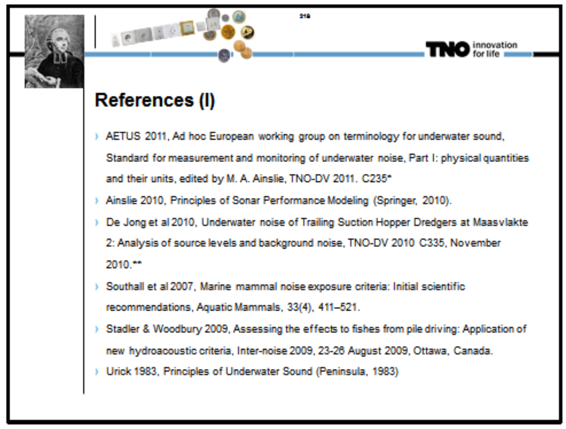
Conclusion: Need for international terminology standard for underwater sound
European collaboration
AETUS (~30 scientists from 8 nations)
NL (TNO), UK (NPL, ISVR), Germany (BSH) ...
Consensus report (AETUS 2011)
ISO TC 43 (Acoustics) SC 3 (Underwater acoustics)
Chair George Frisk
Secretary Susan Blaeser: sblaeser@aip.org
Inaugural meeting at WHOI
11-13 June 2012
Radiated noise from ships
Terminology
...
TC 43 Acoustics
TC 43/SC 1 Noise
TC 43/SC 2 Room acoustics
TC 43/SC 3 Underwater acoustics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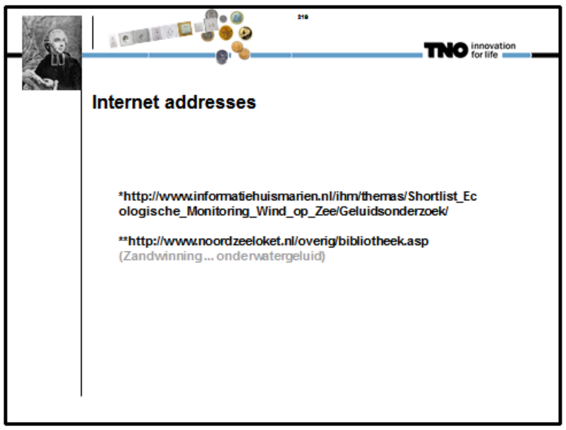
References (I)
AETUS 2011, Ad hoc European working group on terminology for underwater sound, Standard for measurement and monitoring of underwater noise, Part I: physical quantities and their units, edited by M. A. Ainslie, TNO-DV 2011. C235*
Ainslie 2010, Principles of Sonar Performance Modeling (Springer, 2010).
De Jong et al 2010, Underwater noise of Trailing Suction Hopper Dredgers at Maasvlakte 2: Analysis of source levels and background noise, TNO-DV 2010 C335, November 2010.**
Southall et al 2007, Marine mammal noise exposure criteria: Initial scientific recommendations, Aquatic Mammals, 33(4), 411–521.
Stadler & Woodbury 2009, Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria, Inter-noise 2009, 23-26 August 2009, Ottawa, Canada.
Urick 1983, Principles of Underwater Sound (Peninsula, 1983)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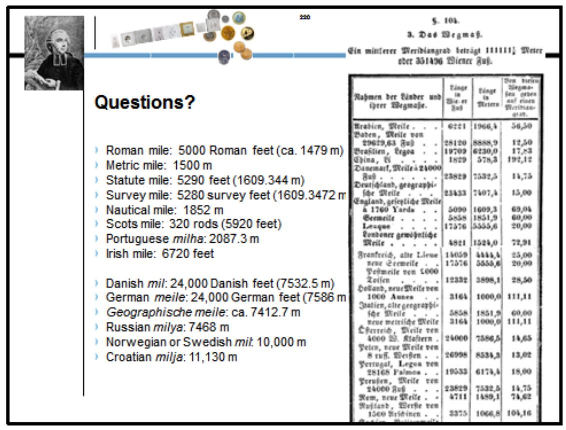
Internet addresses
*http://www.informatiehuismarien.nl/ihm/themas/Shortlist_Ecologische_Monitoring_Wind_op_Zee/Geluidsonderzoek/
**http://www.noordzeeloket.nl/overig/bibliotheek.asp
(Zandwinning ... onderwatergeluid)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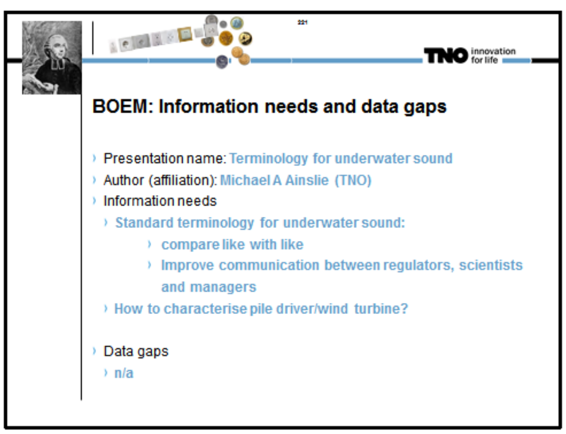
Questions?
Roman mile: 5000 Roman feet (ca. 1479 m)
Metric mile: 1500 m
Statute mile: 5280 feet (1609.344 m)
Survey mile: 5280 survey feet (1609.3472 m
Nautical mile: 1852 m
Scots mile: 320 rods (5920 feet)
Portuguese milha: 2087.3 m
Irish mile: 6720 feet
Danish mil: 24,000 Danish feet (7532.5 m)
German meile: 24,000 German feet (7586 m
Geographische meile: ca. 7412.7 m
Russian milya: 7468 m
Norwegian or Swedish mil: 10,000 m
Croatian milja: 11,130 m
§. 104.
3. Das Wegmaß.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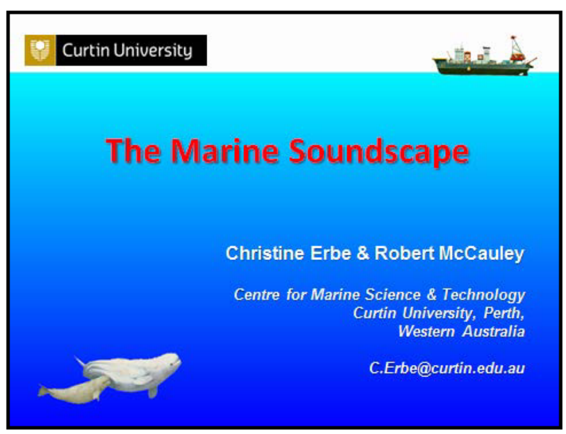
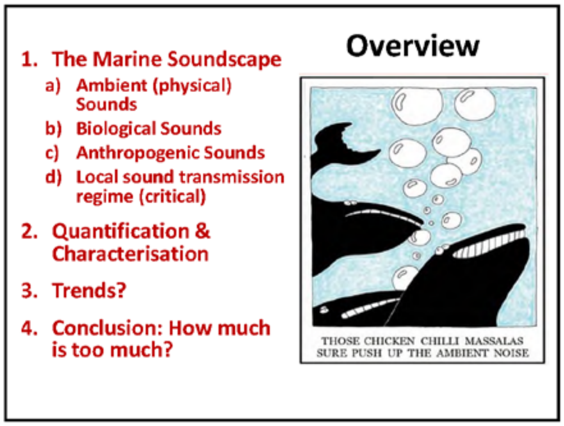
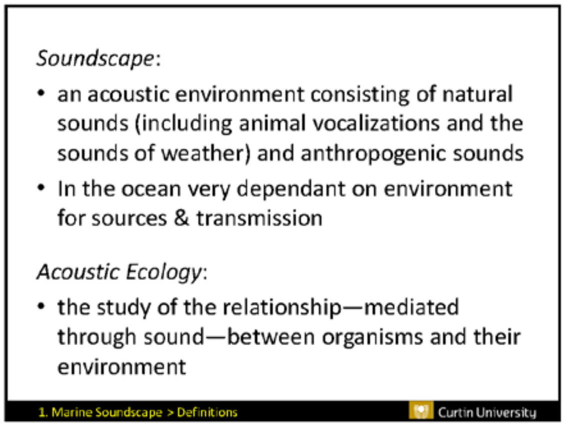
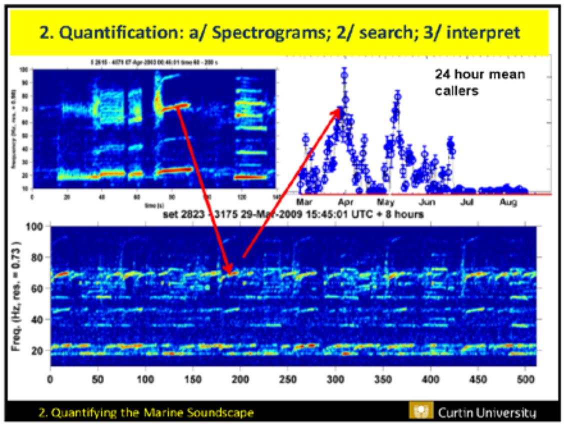
BOEM: Information needs and data gaps
Presentation name: Terminology for underwater sound
Author (affiliation): Michael A Ainslie (TNO)
Information needs
Standard terminology for underwater sound:
compare like with like
Improve communication between regulators, scientists and managers
How to characterise pile driver/wind turbine?
Data gaps
n/a

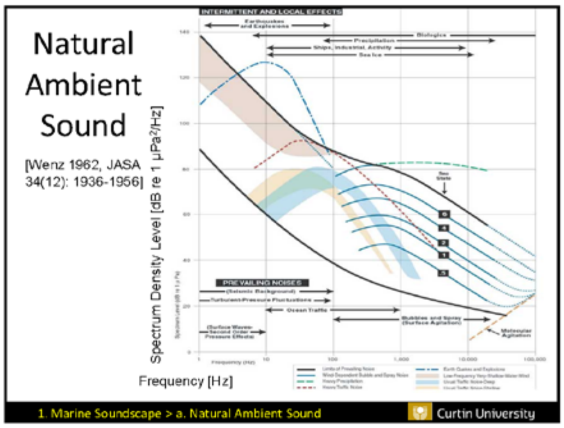

Curtin University
The Marine Soundscape
Christine Erbe & Robert McCauley
Centre for Marine Science & Technology
Curtin University, Perth,
Western Australia
C.Erbe@curtin.edu.au

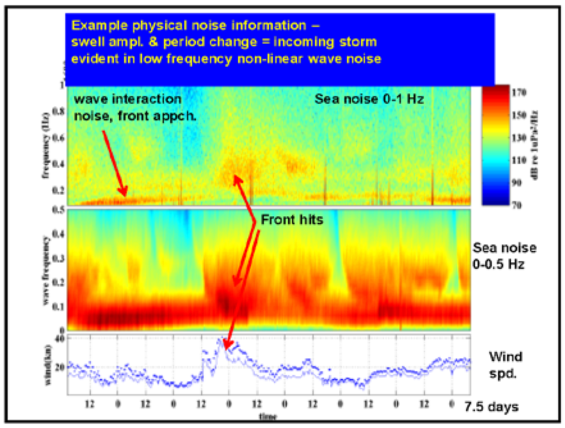

Overview
1. The Marine Soundscape
a) Ambient (physical) Sounds
b) Biological Sounds
c) Anthropogenic Sounds
d) Local sound transmission regime (critical)
2. Quantification & Characterisation
3. Trends?
4. Conclusion: How much is too much?
THOSE CHICKEN CHILLI MASSALAS SURE PUSH UP THE AMBIENT NOISE

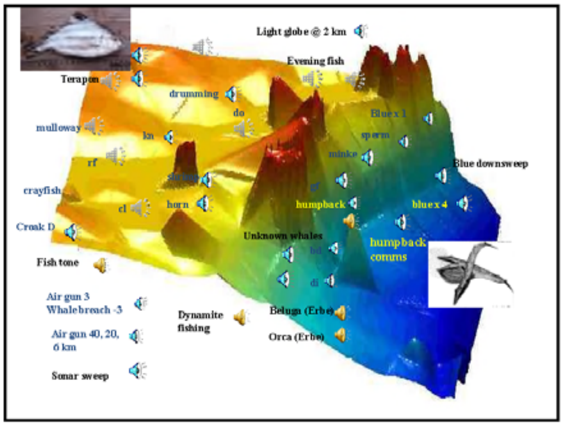

Soundscape:
• an acoustic environment consisting of natural sounds (including animal vocalizations and the sounds of weather) and anthropogenic sounds
• In the ocean very dependant on environment for sources & transmission
Acoustic Ecology:
• the study of the relationship—mediated through sound—between organisms and their environment
1. Marine Soundscape > Definitions
Curtin University

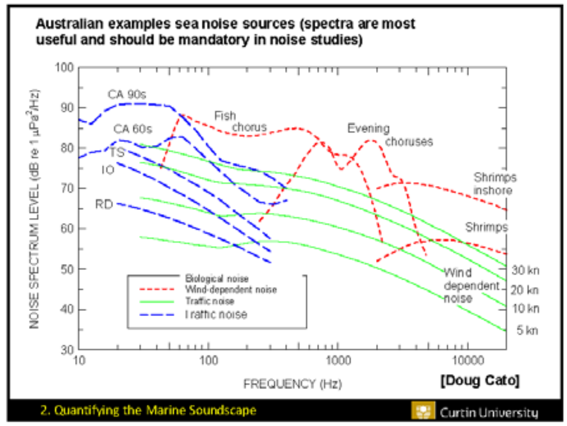

How do we measure soundscapes?
CRITICAL to understand what one is to measure, instrument nature & artefacts - otherwise get misleading results
1- Shiny instrument
2- Load into vehicle & boat
3- Throw it away


2. Quantification: a/ Spectrograms; 2/ search; 3/ interpret
24 hour mean callers
Mar Apr May Jun Jul Aug
Freq. (Hz, res. = 0.73)
0 50 100 150 200 250 300 350 400 450 500
2. Quantifying the Marine Soundscape
Curtin University


Natural Ambient Sound
[Wenz 1962, JASA 34(12): 1936-1956]
Spectrum Density Level [dB re 1 μPa²/Hz]
Frequency [Hz]
1. Marine Soundscape > a. Natural Ambient Sound
Curtin University


Example physical noise information – swell ampl. & period change = incoming storm evident in low frequency non-linear wave noise
wave interaction noise, front appch.
Sea noise 0-1 Hz
Front hits
Sea noise 0-0.5 Hz
Wind spd.
7.5 days


Light globe @ 2 km
Evening fish
Terapon
drumming
mulloway
crayfish
Croak D
Fish tone
Air gun 3
Whalebreach -3
Air gun 40, 20, 6 km
Sonar sweep
Dynamite fishing
Belugu (Erbe)
Orca (Erbe)
Unknown whales
humpback
humpback comms
Blue downsweep
bluex 4
minke
sperm
Bluex 1
horn


Australian examples sea noise sources (spectra are most useful and should be mandatory in noise studies)
NOISE SPECTRUM LEVEL (dB re 1 µPa²/Hz)
FREQUENCY (Hz)
[Doug Cato]
CA 90s
CA 60s
TS
IO
RD
Fish chorus
Evening choruses
Shrimps inshore
Shrimps
Wind dependent noise
30 kn
20 kn
10 kn
5 kn
Biological noise
Wind-dependent noise
Traffic noise
Traffic noise
2. Quantifying the Marine Soundscape
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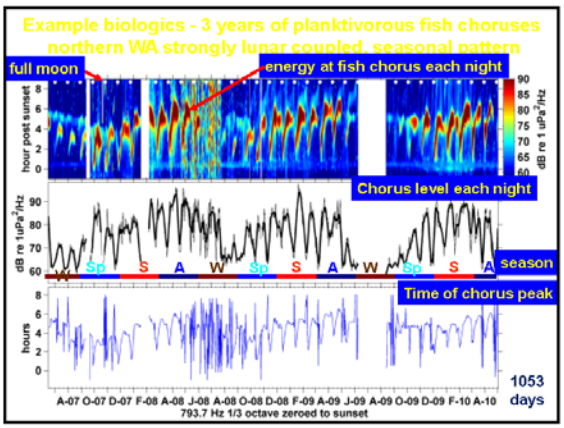
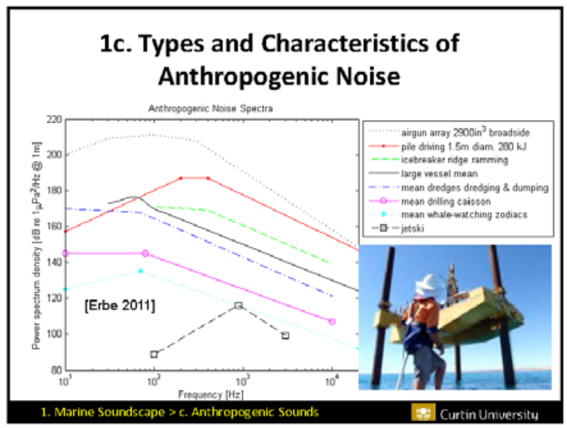

Example biologics - 3 years of planktivorous fish choruses northern WA strongly lunar coupled, seasonal pattern
full moon
energy at fish chorus each night
hour post sunset
dB re 1 uPa²/Hz
Chorus level each night
season
Time of chorus peak
hours
1053 days
793.7 Hz 1/3 octave zeroed to sunset


1c. Types and Characteristics of Anthropogenic Noise
Anthropogenic Noise Spectra
airgun array 2900in³ broadside
pile driving 1.5m diam. 280 kJ
icebreaker ridge ramming
large vessel mean
mean dredges dredging & dumping
mean drilling caisson
mean whale-watching zodiacs
jetski
[Erbe 2011]
Power spectrum density [dB re 1µPa²/Hz @ 1m]
Frequency [Hz]
1. Marine Soundscape > c. Anthropogenic Sounds
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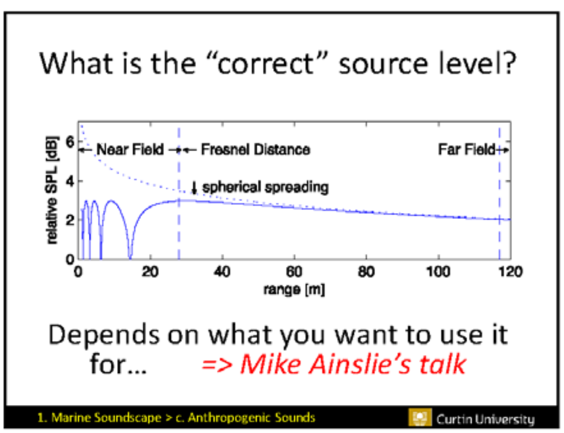
What is the "correct" source level?
relative SPL [dB]
Near Field
Fresnel Distance
Far Field
spherical spreading
range [m]
Depends on what you want to use it for...
=> Mike Ainslie's talk
1. Marine Soundscape > c. Anthropogenic Sounds
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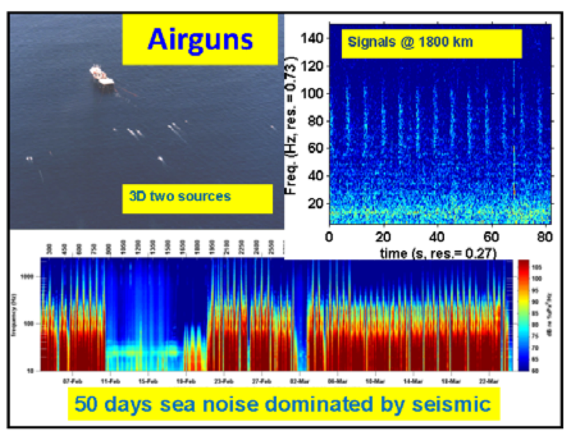
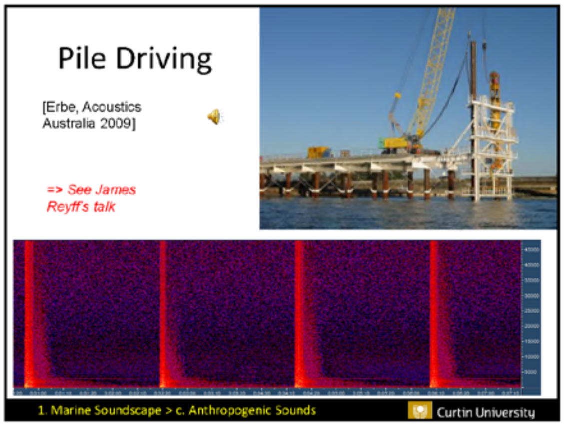

Airguns
3D two sources
Signals @ 1800 km
Freq. (Hz, res. = 0.73)
time (s, res.= 0.27)
50 days sea noise dominated by seismic


Pile Driving
[Erbe, Acoustics Australia 2009]
=> See James Reyff's talk
1. Marine Soundscape > c. Anthropogenic Sounds
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Large Vessels
Propeller cavitation noise dominant when underway
small number noisy ships dominate ocean noise
International effort to quieten shipping
[Erbe & Farmer, DSRII JASA 1998, 2000]
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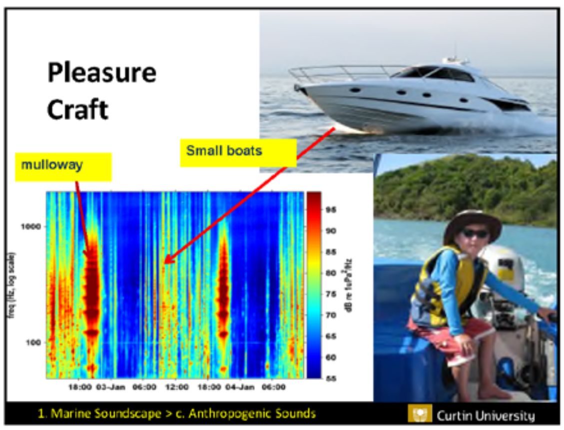
Pleasure Craft
mulloway
Small boats
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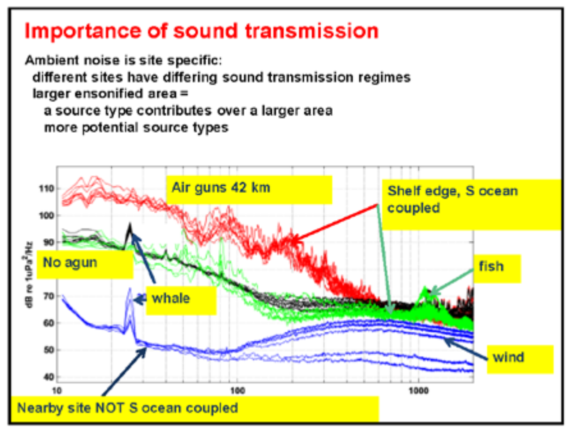
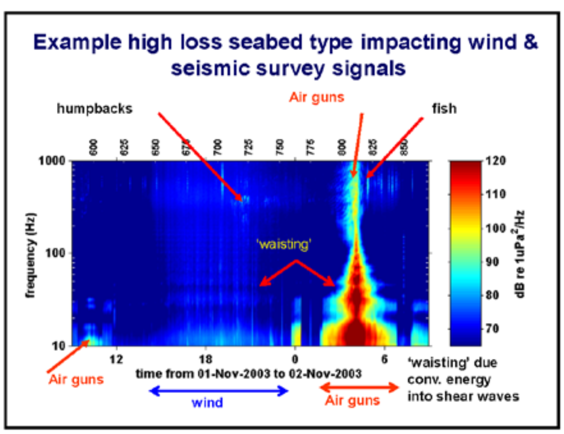
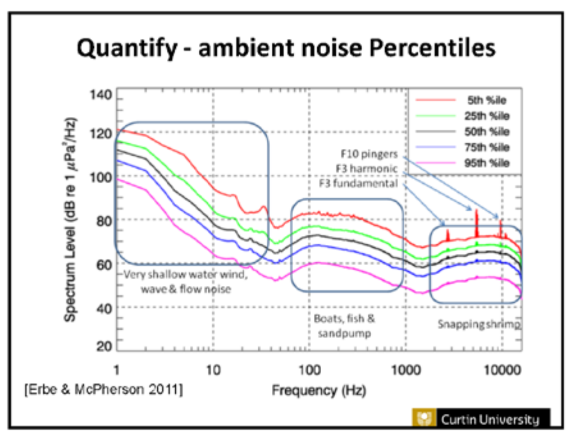
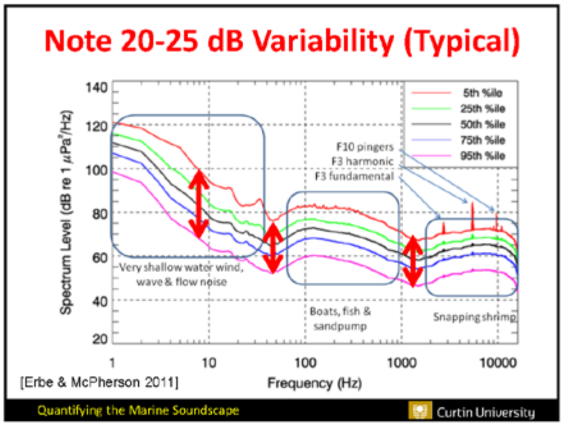
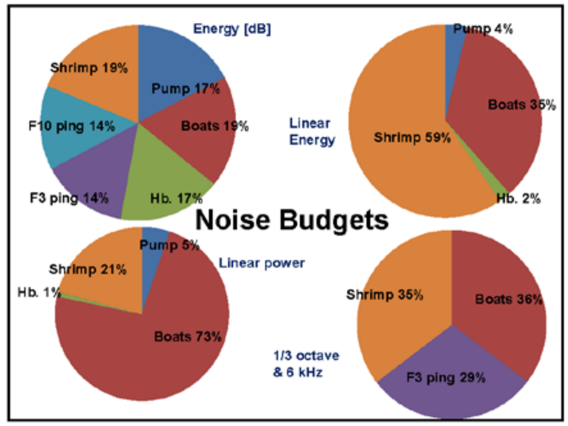
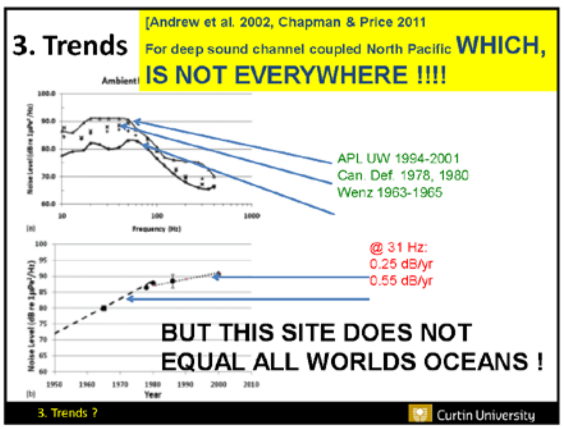

Importance of sound transmission
Ambient noise is site specific:
different sites have differing sound transmission regimes
larger ensonified area =
a source type contributes over a larger area
more potential source types
Air guns 42 km
Shelf edge, S ocean coupled
No agun
whale
fish
wind
Nearby site NOT S ocean coupled

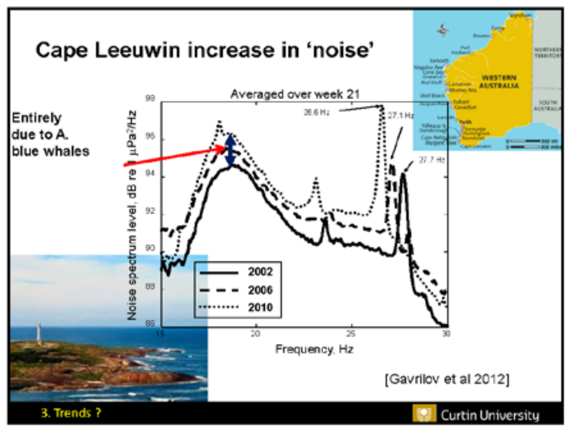

Example high loss seabed type impacting wind & seismic survey signals
humpbacks
Air guns
fish
'waisting'
frequency (Hz)
dB re 1uPa²/Hz
time from 01-Nov-2003 to 02-Nov-2003
Air guns
wind
Air guns
'waisting' due conv. energy into shear waves

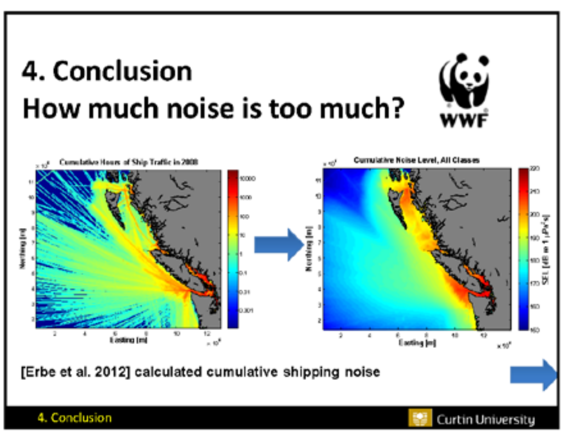

Quantify - ambient noise Percentiles
5th %ile
25th %ile
50th %ile
75th %ile
95th %ile
F10 pingers
F3 harmonic
F3 fundamental
Very shallow water wind, wave & flow noise
Boats, fish & sandpump
Snapping shrimp
Spectrum Level (dB re 1 μPa²/Hz)
Frequency (Hz)
[Erbe & McPherson 2011]
Curtin University

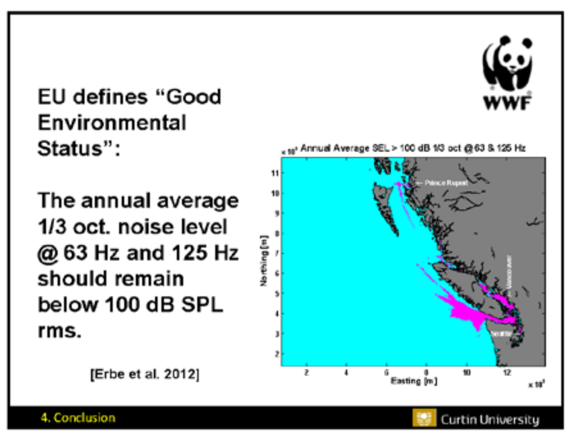

Note 20-25 dB Variability (Typical)
Spectrum Level (dB re 1 µPa²/Hz)
5th %ile
25th %ile
50th %ile
75th %ile
95th %ile
F10 pingers
F3 harmonic
F3 fundamental
Very shallow water wind, wave & flow noise
Boats, fish & sandpump
Snapping shrimp
Frequency (Hz)
[Erbe & McPherson 2011]
Quantifying the Marine Soundscape
Curtin University


Energy [dB]
Shrimp 19%
Pump 17%
F10 ping 14%
Boats 19%
F3 ping 14%
Hb. 17%
Linear Energy
Pump 4%
Boats 35%
Shrimp 59%
Hb. 2%
Noise Budgets
Pump 5%
Shrimp 21%
Hb. 1%
Boats 73%
Linear power
Shrimp 35%
Boats 36%
F3 ping 29%
1/3 octave & 6 kHz


3. Trends
[Andrew et al. 2002, Chapman & Price 2011
For deep sound channel coupled North Pacific WHICH,
IS NOT EVERYWHERE !!!!
APL UW 1994-2001
Can. Def. 1978, 1980
Wenz 1963-1965
@ 31 Hz:
0.25 dB/yr
0.55 dB/yr
BUT THIS SITE DOES NOT
EQUAL ALL WORLDS OCEANS !
3. Trends ?
Curtin University


Cape Leeuwin increase in 'noise'
Entirely due to A. blue whales
Averaged over week 21
Noise spectrum level, dB re 1 µPa²/Hz
2002
2006
2010
Frequency, Hz
[Gavrilov et al 2012]
WESTERN AUSTRALIA
3. Trends ?
Curtin University


4. Conclusion
How much noise is too much?
WWF
Cumulative Hours of Ship Traffic in 2008
Cumulative Noise Level, All Classes
[Erbe et al. 2012] calculated cumulative shipping noise
4. Conclusion
Curtin University


EU defines "Good Environmental Status":
The annual average 1/3 oct. noise level @ 63 Hz and 125 Hz should remain below 100 dB SPL rms.
[Erbe et al. 2012]
WWF
Annual Average SEL > 100 dB 1/3 oct @ 63 & 125 Hz
Northing [m]
Easting [m]
4. Conclusion
Curtin University

"The Marine Soundscape"

Christine Erbe & Robert McCauley
Centre for Marine Science & Technology
Curtin University, Perth, Western Australia
C.Erbe@curtin.edu.au

- **Characterising Soundscapes**: Need a consistent way (& metrics) to characterise soundscapes, e.g. power spectrum density budgets (spectra) [ie. Cato Curves]
- **Trends**: Need long-term datasets to determine trends (>10 yrs); trends will differ by location
- **Modelling Soundscapes**: Very difficult to predict soundscapes (into the future or past), due to number of sources & variability, and sound propagation specifics
- **Measuring Soundscapes**: IQOE Science Plan suggests monitoring soundscapes now in areas of future change and/or critical habitat – needs long term commitment
- **Ocean observatories**: ie. EU & Australian IMOS

Summary Slide — Curtin University

Now what ?!

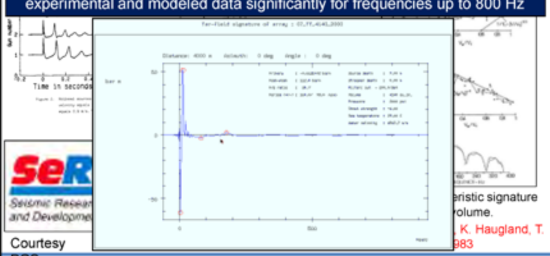
Outline

- Early calibration measurements & source modeling
- Early near and far field measurements
- New studies – OGP Sound and Marine Life (SAML) JIP
  - 3D sound source characterization of an air gun array
  - Single air gun and cluster measurements
- Near field vs. far field measurements
- JASCO/OGP soft start modeling study
- Marine vibroseis
  - Marine vibroseis JIP
  - Marine vibrator characteristics
- Information needs and data gaps

21 March, 2012 — *250*

Early Calibration Measurements - SERES

- Modeled source spectra generated with USN standard underwater PE propagation model RAM and notional signatures generated by Gundalf show a good agreement with experimental data in a frequency band up to 300 Hz for different arrival angles
- Notional signatures generated by Nucleus improved agreement between experimental and modeled data significantly for frequencies up to 800 Hz



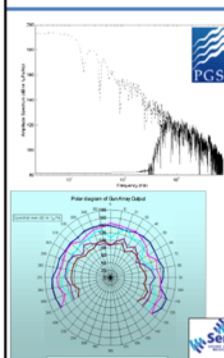
...eristic signature ...olume.

..., K. Haugland, T. ...983

Courtesy PGS

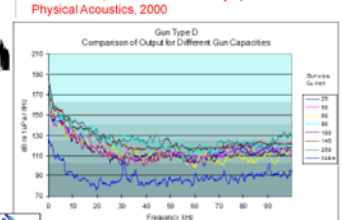
21 March, 2012 — *251*

Historical Review – Near & Far Field measurements



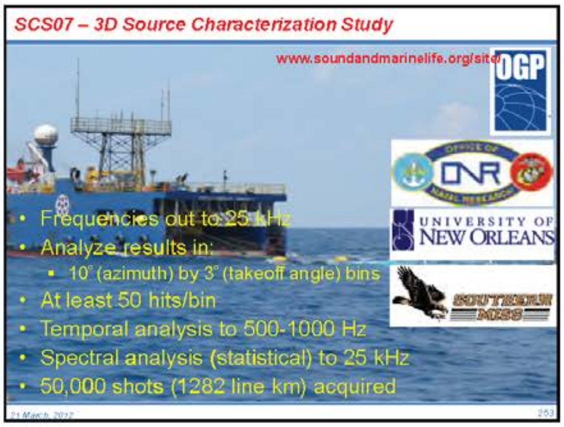
Amplitude spectrum of vertical far-field signature from a typical single 70 in^3 air gun fired at 4 m depth at 140 bar air-pressure. A digital 6kHz high-pass filter is shown as the overlaid solid line curve.

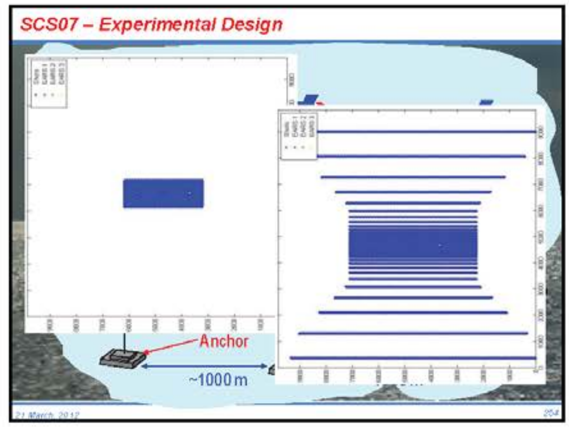
Environmental aspects of marine seismic air guns, Audun Sødal, 23rd Scandinavian Symposium on Physical Acoustics, 2000

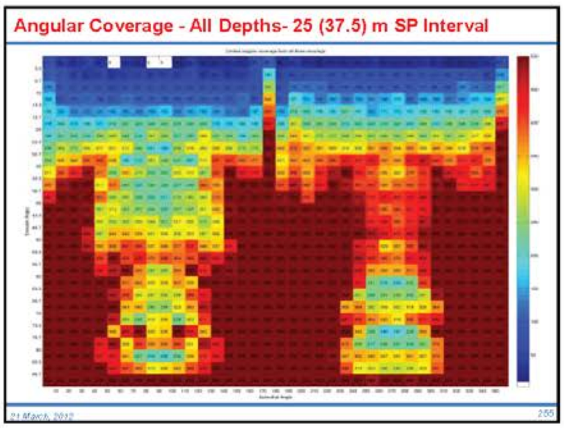


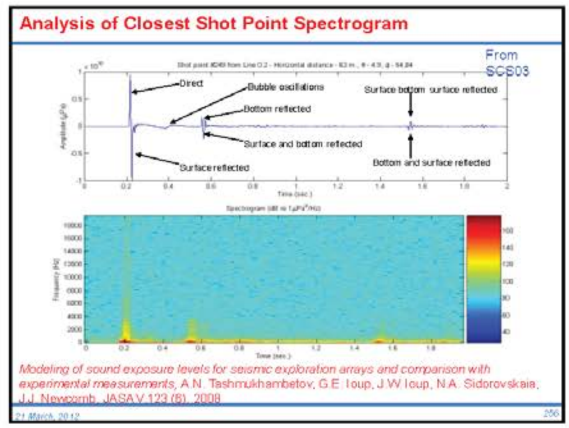
Noise monitoring program – Sections 2-4, Seiche Measurements Ltd for UKOOA, 2001

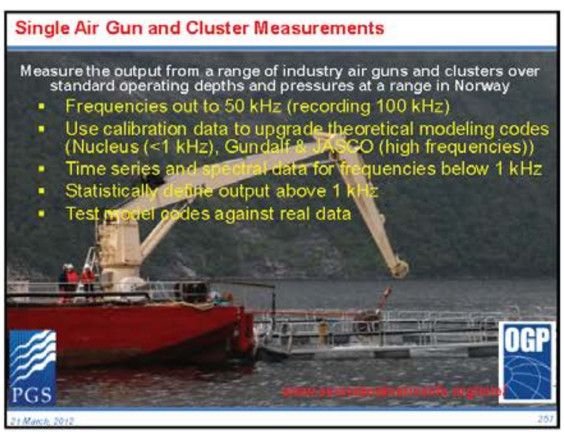
21 March, 2012 — *252*


SCS07 – 3D Source Characterization Study
www.soundandmarinelife.org/site
OGP
ONR
UNIVERSITY OF NEW ORLEANS
SOUTHERN MISS
• Frequencies out to 25 kHz
• Analyze results in:
▪ 10° (azimuth) by 3° (takeoff angle) bins
• At least 50 hits/bin
• Temporal analysis to 500-1000 Hz
• Spectral analysis (statistical) to 25 kHz
• 50,000 shots (1282 line km) acquired
21 March 2012
253


SCS07 – Experimental Design
Anchor
~1000 m
21 March 2012
254


Angular Coverage - All Depths- 25 (37.5) m SP Interval
21 March 2012
255


Analysis of Closest Shot Point Spectrogram
From SCS03
Direct
Bubble oscillations
Bottom reflected
Surface bottom surface reflected
Surface and bottom reflected
Surface reflected
Bottom and surface reflected
Modeling of sound exposure levels for seismic exploration arrays and comparison with experimental measurements, A.N. Tashmukhambetov, G.E. Ioup, J.W. Ioup, N.A. Sidorovskaia, J.J. Newcomb, JASA V.123 (6), 2008
21 March 2012
256


Single Air Gun and Cluster Measurements
Measure the output from a range of industry air guns and clusters over standard operating depths and pressures at a range in Norway
▪ Frequencies out to 50 kHz (recording 100 kHz)
▪ Use calibration data to upgrade theoretical modeling codes (Nucleus (<1 kHz), Gundalf & JASCO (high frequencies))
▪ Time series and spectral data for frequencies below 1 kHz
▪ Statistically define output above 1 kHz
▪ Test model codes against real data
PGS
OGP
21 March 2012
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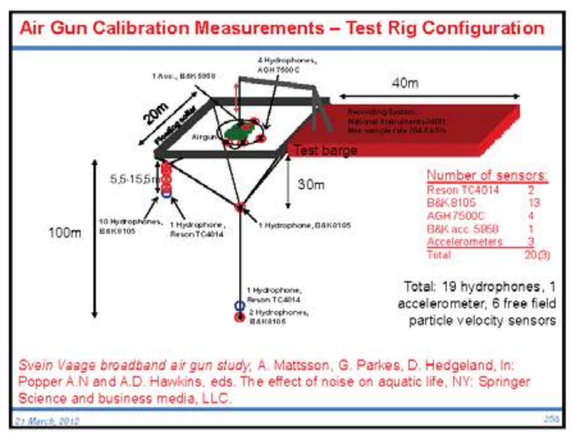
Air Gun Calibration Measurements – Test Rig Configuration
40m
20m
Test barge
5,5-15,5m
30m
100m
Number of sensors:
Reson TC4014 2
B&K 8105 13
AGH 7500C 4
B&K acc 5958 1
Accelerometers 3
Total 20(3)
Total: 19 hydrophones, 1 accelerometer, 6 free field particle velocity sensors
Svein Vaage broadband air gun study, A. Mattsson, G. Parkes, D. Hedgeland, In: Popper A.N and A.D. Hawkins, eds. The effect of noise on aquatic life, NY: Springer Science and business media, LLC.
21 March 2012
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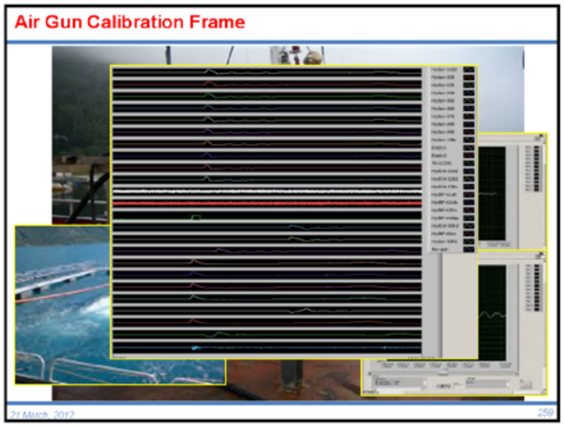
Air Gun Calibration Frame
21 March 2012
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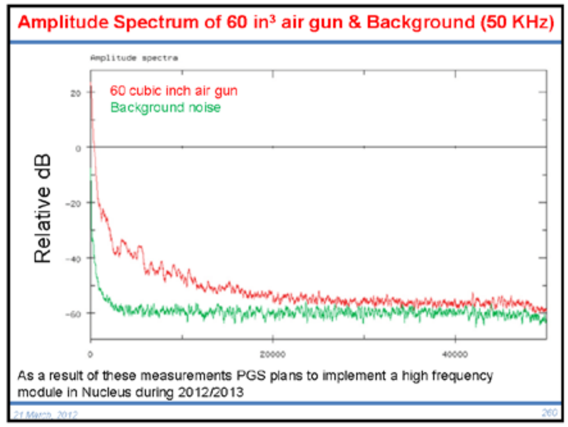
Amplitude Spectrum of 60 in³ air gun & Background (50 KHz)
Amplitude spectra
60 cubic inch air gun
Background noise
Relative dB
20
0
-20
-40
-60
0
20000
40000
As a result of these measurements PGS plans to implement a high frequency module in Nucleus during 2012/2013
21 March 2012
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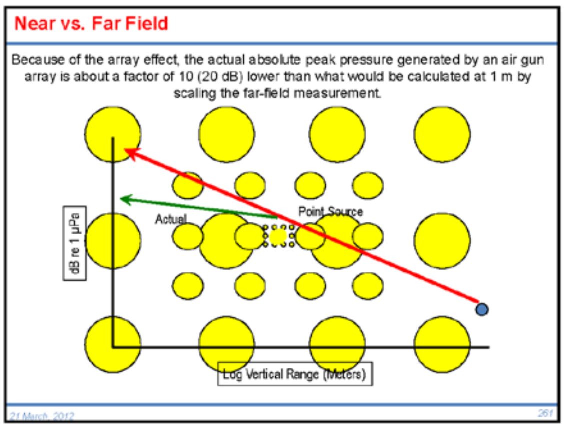
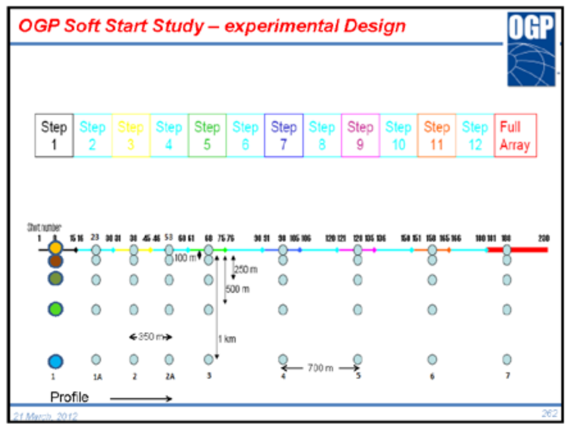

Near vs. Far Field
Because of the array effect, the actual absolute peak pressure generated by an air gun array is about a factor of 10 (20 dB) lower than what would be calculated at 1 m by scaling the far-field measurement.
Actual
Point Source
dB re 1 µPa
Log Vertical Range (Meters)
21 March 2012
261


OGP Soft Start Study – experimental Design
OGP
Step 1
Step 2
Step 3
Step 4
Step 5
Step 6
Step 7
Step 8
Step 9
Step 10
Step 11
Step 12
Full Array
Shot number
100 m
250 m
500 m
1 km
350 m
700 m
1
1A
2
2A
3
4
5
6
7
Profile
21 March 2012
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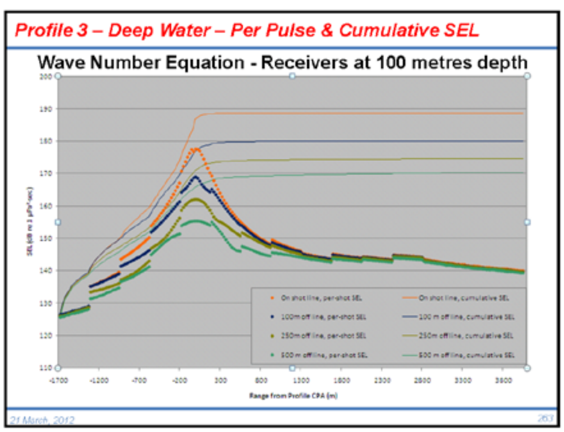
Profile 3 – Deep Water – Per Pulse & Cumulative SEL
Wave Number Equation - Receivers at 100 metres depth
On shot line, per-shot SEL
On shot line, cumulative SEL
100m off line, per-shot SEL
100 m off line, cumulative SEL
250m off line, per-shot SEL
250m off line, cumulative SEL
500 m offline, per shot SEL
500 m off line, cumulative SEL
Range from Profile CPA (m)
21 March 2012
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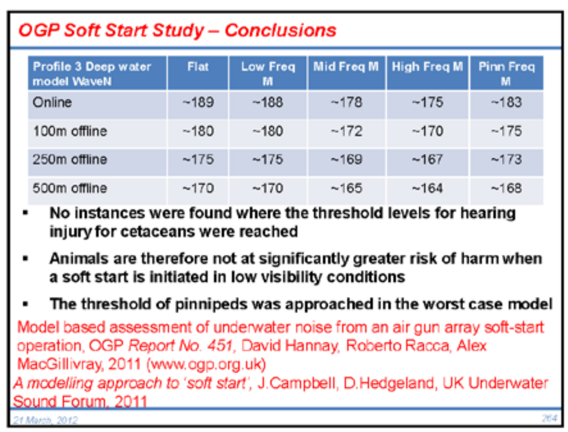
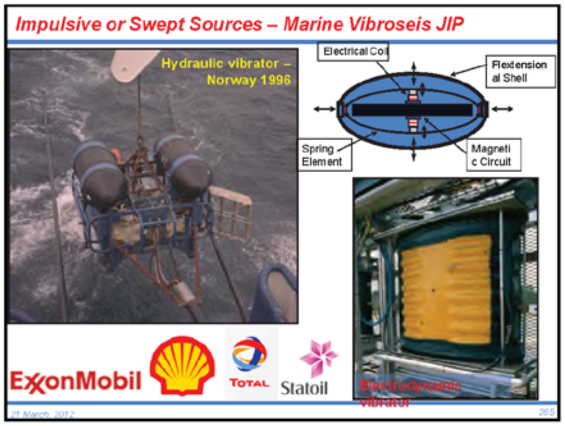
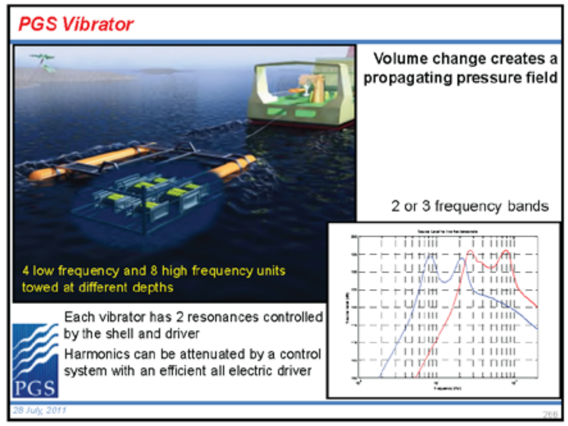

OGP Soft Start Study – Conclusions

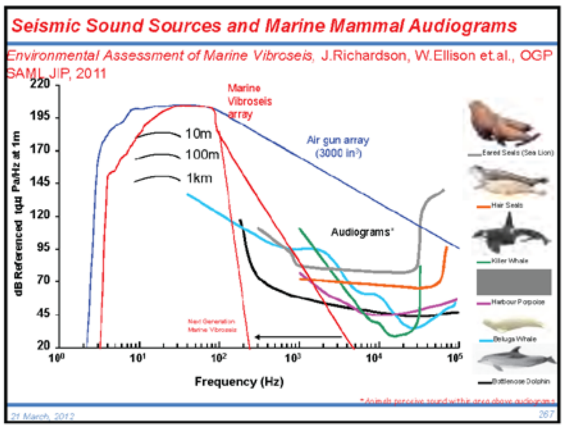
Profile 3 Deep water model WaveN	Flat	Low Freq M	Mid Freq M	High Freq M	Pinn Freq M
Online	~189	~188	~178	~175	~183
100m offline	~180	~180	~172	~170	~175
250m offline	~175	~175	~169	~167	~173
500m offline	~170	~170	~165	~164	~168

- No instances were found where the threshold levels for hearing injury for cetaceans were reached
- Animals are therefore not at significantly greater risk of harm when a soft start is initiated in low visibility conditions
- The threshold of pinnipeds was approached in the worst case model

Model based assessment of underwater noise from an air gun array soft-start operation, OGP Report No. 451, David Hannay, Roberto Racca, Alex MacGillivray, 2011 (www.ogp.org.uk)
A modelling approach to 'soft start', J.Campbell, D.Hedgeland, UK Underwater Sound Forum, 2011
21 March 2012
264







Information Needs and Data Gaps

Title: Seismic Sources
Author: Mike Jenkerson - ExxonMobil Exploration Co.

Data Gaps

- Update current air gun modeling codes
  - Increase model frequency range to 25+ kHz
  - Test accuracy of modeling codes at higher frequencies
  - Continue to acquire calibration data for new air guns
  - Improve particle velocity measurements
- Complete analysis of 3D air gun array (SCS07)
- Evaluate marine vibroseis transducers
  - Geophysical & environmental testing of prototype transducers
  - Conduct particle velocity measurements

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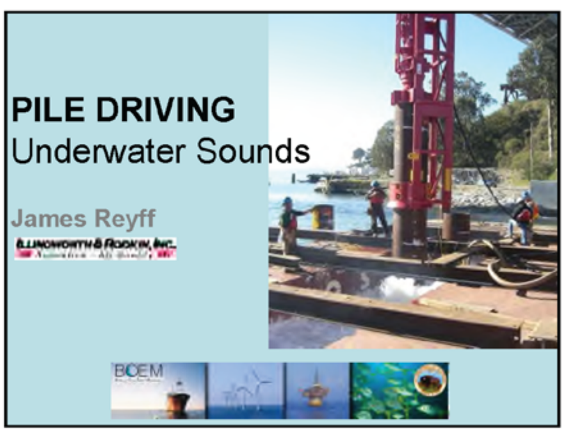
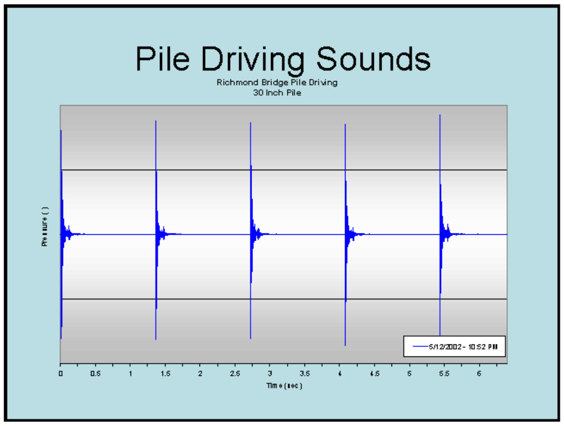


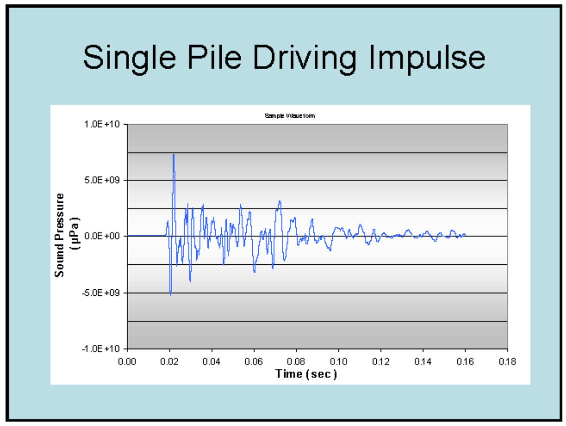
Basic Sound Descriptors
for Impact Pile Driving

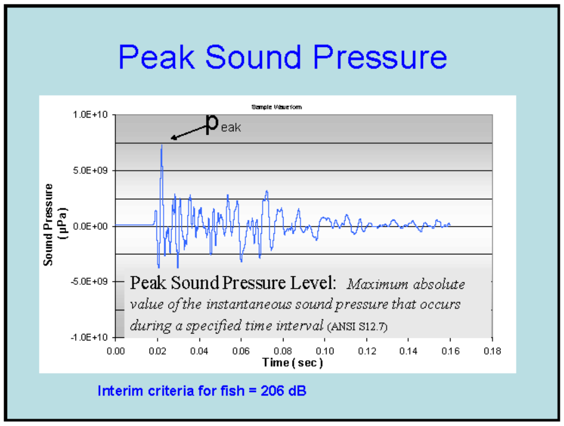
–Peak Pressure

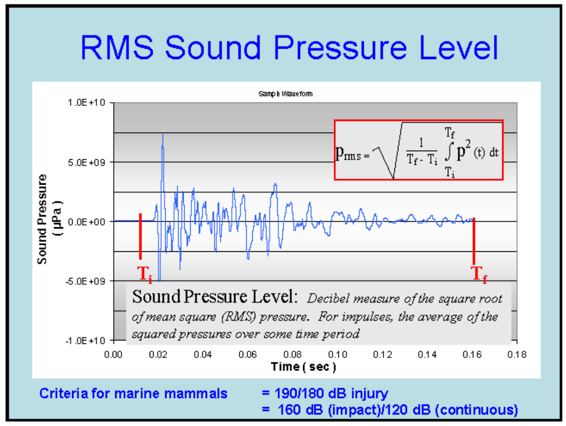
–Root Mean Square (RMS) – over pulse duration

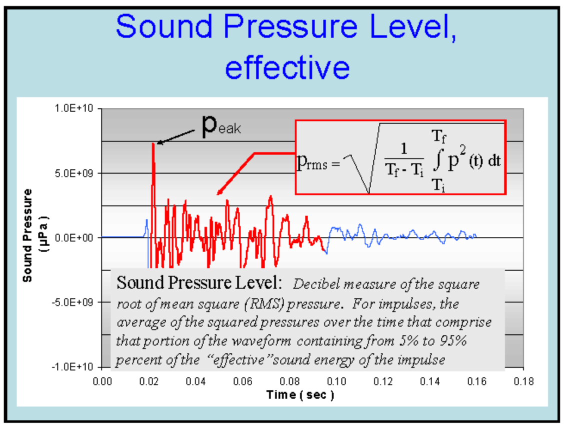
–Sound Exposure Level (SEL) – over pulse and accumulated

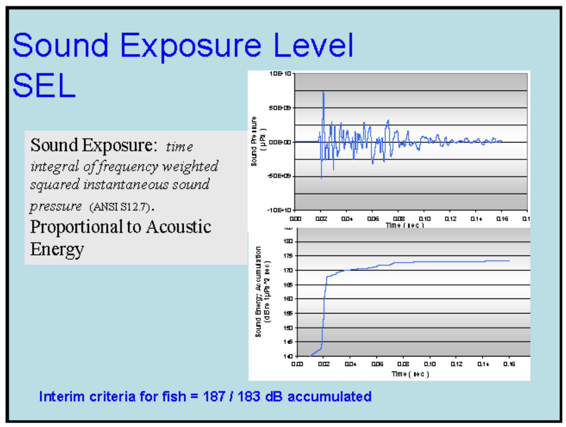

Pile Driving Sounds
Richmond Bridge Pile Driving
30 Inch Pile
5/12/2002 - 10:52 PM


Single Pile Driving Impulse
Sample Waveform
Sound Pressure (µPa)
1.0E+10
5.0E+09
0.0E+00
-5.0E+09
-1.0E+10
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
Time (sec)


Peak Sound Pressure
Peak
Sound Pressure (µPa)
Time (sec)
Peak Sound Pressure Level: Maximum absolute value of the instantaneous sound pressure that occurs during a specified time interval (ANSI S12.7)
Interim criteria for fish = 206 dB


RMS Sound Pressure Level
$P_{rms} = \sqrt{\frac{1}{T_f - T_i} \int_{T_i}^{T_f} p^2(t)\, dt}$
T_i
T_f
Sound Pressure (µPa)
Time (sec)
Sound Pressure Level: Decibel measure of the square root of mean square (RMS) pressure. For impulses, the average of the squared pressures over some time period
Criteria for marine mammals = 190/180 dB injury
= 160 dB (impact)/120 dB (continuous)


Sound Pressure Level, effective
Peak
$P_{rms} = \sqrt{\frac{1}{T_f - T_i} \int_{T_i}^{T_f} p^2(t)\, dt}$
Sound Pressure (µPa)
Time (sec)
Sound Pressure Level: Decibel measure of the square root of mean square (RMS) pressure. For impulses, the average of the squared pressures over the time that comprise that portion of the waveform containing from 5% to 95% percent of the "effective" sound energy of the impulse

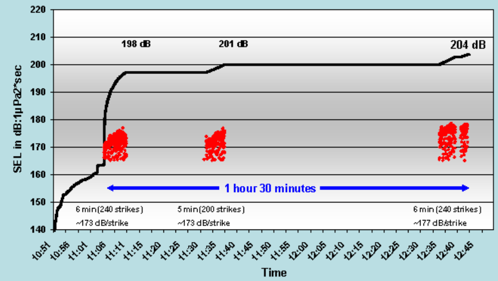

Sound Exposure Level
SEL
Sound Exposure: time integral of frequency weighted squared instantaneous sound pressure (ANSI S12.7).
Proportional to Acoustic Energy
Interim criteria for fish = 187 / 183 dB accumulated

Accumulated SEL

Accumulated SEL

1.3-Meter Diameter Steel Piles

SEL Measured at 10 Meters



Vibratory Pile Driving

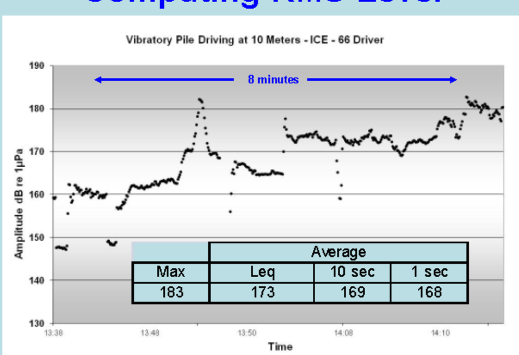
- Much lower amplitude sounds than impact pile driving (20 to 30 dB lower)
- Noise tends to be more continuous
- Higher Frequency sounds

Vibratory Pile Driving

Potential Impacts

- No restrictive levels identified for fish
  - No Peak or SEL levels
- Potential injury thresholds for marine mammals unlikely (i.e., levels generally less than 180 dB RMS near source)
- Harassment to marine mammals likely to extend many kilometers from pile based on 120 dB RMS level

Computing RMS Level



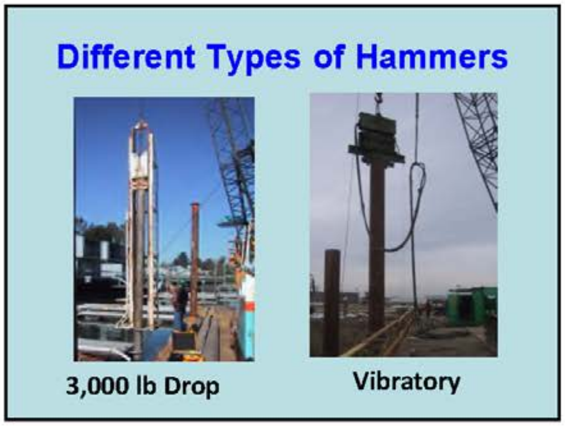
Max	Leq	Average 10 sec	Average 1 sec
183	173	169	168

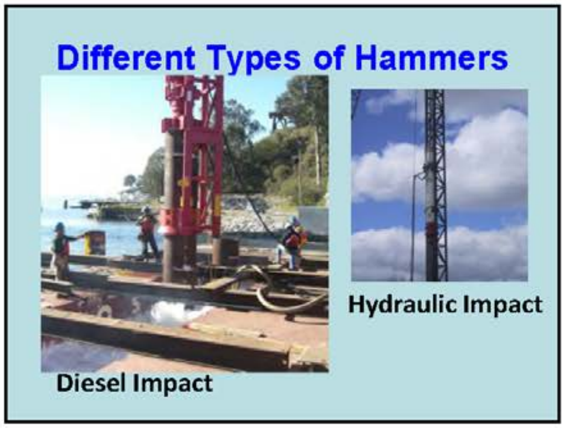
How Much Sound Does Pile Driving Make?

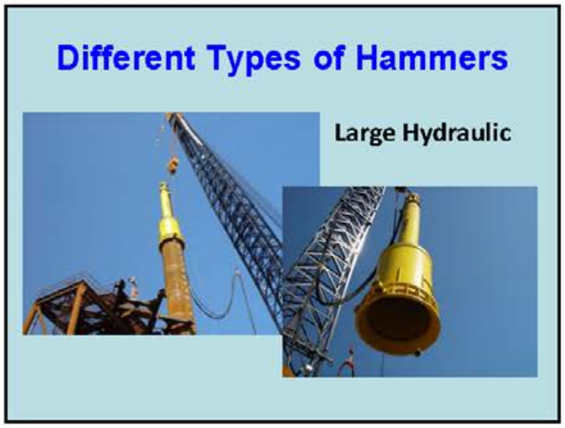
Depends on …

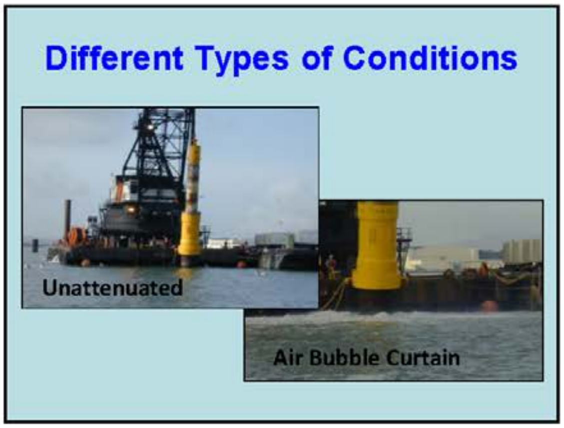
- Type and size of Pile
- Type of Driving Method
- Hammer Size and Energy
- Attenuation methods
- Substrate Conditions
- Sound propagation conditions


Different Types of Piles


Different Types of Hammers
3,000 lb Drop
Vibratory


Different Types of Hammers
Hydraulic Impact
Diesel Impact


Different Types of Hammers
Large Hydraulic


Different Types of Conditions
Unattenuated
Air Bubble Curtain


Different Types of Conditions
On Land Near Water

Summary Table – Impact Driving

Pile Type and Size	Relative Water Depth	Average Sound Pressure Measured in dB		
		Peak	RMS*	SEL
0.30-meter Steel H-type - Thin	<5 meters	190	175	160
0.6-meter AZ Steel Sheet	~15 meters	205	190	180
0.61-meter Concrete Pile	~15 meters	188	176	166
0.36-meter Steel Pipe Pile	~15 meters	200	184	174
0.61-meter Steel Pipe Pile	~15 meters	207	194	178
0.8-meter Steel Pipe Pile	~10 meters	210	193	183
1.5-meter Steel CISS	<5 meters	210	195	185
2.4-meter Steel CISS	~15 meters	220	205	195

* Impulse level
**SEL for 1 second of continuous driving

Summary Table – Vibratory Driving

Pile Type and Approximate Size	Relative Water Depth	Average Sound Pressure Measured in dB		
		Peak	RMS*	SEL
0.30-meter Steel H-type	<5 meters	165	150	150
0.30-meter Steel Pipe Pile	<5 meters	171	155	155
0.8-meter Steel Pipe Pile	~5 meters	180	170	170
0.6-meter AZ Steel Sheet	~15 meters	175	160	160
1-meter Steel Pipe Pile - Loudest	~5 meters	185	175	175
1.8-meter Steel Pipe Pile	~5 meters	183	170	170

* 1 sec RMS
**SEL for 1 second of continuous driving

RMS levels based on 1-sec RMS

Minimization Measures

- Air bubble curtains/Dewatered casings
  - Confined / unconfined
- Dewatered cofferdams
- Avoid in water driving
  - Move footings out of water
- Use Vibratory Drivers???
- Construction windows
  - Avoid times when species are present

Reducing Sounds

Reducing Sounds

Air Bubble Curtain

Reducing Sounds

Dewatered Casing

Reducing Sounds

Dewatered Casing

Reducing Sounds

Dewatered Cofferdam

Underwater Sound Propagation

- Default 15 Log_{10} Rate (4.5 dB per doubling of distance)
- Measurement Examples
  - Large piles in relatively deep water
  - Piles in very shallow water
  - Large piles in varying water depth

NOAA Worksheet for

Stationary Fish

Fill in green cells: estimated sound levels and distances at which they were measured, estimated number of pile strikes, level for effective quiet and transmision loss constant.

	Acoustic Metric			
	Peak	SEL	RMS	Effective Quiet
Measured single strike level (dB)	206	180	196	150
Distance (m)	10	10	10	

Estimated number of strikes	1000

Cumulative SEL at measured distance
210

Distance (m) to threshold

	Auditory tissue injury			Behavior
	Peak	Cumulative SEL dB**		RMS
	dB	Fish ≥ 2 g	Fish < 2 g	dB
Transmission loss constant (15 if unknown)	206	187	183	150
15	6	341	631	10000

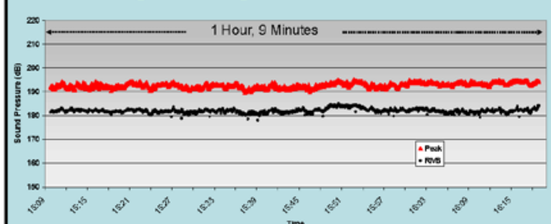
** This calculation assumes that single strike SELs < 150 dB do not accumulate to cause injury (Effective Quiet).

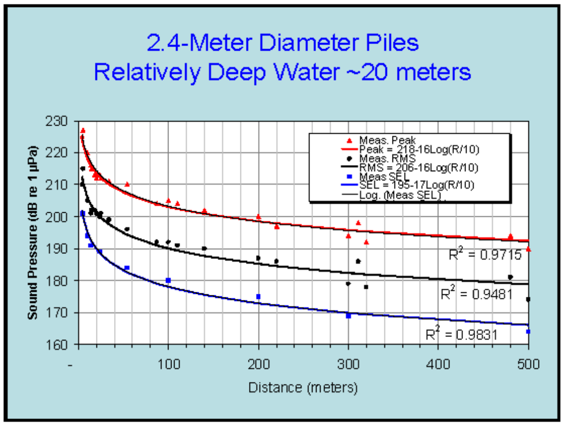
Credit – *David Woodbury, NMFS Southwest Division*

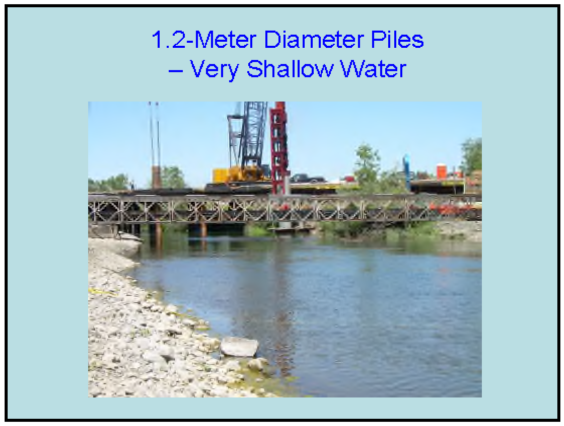
Propagation of Impact Sounds

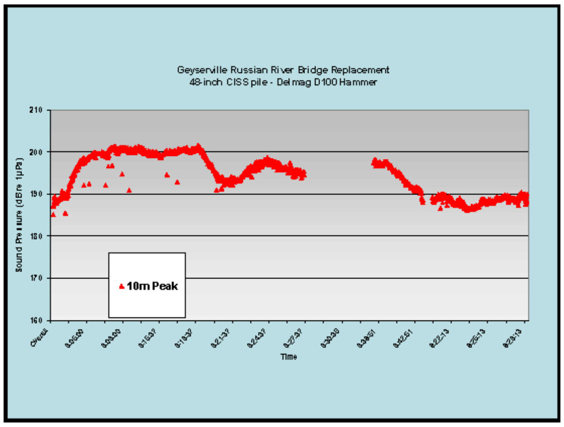
2.4-Meter Diameter Piles

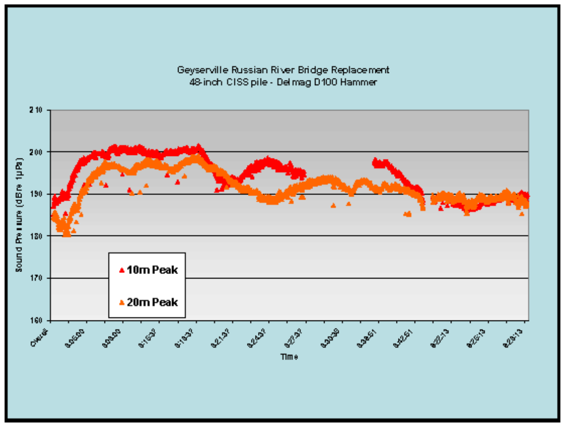
2.4-Meter Diameter Pile
Single Driving Event - Attenuated

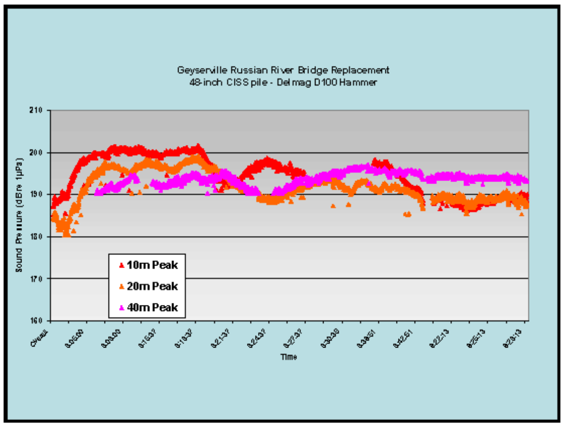


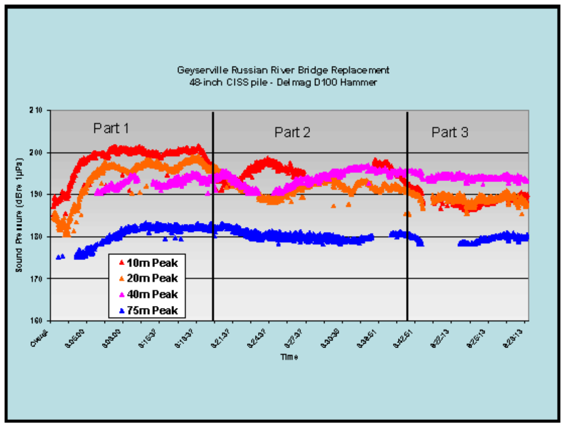

2.4-Meter Diameter Piles
Relatively Deep Water ~20 meters
Meas. Peak
Peak = 218-16Log(R/10)
Meas. RMS
RMS = 206-16Log(R/10)
Meas SEL
SEL = 195-17Log(R/10)
Log. (Meas SEL)
R² = 0.9715
R² = 0.9481
R² = 0.9831
Sound Pressure (dB re 1 µPa)
Distance (meters)

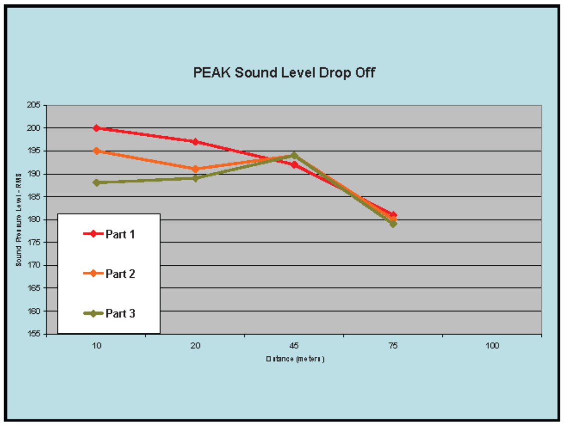

1.2-Meter Diameter Piles
– Very Shallow Water

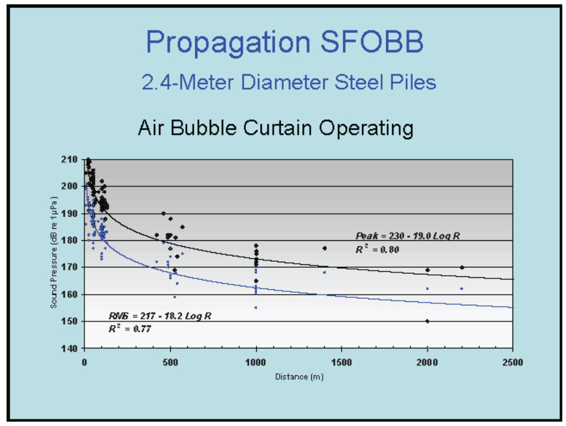

Geyserville Russian River Bridge Replacement
48-inch CISS pile - Delmag D100 Hammer
10m Peak
Time

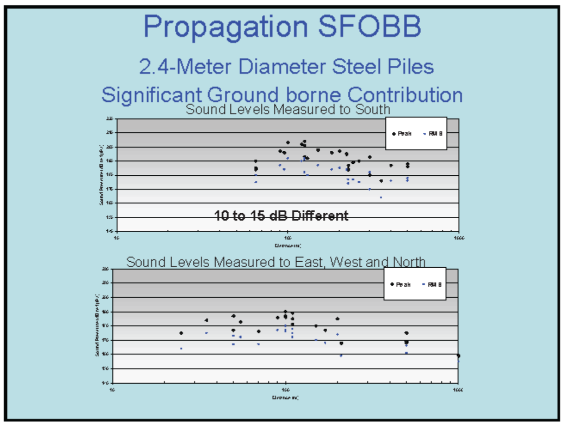

Geyserville Russian River Bridge Replacement
48-inch CISS pile - Delmag D100 Hammer
10m Peak
20m Peak
Time

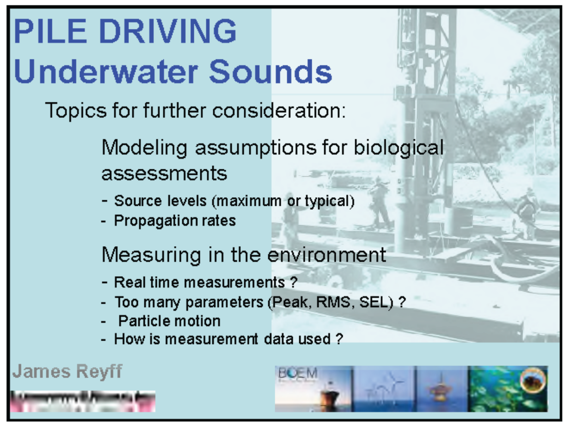

Geyserville Russian River Bridge Replacement
48-inch CISS pile - Delmag D100 Hammer
10m Peak
20m Peak
40m Peak
Time


Geyserville Russian River Bridge Replacement
48-inch CISS pile - Delmag D100 Hammer
Part 1
Part 2
Part 3
10m Peak
20m Peak
40m Peak
75m Peak
Time

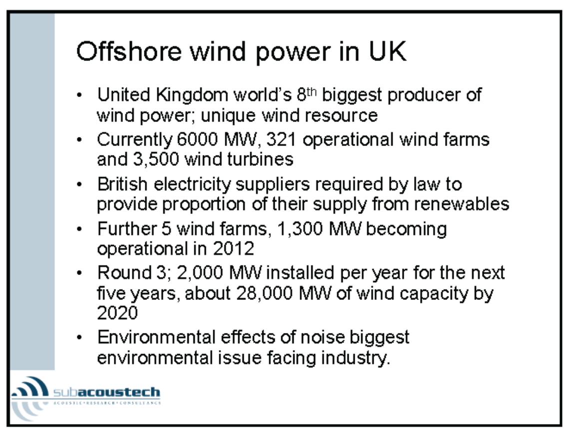

PEAK Sound Level Drop Off
Sound Pressure Level - RMS
Distance (meters)
Part 1
Part 2
Part 3
205
200
195
190
185
180
175
170
165
160
155
10
20
45
75
100

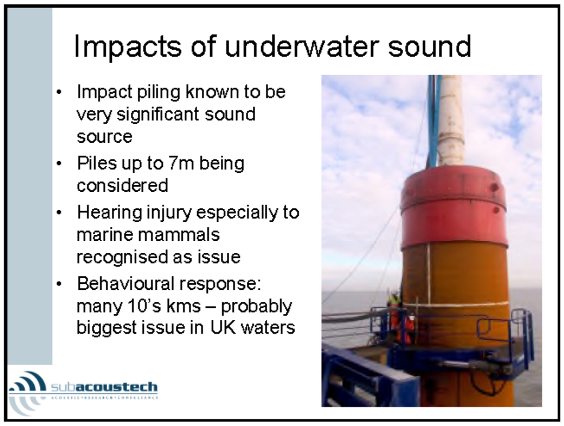

Propagation SFOBB
2.4-Meter Diameter Steel Piles
Air Bubble Curtain Operating
Peak = 230 - 19.0 Log R
R^2 = 0.80
RMS = 217 - 18.2 Log R
R^2 = 0.77
Sound Pressure (dB re 1μPa)
Distance (m)
210
200
190
180
170
160
150
140
0
500
1000
1500
2000
2500

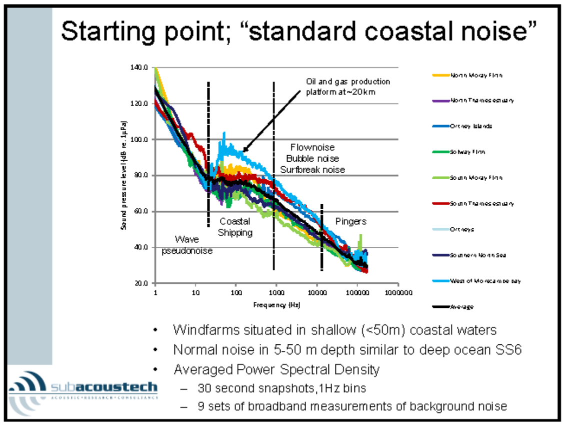

Propagation SFOBB
2.4-Meter Diameter Steel Piles
Significant Ground borne Contribution
Sound Levels Measured to South
10 to 15 dB Different
Sound Levels Measured to East, West and North

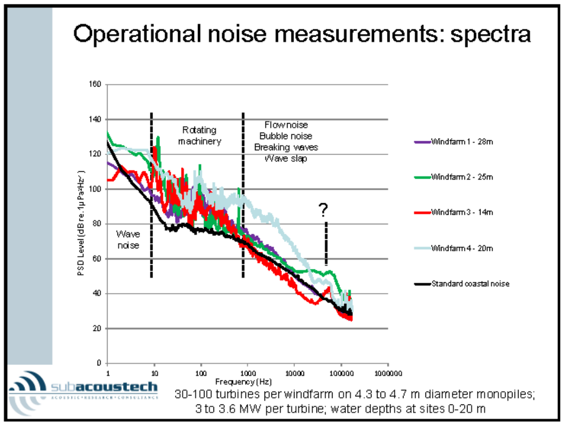

PILE DRIVING
Underwater Sounds
Topics for further consideration:
Modeling assumptions for biological assessments
- Source levels (maximum or typical)
- Propagation rates
Measuring in the environment
- Real time measurements ?
- Too many parameters (Peak, RMS, SEL) ?
- Particle motion
- How is measurement data used ?
James Reyff
BOEM

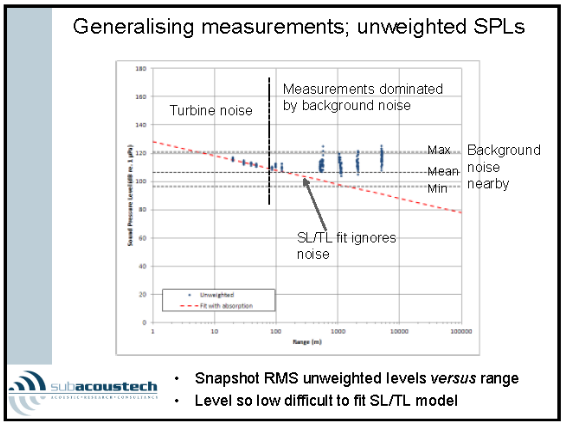

Are windfarms noisy?
BOEM Workshop on the Effects of Noise on Fish, Fisheries, and Invertebrates
Tuesday, March 20, 2012
Dr J Nedwell
subacoustech environmental

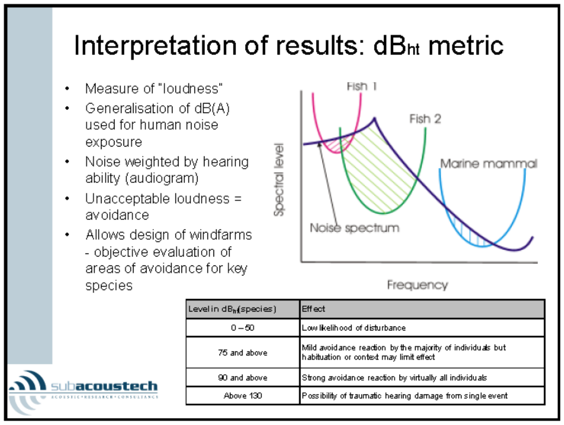

Offshore wind power in UK
• United Kingdom world's 8th biggest producer of wind power; unique wind resource
• Currently 6000 MW, 321 operational wind farms and 3,500 wind turbines
• British electricity suppliers required by law to provide proportion of their supply from renewables
• Further 5 wind farms, 1,300 MW becoming operational in 2012
• Round 3; 2,000 MW installed per year for the next five years, about 28,000 MW of wind capacity by 2020
• Environmental effects of noise biggest environmental issue facing industry.
subacoustech



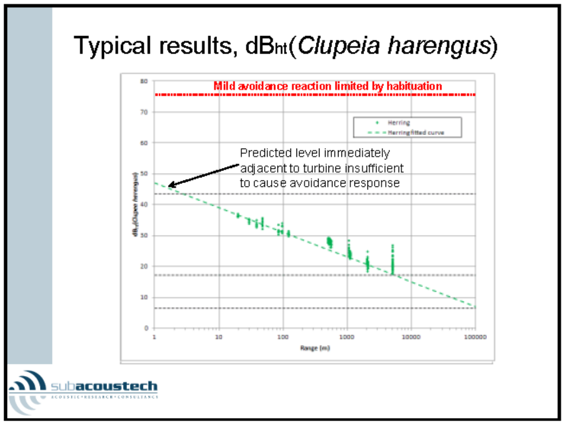








Level in dB_{ht}(species)	Effect
0 – 50	Low likelihood of disturbance
75 and above	Mild avoidance reaction by the majority of individuals but habituation or context may limit effect
90 and above	Strong avoidance reaction by virtually all individuals
Above 130	Possibility of traumatic hearing damage from single event



Temporal considerations

- Area of sea excluded by a individual turbine small, but for 25 years
- Consider habitat loss (area excluded as area times time) based on 50 dB_{ht} (toughest criterion)

Assumptions:

Impact Piling:	A 4m diameter pile installed over 3 hours
Vessel Noise:	3 vessels on site for 7 days
Suction Dredging:	1 vessel on site for 2 days
Trenching:	1 vessel on site for 1 day
Operational Turbine:	Operational for a period of 25 years

50dBht Area of Sea Excluded	Impact Piling (km^2-hrs)	Vessel Noise (km^2-hrs)	Suction Dredging (km^2-hrs)	Trenching (km^2-hrs)	Operational Turbine (km^2-hrs)
Cod	12,000	46	66	57	1
Dab	4,200	< 1	2	< 1	< 1
Herring	17,000	31	100	880	11
B.Dolphin	11,000	2,300	800	980	< 1
H.Porpoise	16,000	1,900	3,800	2,700	6
H.Seal	12,000	220	260	240	< 1

Conclusion: Even allowing for time, estimates of habitat loss caused by operation are dwarfed by all other sources and especially noise from piling

subacoustech

Summary

If noise during windfarm construction can be controlled, best information indicates that noise during operation is unlikely to be a problem

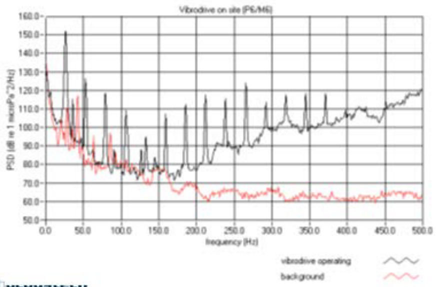
subacoustech

Commercial blasting

subacoustech

Subacoustech Ltd Commercial in Confidence

Vibrodrive on site (24 metres)



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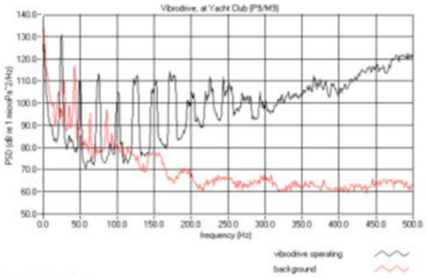
Vibrodrive at yacht club (82 metres)



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Range to 50 dB_{ht} at Windfarm 2

Species	Herring	Cod	Dab	Bottle-nose Dolphin	Striped Dolphin	Harbour porpoise	Harbour seal
Max	80	85	54	85	82	88	64
Mean	60	59	43.4	71	75	81.5	64
Range to 50 dBht	110	110	3	600	600	3000	200

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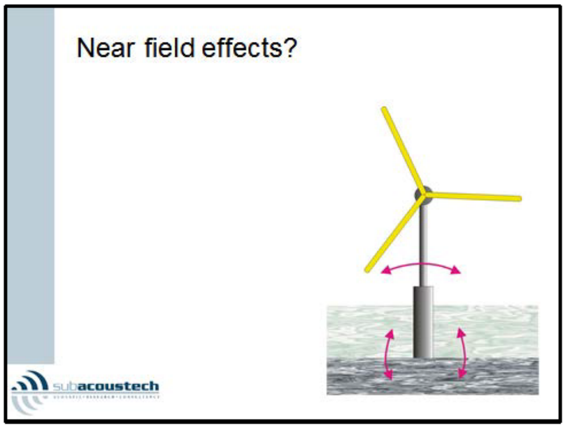
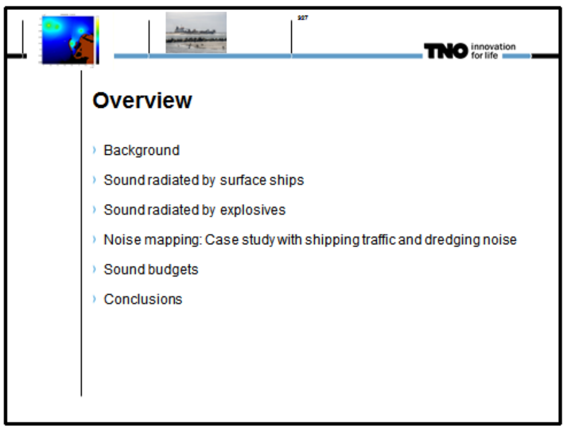
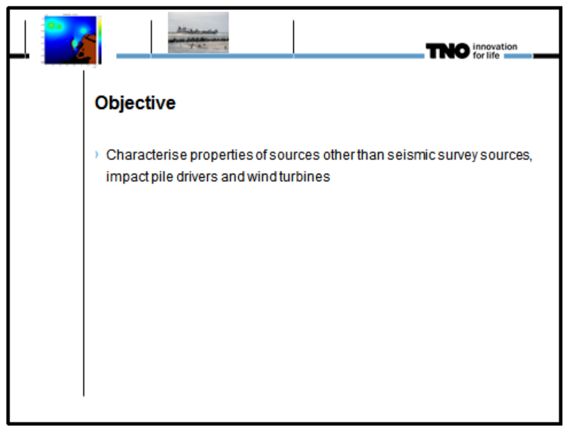
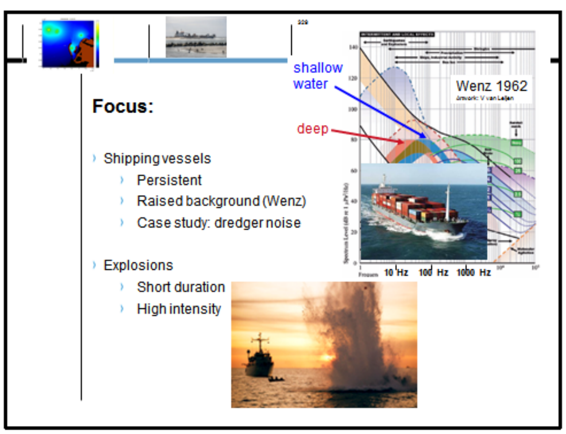
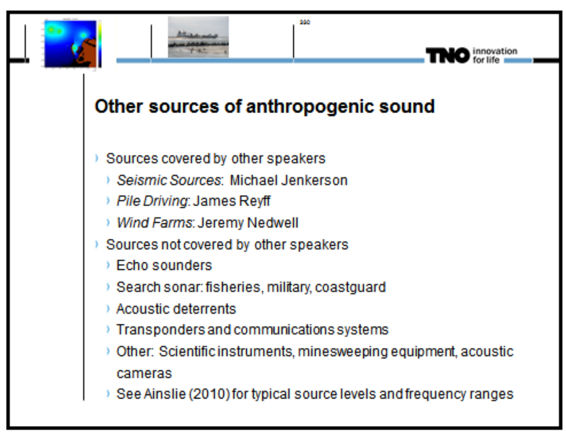

Near field effects?
subacoustech

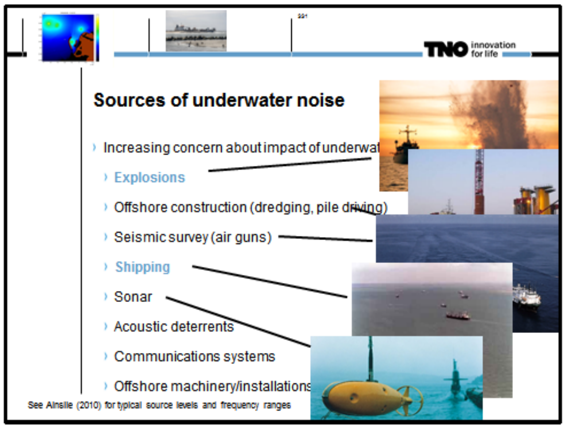

TNO innovation for life
Other Anthropogenic Sources of Interest
M A Ainslie
Effects of Noise on Fish, Fisheries, and Invertebrates: A BOEM Workshop on Data Gaps and Research Needs, 20-22 March 2012, Town and Country Resort, San Diego, CA

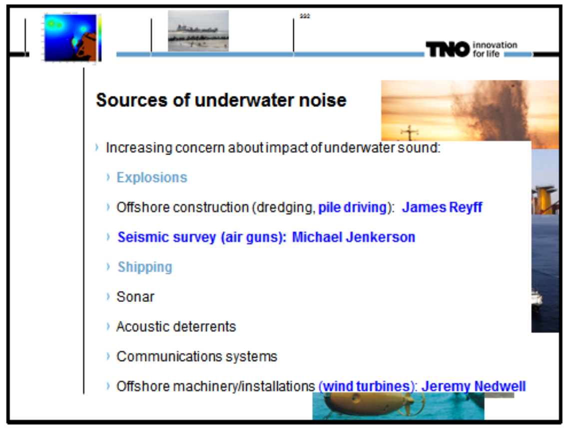

TNO innovation for life
Overview
Background
Sound radiated by surface ships
Sound radiated by explosives
Noise mapping: Case study with shipping traffic and dredging noise
Sound budgets
Conclusions

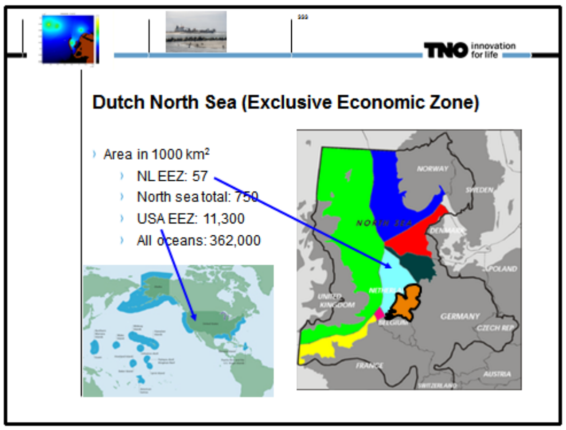

TNO innovation for life
Objective
Characterise properties of sources other than seismic survey sources, impact pile drivers and wind turbines

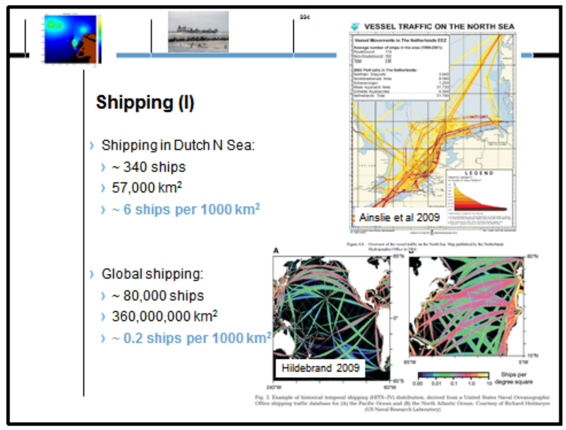

Focus:
Shipping vessels
Persistent
Raised background (Wenz)
Case study: dredger noise
Explosions
Short duration
High intensity
shallow water
deep
Wenz 1962
10 Hz
100 Hz
1000 Hz

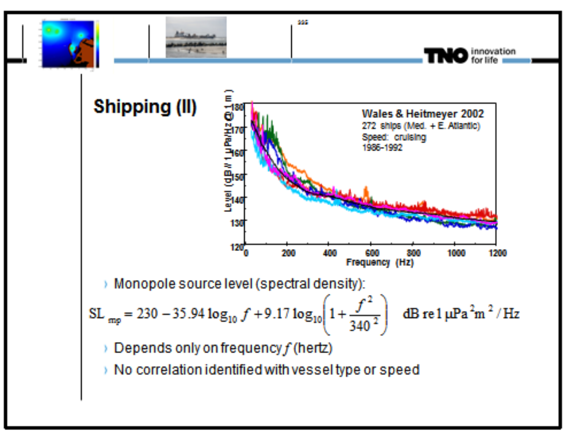

TNO innovation for life
Other sources of anthropogenic sound
Sources covered by other speakers
Seismic Sources: Michael Jenkerson
Pile Driving: James Reyff
Wind Farms: Jeremy Nedwell
Sources not covered by other speakers
Echo sounders
Search sonar: fisheries, military, coastguard
Acoustic deterrents
Transponders and communications systems
Other: Scientific instruments, minesweeping equipment, acoustic cameras
See Ainslie (2010) for typical source levels and frequency ranges

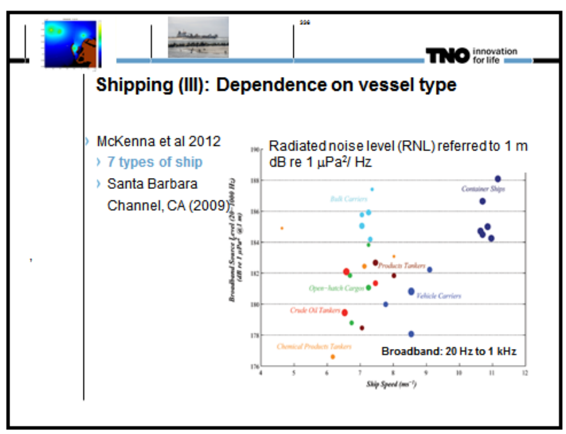

TNO innovation for life
Sources of underwater noise
Increasing concern about impact of underwat
Explosions
Offshore construction (dredging, pile driving)
Seismic survey (air guns)
Shipping
Sonar
Acoustic deterrents
Communications systems
Offshore machinery/installations
See Ainslie (2010) for typical source levels and frequency ranges


TNO innovation for life
Sources of underwater noise
Increasing concern about impact of underwater sound:
Explosions
Offshore construction (dredging, pile driving): James Reyff
Seismic survey (air guns): Michael Jenkerson
Shipping
Sonar
Acoustic deterrents
Communications systems
Offshore machinery/installations (wind turbines): Jeremy Nedwell


TNO innovation for life
Dutch North Sea (Exclusive Economic Zone)
Area in 1000 km²
NL EEZ: 57
North sea total: 750
USA EEZ: 11,300
All oceans: 362,000
NORWAY
SWEDEN
NORTH SEA
DENMARK
POLAND
UNITED KINGDOM
GERMANY
BELGIUM
CZECH REP
FRANCE
AUSTRIA

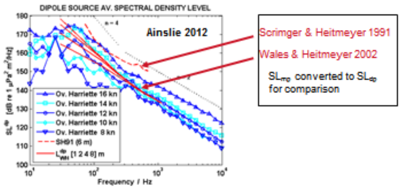

TNO innovation for life
VESSEL TRAFFIC ON THE NORTH SEA
Shipping (I)
Shipping in Dutch N Sea:
~ 340 ships
57,000 km²
~ 6 ships per 1000 km²
Ainslie et al 2009
Global shipping:
~ 80,000 ships
360,000,000 km²
~ 0.2 ships per 1000 km²
Hildebrand 2009


TNO innovation for life
Shipping (II)
Wales & Heitmeyer 2002
272 ships (Med. + E. Atlantic)
Speed: cruising
1986-1992
Level (dB // 1 μPa/Hz @ 1 m)
Frequency (Hz)
Monopole source level (spectral density):
$SL_{mp} = 230 - 35.94 \log_{10} f + 9.17 \log_{10}\left(1 + \frac{f^2}{340^2}\right)$ dB re 1 μPa²m²/Hz
Depends only on frequency f (hertz)
No correlation identified with vessel type or speed


TNO innovation for life
Shipping (III): Dependence on vessel type
McKenna et al 2012
7 types of ship
Santa Barbara Channel, CA (2009)
Radiated noise level (RNL) referred to 1 m
dB re 1 μPa²/ Hz
Container Ships
Bulk Carriers
Products Tankers
Open-hatch Cargo
Vehicle Carriers
Crude Oil Tankers
Chemical Products Tankers
Broadband: 20 Hz to 1 kHz
Ship Speed (ms⁻¹)

Shipping (IV): dependence on ship speed

- Arveson & Vendittis 2000
  - Single cargo ship "Overseas Harriette"
  - Radiated noise level (~ SL_{dp})
  - **Speed: 8 to 16 knots**



Explosions (I)

- Dutch North Sea:
  - Disposal WW2 ordnance: ~10 GJ/y [Ainslie et al 2009] (shock wave)
- Estimated order of magnitude requirement for total North Sea
  - ~ 300,000 tonnes ordnance (300,000 gigajoules)
  - requires **100 GJ/y for 3,000 years**
- Beaufort's Dyke (Irish Sea)
  - ~ 1,00,000 tonnes ordnance (1,000,000 gigajoules)
  - requires **100 GJ/y for 10,000 years**
- Global:
  - Ship shock trials: 3300 GJ/y [Hildebrand 2004]

Explosives (II)

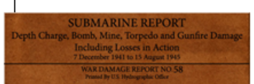
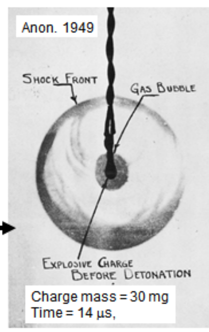
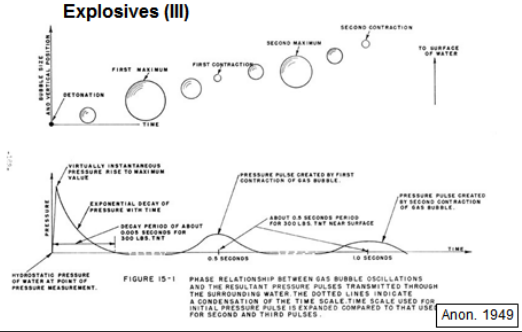

SUBMARINE REPORT
Depth Charge, Bomb, Mine, Torpedo and Gunfire Damage
Including Losses in Action
7 December 1941 to 15 August 1945
WAR DAMAGE REPORT NO 58

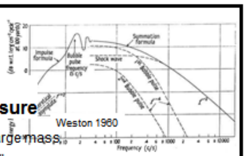
Photo 15-1: German photograph showing gas bubble and shock front 0.000014 second after detonation of 30 milligrams of explosive similar to TNT. This photograph is the result of a double exposure, the first being taken before detonation to show the exact position and shape of the explosive charge.



Explosives (III)



Explosions (IV): Source energy; peak pressure



- Energy depends on TNT equiv. charge mass:
  - Shock wave (> 200 Hz): 1 MJ/kg
  - Bubble pulse (< 200 Hz): ~2 MJ/kg (depth dependent)
- Energy source level (shock wave) [Ainslie 2010]:

$$SL_E \approx 231 + 10\log_{10} W \quad \text{dB re } \mu\text{Pa}^2\ \text{m}^2\ \text{s}.$$

- Peak pressure: Distance at which $p_{z\text{-}p}$ of 20 kPa is reached in deep water:
  - s = 130 m for 2 g seal bomb
  - s = 4.9 km for 100 kg ordnance
  - s = 18 km for 5000 kg shock trial

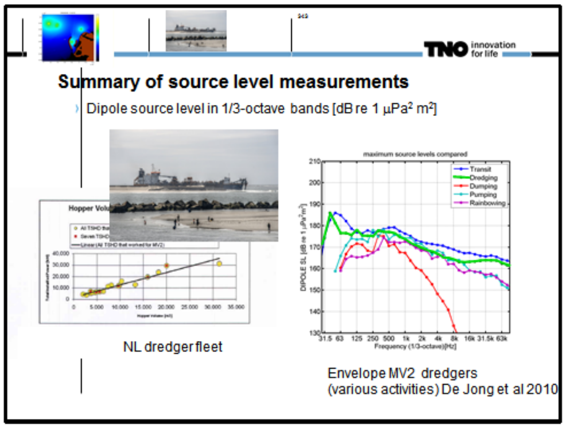
$$p_{z\text{-}p} = 52.4\left(\frac{s}{W^{1/3}}\right)^{-1.13}\ \text{MPa}$$

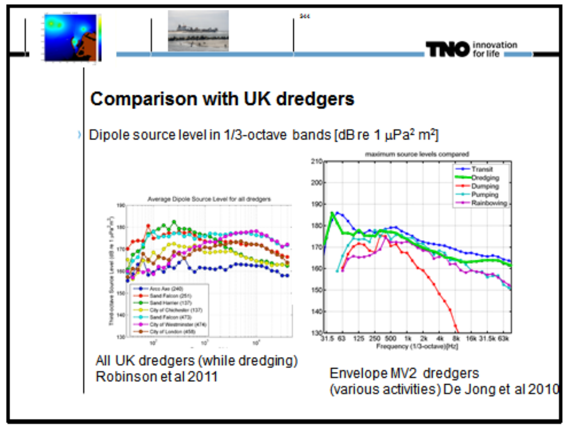
Distance s in m
TNT charge mass W in kg

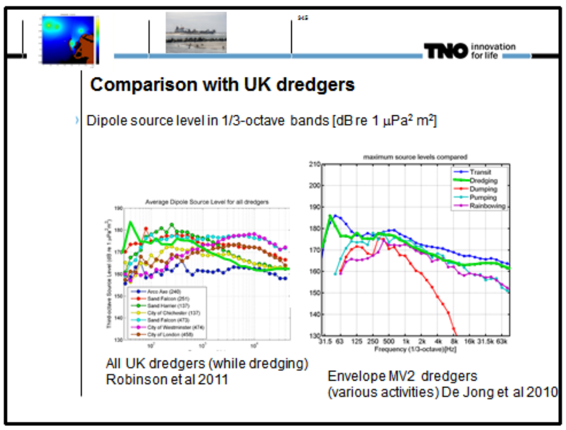
- FHWG "Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities" [FHWG 2008] (assume $L_{z\text{-}p}$ intended)
  - $L_{z\text{-}p}$ = 206 dB re 1 µPa (zero to peak sound pressure = 20 kPa)

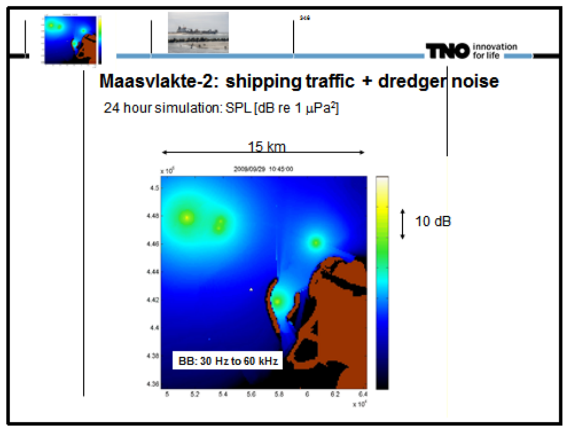
Noise mapping: Case study

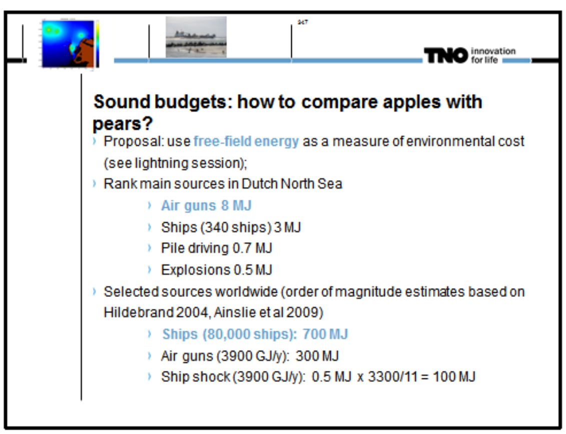
- Heavy shipping traffic with nearby dredgers
- Extension Port of Rotterdam, NL
  - "Maasvlakte 2" (MV2)
- Background measurements, 2008 [Dreschler et al 2009
- Dredger noise measurements, 2009 [de Jong et al 2010]
  - Trailing suction hopper dredgers
  - Source level
- Environmental impact (work in progress)

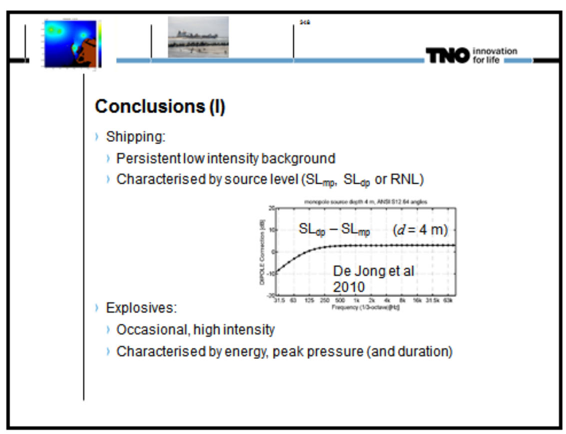

Summary of source level measurements
Dipole source level in 1/3-octave bands [dB re 1 μPa² m²]
NL dredger fleet
Envelope MV2 dredgers
(various activities) De Jong et al 2010


Comparison with UK dredgers
Dipole source level in 1/3-octave bands [dB re 1 μPa² m²]
All UK dredgers (while dredging)
Robinson et al 2011
Envelope MV2 dredgers
(various activities) De Jong et al 2010


Comparison with UK dredgers
Dipole source level in 1/3-octave bands [dB re 1 μPa² m²]
All UK dredgers (while dredging)
Robinson et al 2011
Envelope MV2 dredgers
(various activities) De Jong et al 2010


Maasvlakte-2: shipping traffic + dredger noise
24 hour simulation: SPL [dB re 1 μPa²]
15 km
10 dB
BB: 30 Hz to 60 kHz


Sound budgets: how to compare apples with pears?
Proposal: use free-field energy as a measure of environmental cost (see lightning session);
Rank main sources in Dutch North Sea
Air guns 8 MJ
Ships (340 ships) 3 MJ
Pile driving 0.7 MJ
Explosions 0.5 MJ
Selected sources worldwide (order of magnitude estimates based on Hildebrand 2004, Ainslie et al 2009)
Ships (80,000 ships): 700 MJ
Air guns (3900 GJ/y): 300 MJ
Ship shock (3900 GJ/y): 0.5 MJ x 3300/11 = 100 MJ


Conclusions (I)
Shipping:
Persistent low intensity background
Characterised by source level (SLmp, SLdp or RNL)
SLdp – SLmp (d = 4 m)
De Jong et al 2010
Explosives:
Occasional, high intensity
Characterised by energy, peak pressure (and duration)

Conclusions (II): Free-field energy

- Largest contributors to sound energy in the Dutch North Sea [Ainslie et al 2009]:
  - Air guns, shipping (1 to 10 MJ)
  - Pile driving, explosions (< 1 MJ)
  - Echo sounders, sonar ~ 0.001 MJ
- Worldwide (order of magnitude estimates):
  - Shipping, air guns, explosions (100 to 1000 MJ)
  - Sonar, pile driving?

References (I)

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- Robinson et al 2011, Measurement of underwater noise arising from marine aggregate dredging operations Final Report, MEPF Ref No: MEPF 09/P108, (MALSF, February 2011).*****
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- Wales & Heitmeyer 2002, An ensemble source spectra model for merchant ship-radiated noise, J. Acoust. Soc. Am. 111, 1211-1231 (2002).
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- Weston 1960, Underwater explosions as acoustic sources, Proc. Phys. Soc. LXXVI, pp 233-249 (1960).

www addresses

*http://www.noordzeeloket.nl/overig/bibliotheek.asp (Nota's en rapporten)

**http://www.ibiblio.org/hyperwar/USN/rep/WDR/WDR58/

***http://www.informatiehuismarien.nl/ihm/themas/Shortlist_Ecologische_Monitoring_Wind_op_Zee/Geluidsonderzoek/

****http://www.noordzeeloket.nl/overig/bibliotheek.asp (Zandwinning ... onderwatergeluid)

*****http://www.cefas.co.uk/media/462859/mepf%20p108%20final%20report.pdf

******http://www.dot.ca.gov/hq/env/bio/fisheries_bioacoustics.htm

BOEM: Information needs and data gaps

- Presentation name: Other Anthropogenic Sources of Interest
- Author (affiliation): Michael A Ainslie (TNO)
- Information needs
  - How are source properties related to environmental impact?
- Data gaps
  - Surface ships: Measurements of radiated noise; dependence on ship size, propulsion type, propeller depth …
  - Explosions: Propagation of shock wave in shallow water
  - All sources: Energy budgets, effectiveness of mitigation measures

Initial Thoughts

- 32,200 species of fishes – fishbase.org
  – More speciose than any other vertebrate on the planet
- Found in just about every body of water on the planet
- Therefore, an amazing amount of diversity

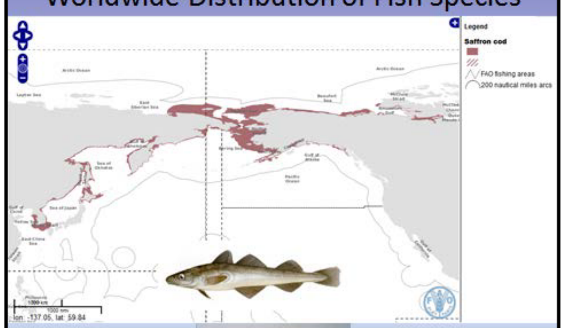
Goals for this Talk

- Acknowledge this diversity, but try to promote categories that fishes can be placed in to allow us to make some generalized predictions of noise exposure responses
- Briefly present several ichthyological topics when considering noise exposure in order to promote further discussion and ideas

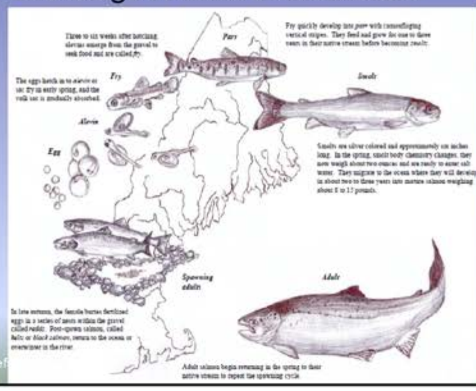
Species Distribution

- Influenced by salinity, temperature, depth, light, presence or absence of land, currents, season, food web, habitat, life stage, reproductive state…………
- And of course our role
  – Fishing
  – Habitat degradation
  – Chemical pollution
  – Noise Pollution?

Worldwide Distribution of Fish Species



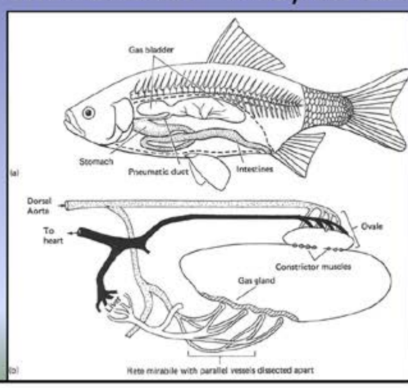
Life Stage Affects Distribution



Anatomical Feature Worth Considering

- Skeleton- cartilage versus bone
  - Chondrichthyans vs. teleosts
  - Cartilage higher elasticity, bone is stronger
- Could extra fat or muscle provide a cushioning from impact--- or be more damaging?
- Reproductive maturity could also have an effect
  - Larger, developed ovaries or testes could also be more susceptible to damage
- Size of the fish---Whale shark vs. anchovy?
  - Life stage sizes

Swim Bladder—A Key Variable



Swim Bladder Size

Physiological Responses

- Extreme differences in response to noise exposure likely dependent on the presence or absence of swim bladder
- Other physiological responses could be conserved throughout most fishes
  - Rapid change in state of gasses in blood, tissues, etc..
  - Production of stress hormones or other stress responses
- See Halvorsen talk on Injury and Effects on Fish Physiology

Hearing Abilities of Fishes

- High diversity and species specific
- Fairly easy to divide fish into different categories based on a continuum of ear adaptations
  - Though it should be acknowledged that only a small fraction of fishes have had their hearing examined
- Important when considering potential masking of auditory scene as well as detection distance of a noise source
  - How different is the auditory scene between different species?
  - Between different life stages?
- See Mann and Fay talks on fish hearing, communication, and auditory scene

Hearing Thresholds for Select Species

160

Salm o

Table 1: Groupings of Fish by Sensitivity to Seismic Sound and Ecological Association

Fish Categories Arranged by Sensitivity to Sound		Large Pelagic	Small Pelagic	Demersal	Reef	Shallow/Estuary	In River
		Ecological Associations					
	gas bladder connected to ear		Herring Sprat Shad	Weakfish Deep-sea cod	Squirrel-fish	Catfish Carp Goldfish	Dace Minnow
	gas bladder close to ear			Cod Haddock Saithe	Red Snapper		
	gas bladder distant from ear	Dorado	Horse Mackerel	Spot	Wrasse	Sand-smelt	Salmon Eel
	no gas bladder	Sharks	Mackerel	Plaice Sole		Flounder	
	fish eggs and larvae	Dorado larvae	Herring Larvae	Cod larvae	Red Snapper larvae	Catfish larvae	Salmon eggs

100 1000

Frequency in Hz

Communication

- Many species use sound for communication
  - Sounds typical occur during spawning or agonistic encounters
  - Species specific call rates, frequencies
  - Species call at different times of the year
  - Different methods for producing sounds
  - We likely have only begun to understand the extent that acoustic communication exists among fishes
- Anthropogenic noise could be masking these important sounds

Diversity in Fishes
Brandon M. Casper
University of Maryland

- Can we reliably make broad generalizations about effects of sound on such a diverse group of species?
- Can we safely predict injury response based on the type as well as presence or absence of the swim bladder?
- What other anatomical features may be useful when predicting effects of noise exposure?

Diversity in Fishes
Brandon M. Casper
University of Maryland

- Are physiological effects of noise exposure not caused by swim bladder motions consistent in all fishes?
- Can we correlate a fish's hearing category and/or ability to produce sounds for communication with its auditory scene?
- If anthropogenic noise is masking a fish's auditory scene, how important is masking in terms of the overall fitness of the fish?

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Low frequency Controlled Exposure Experiments on cephalopods

Marta Solé, Marc Lenoir, Mercè Durfort, Manel López-Bejar, Antoni Lombarte, Mike van der Schaar and Michel André

Technical University of Catalonia, BarcelonaTech, Spain
Institute of Neurosciences of Montpellier, France
University of Barcelona, Barcelona, Spain
Renewable Marine Resources Department, (ICM-CMIMA-CSIC), Spain

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Antecedents:

- Between September and October 2001 and in October 2003 the natural rhythm of annual records of giant squids (*Architeuthis dux*) stranded in the area of the West coast of Asturias (Spain) experienced a significant increase (Guerra et al., 2004a, 2004b; 2011)

- These events were coincident with the proximity of vessels using compressed air guns for geophysical prospection, producing sound waves of low frequency (below 100 Hz) and high intensity (200 dB re 1 µPa at 1m)

- None of the lesions could be related to known causes of death, however, the presence of geophysical prospecting vessels suggested that the death of these animals could be related to effects produced by noise exposure (Guerra et al., 2004b)

- The concern on the effects of climate change and of increasing ambient noise levels on cephalopods sensory systems combined with a lack of information on the sensitivity of the statocysts when exposed to noise, lead to a series of Controlled Exposure Experiments on Mediterranean *Sepia officinalis, Octopus vulgaris, Loligo vulgaris* and *Illex coindeti*

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Capture and Maintenance :

- Cephalopod specimens were caught from the Catalan Coast (NW Mediterranean Sea) over a period of 2 years, between February 2008 and August 2010, and kept in a closed system of recirculating natural seawater (at 18-20ºC, salinity 35‰ and natural oxygen pressure) consisting of 2 mechanically filtered fiberglass reinforced plastic tanks of 2000L capacity, that were connected to each other.

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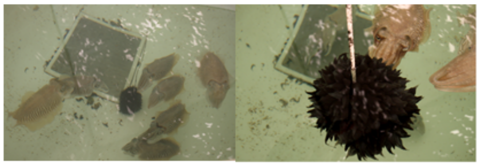
Cephalopod specimens :

- A first set of 30 individuals of *Sepia officinalis* were caught and kept for several weeks to observe and analyse their adaptation to captivity. These animals were swimming, eating, mating, laying eggs and behaving normally over the entire observation period.

- The analysis (LM, SEM & TEM) of their inner sensory statocyst epithelium was used as a first control and did not reveal any lesion.



- 164 adult and young specimens from *Sepia officinalis*, 10 from *Octopus vulgaris*, 9 from *Loligo vulgaris* and 4 from *Illex coindetii*

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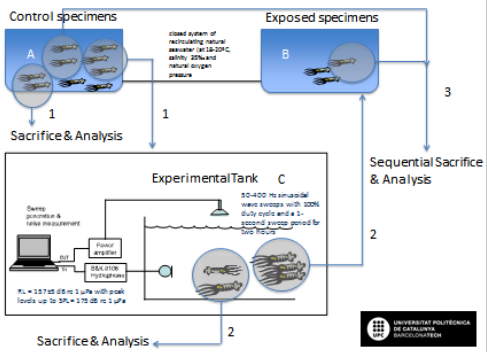
Protocol



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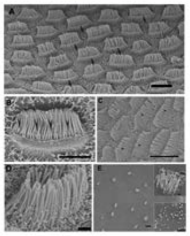
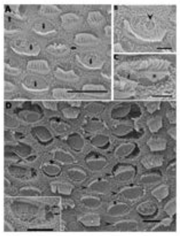
Results (1/6):



SEM. Control *Sepia officinalis (A & B); Octopus vulgaris (C & D) macula* statica princeps; *Octopus vulgaris* inner sac statocyst morphology (E)



SEM. *Sepia officinalis msp*, presents different levels of lesions. A-C: sacrificed immediately after sound exposure. D: sacrificed 48h after

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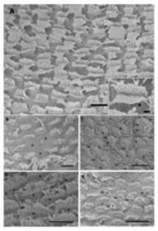
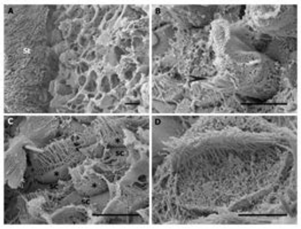
Results (2/6):



SEM. Sepia officinalis (A, B, E) and *Octopus vulgaris* (C, D) *msp*, A-D: sacrificed 48h after sound exposure. E: sacrificed 72h after sound exposure



SEM. Sepia officinalis msp, sacrificed 96h after sound exposure.

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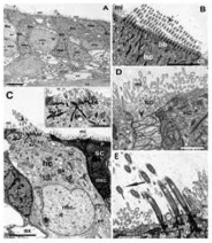
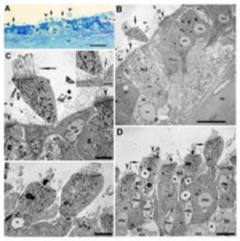
Results (3/6):



TEM. Cellular organization of control *Sepia officinalis* (A, C) and *Octopus vulgaris* (B, D, E) *msp*



LM (A) and TEM (B-E). *Octopus vulgaris macula statica princeps (msp)*, from an individual sacrificed 48h after sound exposure.

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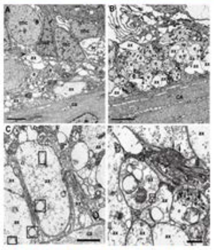
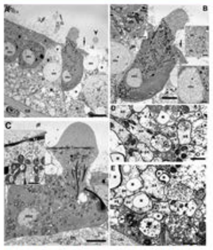
Results (4/6):



TEM. General nervous organization of *Sepia officinalis macula statica princeps* (A, B) and efferent and efferent innervations of the *macula* epithelium in the statocyst of *Octopus vulgaris* (C, D). Control animals.



TEM. *Octopus vulgaris macula statica princeps (msp), from an individual* sacrificed 48h after sound exposure

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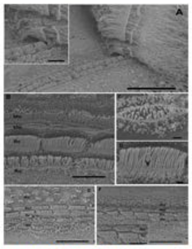
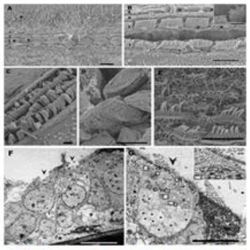
Results (5/6):



SEM. *Sepia officinalis* (A-D) and *Octopus vulgaris* (E, F) *crista-cupula* system. Control animals.



SEM (A-E) and TEM (F, G). *Sepia officinalis* criste. A, B, insert in B: sacrificed immediately after sound exposure. C-E: sacrificed 96h after sound exposure. F, G: sacrificed 24h after sound exposure. Insert in G: sacrificed 48h after sound exposure

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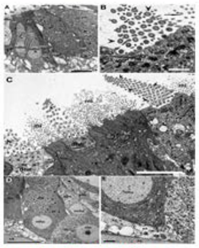
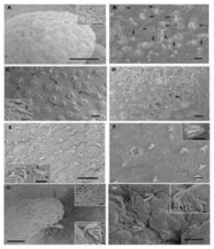
Results (6/6):



TEM. *Octopus vulgaris crista* general morphology (A-C) and nervous organization (D, E). Control animals



SEM. *Sepia officinalis*. Linning ephitelium of animals affected by sound (A-F) and control specimens (G, H)

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Conclusion, Future Research and Perspective:

These results showed:
- lesions new to cephalopod pathology
- exposure to sounds may cause serious lesions on the statocyst sensory epitheliums.
- these lesions are consistent with a massive acoustic trauma found in terrestrial species.

Further investigation is needed to:
- determine threshold levels and to quantify the lesions in the statocysts;
- explain the mechanism onset of these lesions, in particular to determine if the laboratory conditions can be reproduced in open environments;
- definitively understand if these animals are more sensitive to particle motion or acoustic pressure, or to a combination of both.

Future electrophysiological experiments coupled with post-mortem imaging techniques are needed to determine the tolerance to noise thresholds of cephalopods.

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Low frequency Controlled Exposure Experiments on Cephalopods

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Technical University of Catalonia, BarcelonaTech, Spain
michel.andre@upc.edu

Needs to:

- **determine sound characteristics, threshold levels and quantify the lesions in the statocysts under controlled exposure experiments;**
- **explain the mechanism onset of these lesions, in particular to determine if the laboratory conditions can be reproduced in open environments;**
- **look for effects on larvae and possible recovery processes**
- **definitively understand if these animals are more sensitive to particle motion or acoustic pressure, or to a combination of both.**

Injury and Effects on Fish Physiology

Michele B. Halvorsen

Michele.halvorsen@pnnl.gov

Bureau of Ocean Energy Management Workshop
San Diego, CA March 2012

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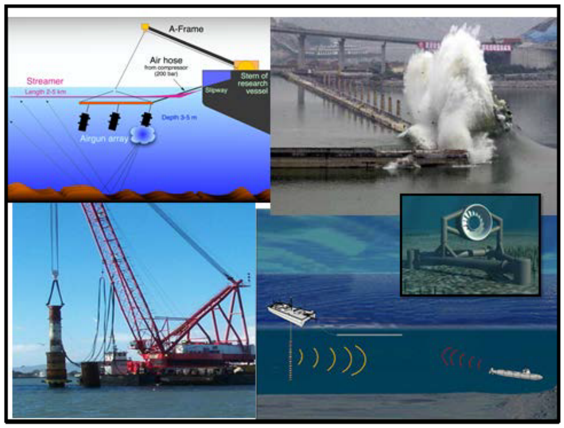

Underwater Noise - Components

- Sound is energy that can do work – thus, it can cause damage
  - Frequency
  - Intensity
  - Spectrum
- Two components of any sound wave
  - Pressure
  - Particle motion
- Near field (pressure & particle motion)
- Far field (mostly pressure, but some motion)

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Underwater Noise Effects

- Energy development in marine environments
  - Installation
  - Decommissioning
  - Exploring
- Concern for aquatic animals
  - Behavioral responses
  - Onset of effects
    - Barotrauma
    - Auditory - TTS
- Pile driving exposures in the laboratory
- Blasting exposures
- Tidal turbine exposures

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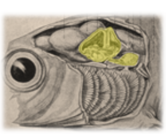
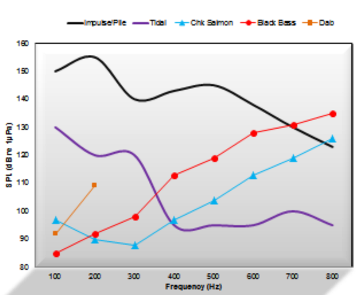
Underwater Noise Effects - Auditory



Auditory
- Changes in hearing threshold
- Hair cell damage



Salmon: Halvorsen et.al., 2009; Bass: Holt et.al., 2010; Dab: Chapman & Sand 1973; Karl von Frisch- ear

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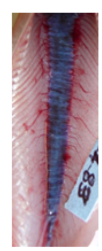
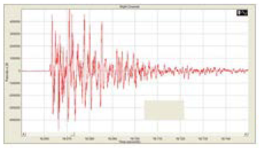
Underwater Noise Effects - Barotrauma

- Contraction and expansion of free gas in body
- Change in state of gas from soluble to free-form
- Swim bladder – (buoyancy state, hearing)
  - Rupture
  - Damage surrounding tissues
- Natural blood-gases
  - Solubility changes
  - Gas comes out of solution
    - Bubbles form in blood and tissues
    - Damage to tissues, vessels, organs
- Equilibration state is very important
  - Neutrally buoyant fish
  - Tissue-gas equilibration with surrounding water
  - Physiological state of fish at exposure is critical

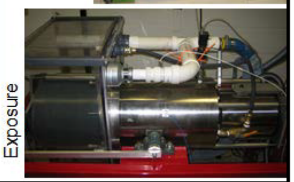


Exposure and Assessment

- Expose fish to impulsive sounds
  - Sound Exposure Level
- Barotrauma injury assessments of neutrally buoyant fish
  - Examples of injuries



Fish loading



Exposure

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Physiological Assessment

- Expose fish
- Biological exam of fish
  - Death
  - Auditory system - TTS
  - Tissue damage- Barotrauma
  - Ultimately, reported data difficult to interpret and extrapolate
    - what does 'x' number of injuries mean to fish ?
- Tool: assessment of the biological response
- Fish Index Trauma (FIT Model)
  - Quantifies a qualitative assessment
  - Addresses 'meaning' of injuries
  - Monitoring / effects criteria

Halvorsen, MB BOEM San Diego 2012

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Barotrauma Effects Response Model

Fish Index Trauma - FIT

Response Weighted Index (RWI)

RWI = ∑ (W x I)

Mortal Injury Wt 5	Moderate Injury Wt 3	Mild Injury Wt 1
Dead within 1 hr	Hemorrhage: gut, capillaries	Hematoma : fins
Hemorrhage: major organs	Hematoma: major organs	deflated swimbladder
Damage: swimbladder	Hematoma: swimbladder	

- Ranked by physiological costs or impairments
- Grouped by *Mortal*, *Moderate*, *Mild*

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RWI = Σ (Injury x Weight)

	Swim bladder hematoma	Liver hemorrhage
Injury	1	1
Weight	3	5
Calc (I x W)	3 x 1	5 x 1
Product	3	5
Σ	3 + 5	
RWI	**8**	

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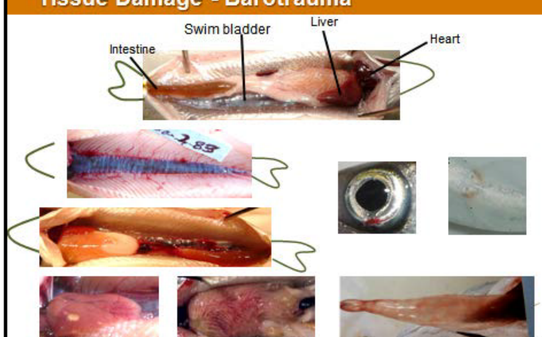
Tissue Damage - Barotrauma



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Brief Summary

- Defined trauma threshold:

SEL_{cum} 210 dB re 1μPa²·s	SEL_{cum} 211 dB re 1μPa²·s
SEL_{ss} 181 dB re 1μPa²·s	SEL_{ss} 179 dB re 1μPa²·s
960 number of impulses	1920 number of impulses

- FIT model has been applied to various sound sources
  - Pile Driving (Halvorsen et al. 2011)
  - Rock Blasting (Carlson et al. 2011)
  - Tidal Turbine (Halvorsen et al. 2011)

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Injury and Effects on Fish Physiology

Michele B. Halvorsen Battelle, Pacific Northwest National Laboratory

Data Gaps:

- 2 injury pathways; Hearing and Barotrauma
- Define a level of detrimental TTS, probably specific to hearing sensitivity group
- Combining TTS with Barotrauma? – Barotrauma may be more sensitive
- Further development of the FIT Model
- Performance testing on fish after ensonification
  - TTS and Barotrauma

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Injury and Effects on Fish Physiology

Michele B. Halvorsen Battelle, Pacific Northwest National Laboratory

Needs/ Gaps

- Effects of depth on fish response (depth might be protective)
- Extrapolation of biological responses to other signals
- Testing various size classes within a species
- Different groups: Physoclistous, physostomous, no swim bladder
- Understand process of injury accrual (do silent breaks = "restart" for accumulation?)
- Exploration of assays to detect the presence of specific proteins (biomarkers) in blood
- Appropriate metric or group of metrics
- Received sound levels: pressure and particle motion

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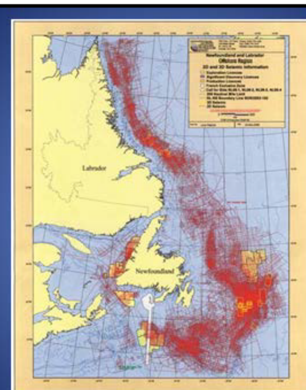
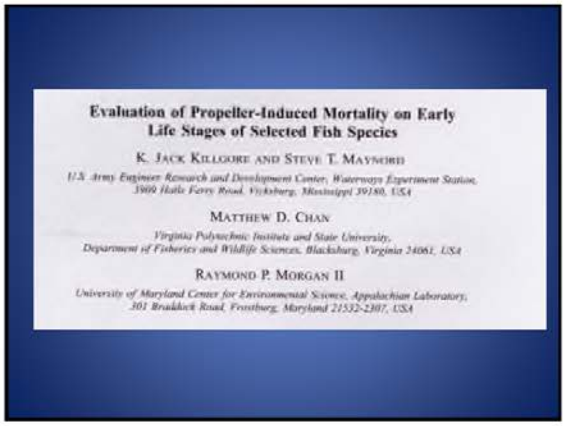
A FEW WORDS ABOUT SOUND AND INVERTEBRATE INJURY

Dr. Jerry Payne
Fisheries and Oceans
Canada





Evaluation of Propeller-Induced Mortality on Early Life Stages of Selected Fish Species

K. Jack Killgore and Steve T. Maynord

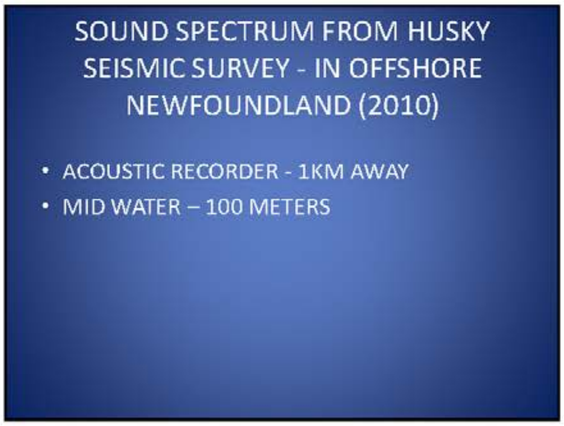
U.S. Army Engineer Research and Development Center, Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180, USA

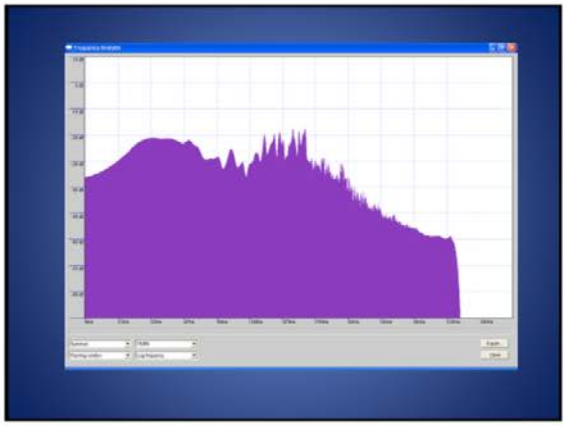
Matthew D. Chan

Virginia Polytechnic Institute and State University, Department of Fisheries and Wildlife Sciences, Blacksburg, Virginia 24061, USA

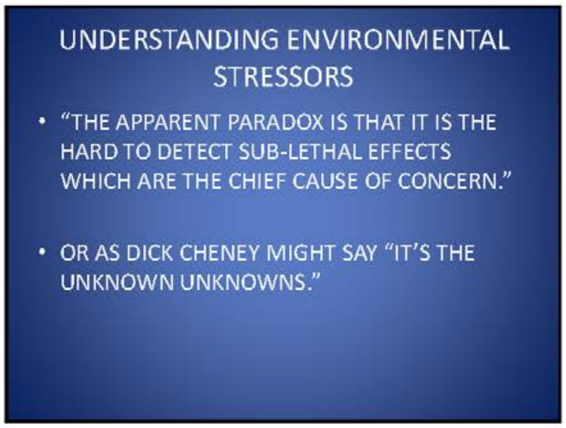
Raymond P. Morgan II

University of Maryland Center for Environmental Science, Appalachian Laboratory, 301 Braddock Road, Frostburg, Maryland 21532-2307, USA

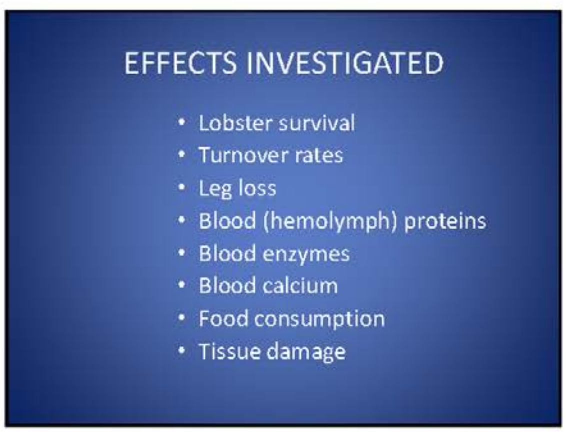


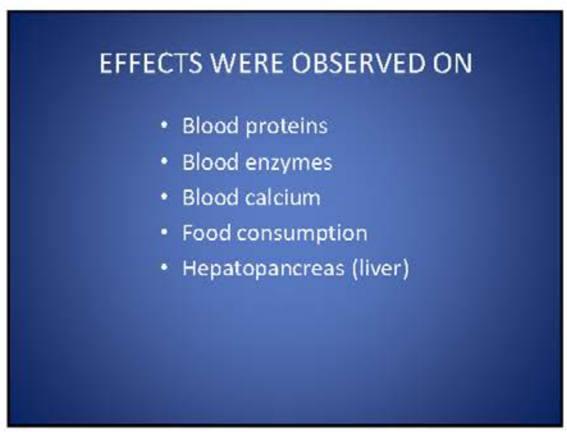



Instant Mortality is Not a Concern with Seismic – It's
the Question of Important
Sub-lethal Effects.
Codfish
Crab
Lobster
Smelt
Jellyfish
Shrimp
Cunners
Capelin


UNDERSTANDING ENVIRONMENTAL STRESSORS
• "THE APPARENT PARADOX IS THAT IT IS THE HARD TO DETECT SUB-LETHAL EFFECTS WHICH ARE THE CHIEF CAUSE OF CONCERN."
• OR AS DICK CHENEY MIGHT SAY "IT'S THE UNKNOWN UNKNOWNS."


Animals were maintained in aquaria at DFO for long term observation and sampling.


EFFECTS INVESTIGATED
• Lobster survival
• Turnover rates
• Leg loss
• Blood (hemolymph) proteins
• Blood enzymes
• Blood calcium
• Food consumption
• Tissue damage


EFFECTS WERE OBSERVED ON
• Blood proteins
• Blood enzymes
• Blood calcium
• Food consumption
• Hepatopancreas (liver)

- RESULTS DEMONSTRATED THE VALUE OF STUDIES ON SUBLETHAL EFFECTS
- WITH THE UNDERSTANDING THAT SERIOUS INJURY IS NOT NECESSARILY IMPLIED
- A SLIGHT CHANGE IN AN ENZYME OR HORMOMAL RESPONSE WOULD NOT BE ACCORDED THE SAME STATUS AS HISTOPATHOLOGY
- WEIGHT OF EVIDENCE APPROACH REQUIRED

BIOMARKERS AND PROVISIONAL ADVICE FOR HIGHER ORDER EFFECTS

- LOBSTER MORBIDITY
- EGG DEVELOPMENT IN SNOWCRAB
- IF ANY SUCH INJURY HAD BEEN FOUND, ADVICE TO REGULATORS WOULD HAVE BEEN "COLORED".

- LIKEWISE, BIOMARKER STUDIES ON FISH HAVE BEEN IMPORTANT FOR ADVICE
- E.G. STUDY BY SONG, MAN, COTT, HANNA, POPPER (SEISMIC IN A CANADIAN RIVER).
- HASTINGS (SEISMIC OFF AUSTRALIA)

Snow Crabs Seismic

CAN ANIMALS HABITUATE TO SOME EXTENT TO THE POTENTIAL INJURIOUS EFFECT OF NOISE

Hear Res. 2006 Mar;213(1-2):118-29. Epub 2006 Feb 8.

Increased resistance to free radical damage induced by low-level sound conditioning.

Harris KC, Bielefeld E, Hu BH, Henderson D.

Center for Hearing and Deafness, University at Buffalo, Buffalo, NY 14214, USA. harriskc@musc.edu

Arthur N. Popper · Michael Salmon
Kenneth W. Horch

Acoustic detection and communication by decapod crustaceans

Accepted: 8 January 2001 / Published online: 21 February 2001
© Springer-Verlag 2001

BIG ISSUE: CRUSTACEAN BEHAVIOR AND FISHERIES

- NO OVERT SIGNS OF SCARING IN EITHER SNOWCRAB, LOBSTER OR SHRIMP

GUIDANCE FROM OLD TESTAMENT

"ASK THE FISH OF THE SEA AND THEY WILL DECLARE UNTO THEE"

BOOK OF JOB 12:8

HOW GOOD WILL THEIR ADVICE BE?

SCARING RADIUS FOR COMMERCIAL CRUSTACEANS: IF SCARED

→ 0.02 km

→ 0.2 km

→ 2.0 km

→ 20 km

- DIFFICULT TO ANSWER IN ANY QUANTITATIVE SENSE
- FIRST ROUGH CUT: STUDY ON CORRELATION BETWEEN SEISMIC TRACKS AND CATCH

Effect of Seismic Energy on
Snow Crab (*Chionoecetes opilio*)

By

LGL LIMITED
environmental research associates

and

Oceans LTD.

For

Environmental Studies Research Fund
444-7th Avenue S.W.
Calgary, AB
T2P 0X8

File No.: CAL-1-00364

7 November 2003
SA694

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FISHERIES RESEARCH

The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia

Gregory D. Parry, Anne Gason

News and events > News Archive

New marine noise research to inform offshore wind farm rollout

30 November 2011

A new study of the impact of noise on the behaviour of fish and crustaceans is to inform the development of offshore wind farms around the UK.

The innovative new University of Hull research project uses underwater television, high frequency sonar and playback system to replicate and monitor the effect of any artificial noise in the sea, such as ships, concrete piling strokes or offshore wind turbines.

<Dr Rafael Perez-Dominguez

WHAT ABOUT ZOOPLANKTON?

- MAJOR KNOWLEDGE GAP ALL AROUND
- FOLLOW THE FOOT STEPS OF SUCH AGENCIES AS PARCOM AND ICES IN TOXICITY ASSESSMENTS WHEREBY FOCUS IS ON A FEW REPRESENTATIVE SPECIES, E.G. A COPEPOD IN THE CASE OF AN INVERTEBRATE?
- SCARING OF ZOOPLANKTON ASSEMBLAGES

CALANUS FINMARCHICUS: A KEYSTONE CANDIDATE

- ONE OF THE MOST COMMONLY FOUND SPECIES IN THE NORTH SEA AND NORWEGIAN SEA, AS WELL AS IN ARCTIC AND SUB-ARCTIC WATERS OF THE N.W. ATLANTIC
- PROVIDES FOOD FOR A VARIETY OF MARINE ORGANISMS – FISH, WHALES, SHRIMP
- AMENABLE TO LAB AND FIELD MESOCOSM STUDIES: BEHAVIOR, INJURY

WHAT ABOUT POTENTIAL EFFECTS ON SEDIMENTARY INVERTEBRATE COMMUNITIES

- SEISMIC
- MULTIBEAM - SOUNDERS

SQUID: HIGH PROFILE SPECIES

- THE STUDY NOTING EFFECTS ON EXPOSURE TO SOUND/VIBRATION INDICATES NEED FOR FURTHER INVESTIGATION.
- ALSO RELEVANT FOR CONCERNS ABOUT FIELD OBSERVATIONS ON GIANT SQUID

GROWTH OF AQUACULTURE SHRIMP

- THE STUDY NOTING EFFECTS ON CHRONIC EXPOSURE TO LOW LEVELS OF SOUND/VIBRATION INDICATES NEED FOR FURTHER INVESTIGATION
- SEAHORSE AS SUPPORTING EVIDENCE

CHIDING BY ROYAL SOCIETY

NO SCIENTIST IS EVER AT A LOSS FOR MORE STUDIES THAN HE THINKS CAN BE DONE TO DEFINE THE TOXICITY OF A CHEMICAL. IN COMMITTEE ONE SOMETIMES GETS THE FEELING THAT NO ONE WITHOUT A DEGREE IN TOXICOLOGY SHOULD BE ALLOWED TO TAKE A BATH.

ROYAL SOCIETY

INVERTEBRATE BEHAVIOR: THE HERD OF ELEPHANTS IN THE ROOM

- HOW CAN WE APPROACH DICK CHENEY'S "UNKNOWN UNKNOWNS" WITH RESPECT TO POTENTIAL EFFECTS ON COMMUNICATION, FORAGING, NAVIGATION, PREDATOR-AVOIDANCE, REPRODUCTION AND HABITAT SELECTION?
- WHEN THE "FORCE" IS MAINLY FOR RESEARCH NEEDS OF KEY CLIENTS.

On the attraction of larval fishes to reef sounds

David A. Mann[1,*], Brandon M. Casper[1], Kelly S. Boyle[2], Timothy C. Tricas[2]

SOUND AND INVERTEBRATE INJURY
DR. JERRY PAYNE
FISHERIES AND OCEANS, CANADA
CONCLUSIONS (1 SLIDE)
RECOMMENDATIONS (2 SLIDES)

CONCLUSIONS

1. The slate is mostly blank with respect to studies on the potential for various sources of sound to effect delayed mortality or sub-lethal injury in invertebrates.
2. The few studies that have been carried out with crustaceans and a cephalopod indicate a potential for sound to elicit sub-lethal biochemical/physiological/histopathological responses.
3. It is important to note that such biomarker responses come in different colors, from the benign to potentially injurious.
4. The information gap on invertebrates makes it all but impossible – in most instances – to pass informed opinion on questions related to potential risks/no risks associated with sounds from seismic, pile-driving, sonar or vessel traffic.

RECOMMENDATIONS

1. Carry out laboratory or small scale mesocosm studies to assess the effects of sound on commercially important invertebrates such as lobster, crab, shrimp, scallop and squid. Parameters for consideration would include behavior and pathology which could involve biochemical, physiological and histopathological endpoints.
2. Although difficult, a special attempt should be made to focus on deriving some dose-response relationships, including under chronic conditions of exposure.
3. Carry out exposures with actual sources of sound or sound tracks, to the extent feasible.

4. Guide agencies and industry on the extent to which field studies could be useful for assessing effects on animal behavior – e.g. the question of seismic and alteration of crustacean catch.
5. Avail of opportunistic field studies to obtain biomarker data e.g. caging of animals in relation to pile driving or seismic programs.
6. Provide information (if only for assurance) on whether zooplankton assemblages might be significantly affected by loud sounds e.g. seismic surveys. Carry out dose-response studies to assess sub-lethal and potentially injurious effects in a keystone zooplankton species such as Calanus.
7. Encourage basic studies to grapple with the difficult issue of subtle but possibly important effects on animal behavior. Priority would likely be regionally driven in relation to specific species and concern.

RECENT LEGAL RULINGS

- Environmentalists failed to establish that there was a probability of irreparable harm to marine mammals – Justice Michael Kelen
- " I am satisfied that the Inuit will suffer irreparable harm if an injunction is not granted" – Justice Sue Cooper

Importance of Sounds for Animals– Sound Production and Sound Detection

David Mann

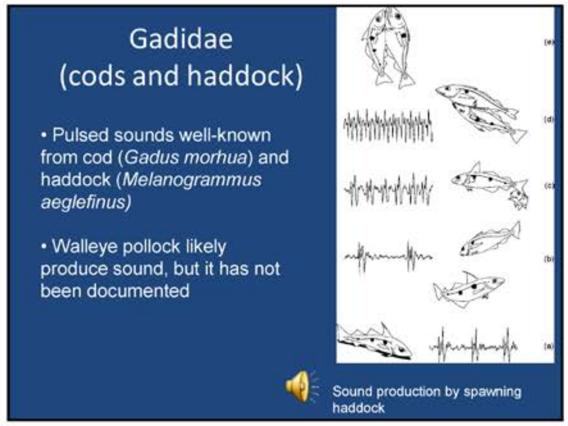
UNIVERSITY OF SOUTH FLORIDA COLLEGE OF MARINE SCIENCE

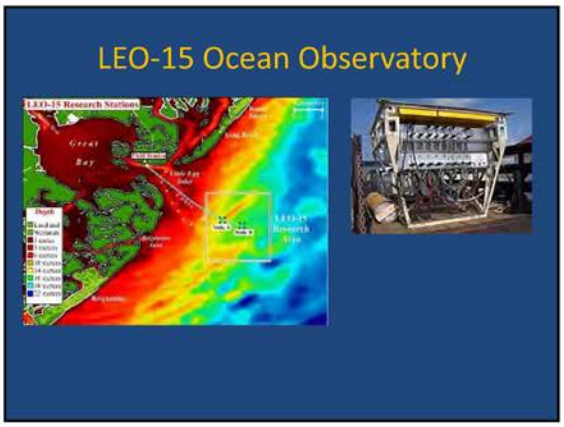
Loggerhead INSTRUMENTS

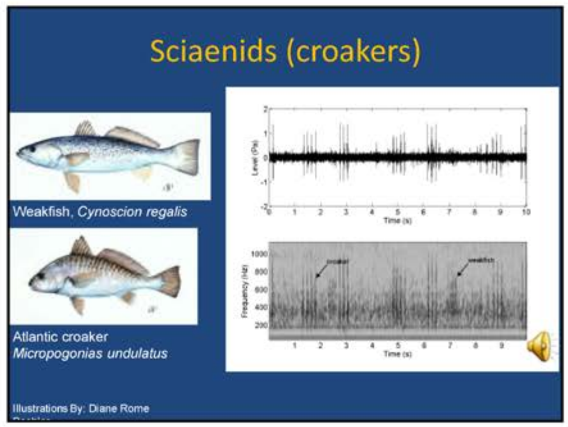
Invertebrate Sound Production

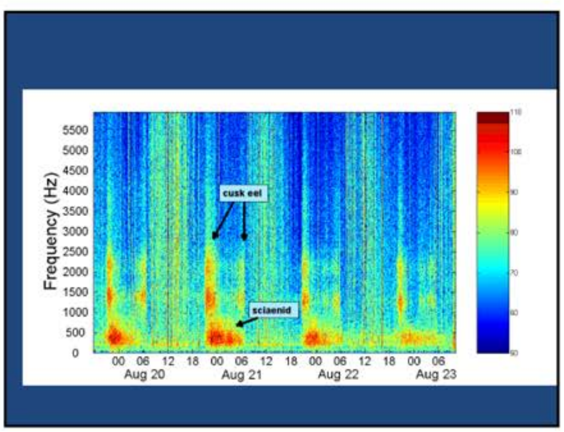
- Snapping shrimp—generate a cavitation bubble to produce very loud, broad-band sound
- Spiny lobster—associated with defense. Not clear it is audible to the lobster.
- No known sounds from squids or octopi

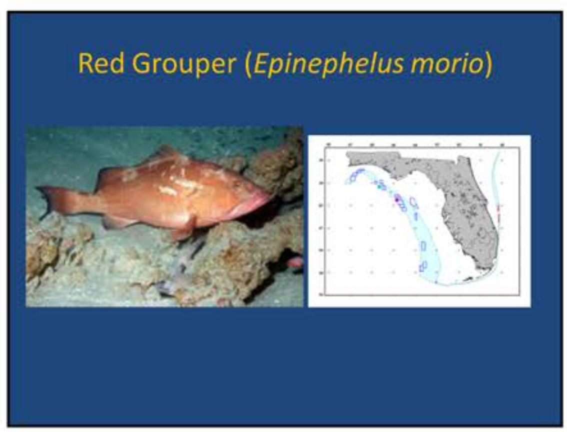

Commercially Important Soniferous Fish Families
• Gadidae (cods)
• Sciaenidae (croakers and drums)
• Serranidae (groupers)


Gadidae (cods and haddock)
• Pulsed sounds well-known from cod (Gadus morhua) and haddock (Melanogrammus aeglefinus)
• Walleye pollock likely produce sound, but it has not been documented
Sound production by spawning haddock

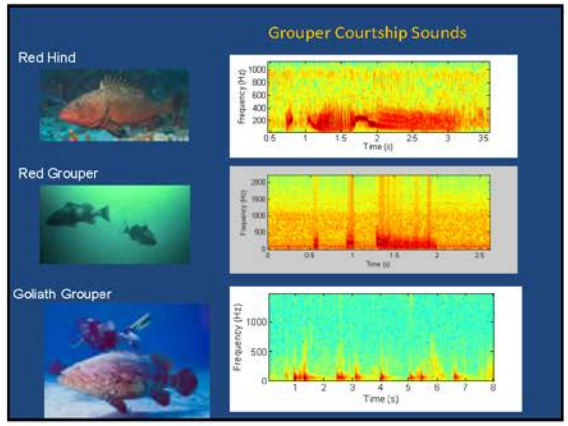

LEO-15 Ocean Observatory

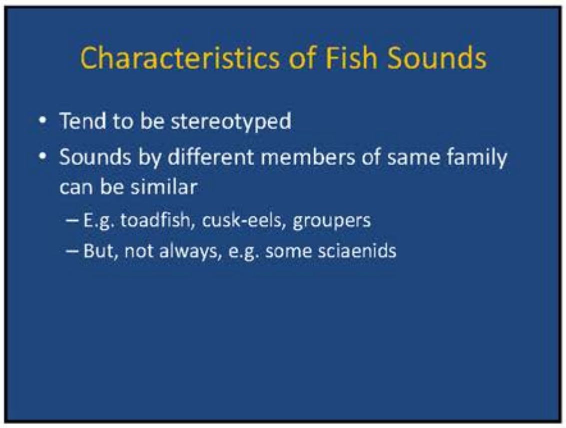

Sciaenids (croakers)
Weakfish, Cynoscion regalis
Atlantic croaker
Micropogonias undulatus
Time (s)
Illustrations By: Diane Rome

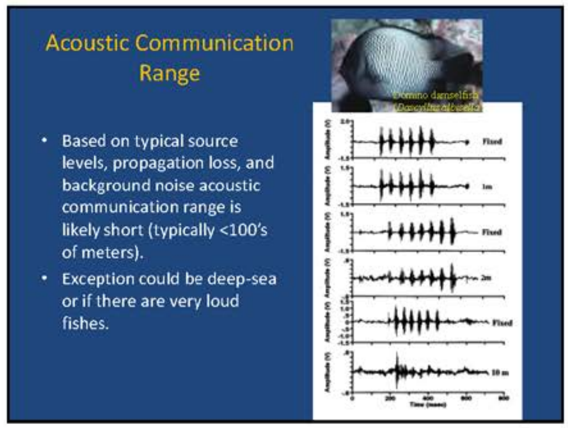

Frequency (Hz)
cusk eel
sciaenid
Aug 20
Aug 21
Aug 22
Aug 23

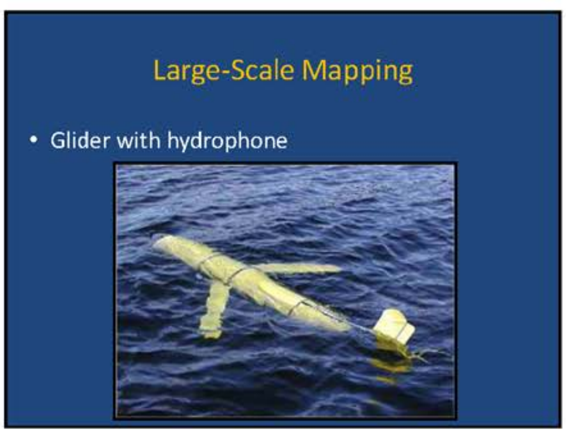

Red Grouper (Epinephelus morio)

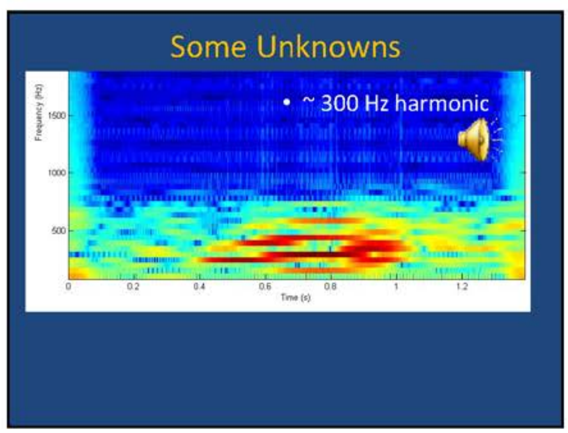

80 m depth

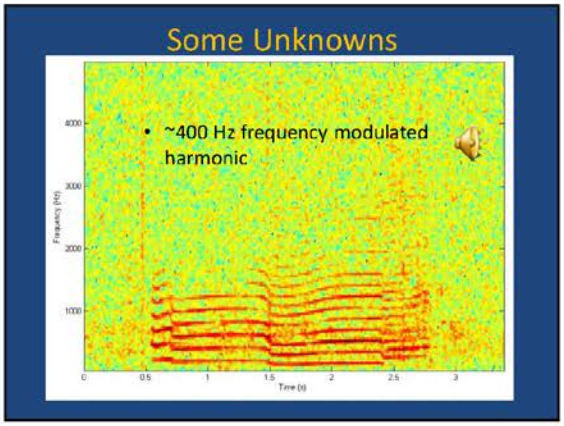

Grouper Courtship Sounds
Red Hind
Red Grouper
Goliath Grouper
Frequency (Hz)
Time (s)

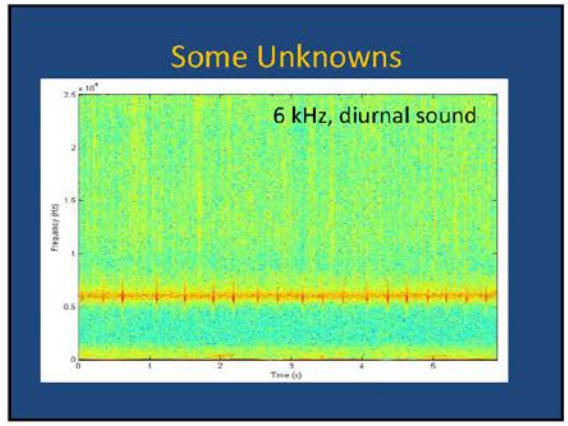

Characteristics of Fish Sounds
• Tend to be stereotyped
• Sounds by different members of same family can be similar
– E.g. toadfish, cusk-eels, groupers
– But, not always, e.g. some sciaenids

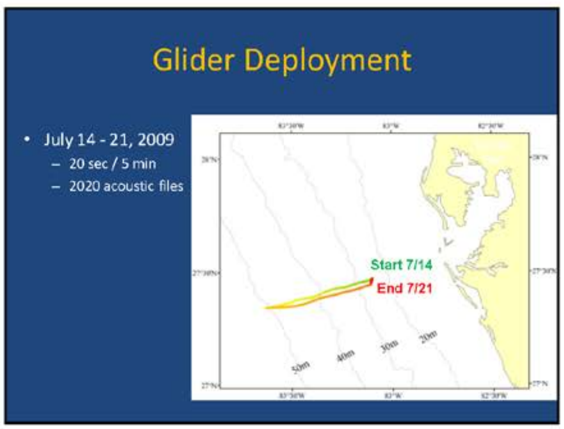

Acoustic Communication Range
• Based on typical source levels, propagation loss, and background noise acoustic communication range is likely short (typically <100's of meters).
• Exception could be deep-sea or if there are very loud fishes.

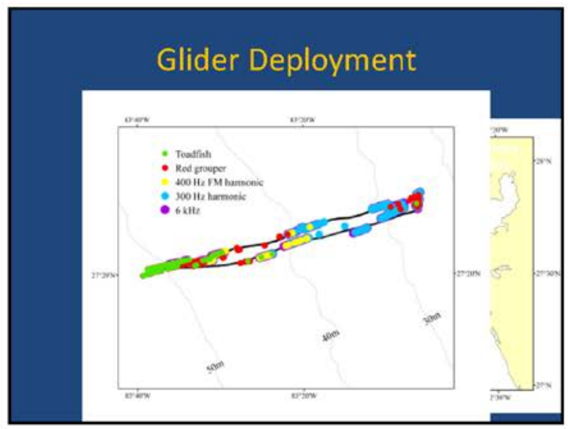

Large-Scale Mapping
• Glider with hydrophone

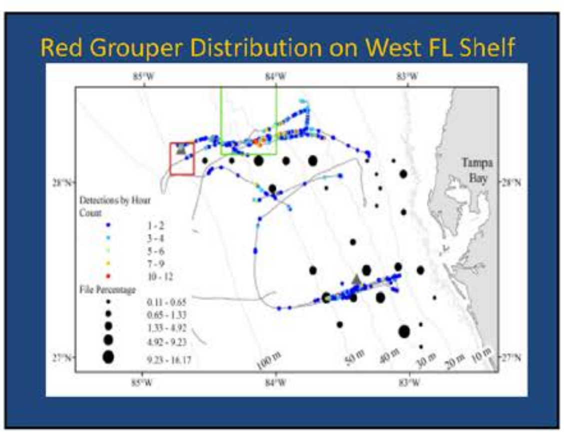

Some Unknowns
• ~ 300 Hz harmonic


Some Unknowns
• ~400 Hz frequency modulated harmonic
Frequency (Hz)
Time (s)

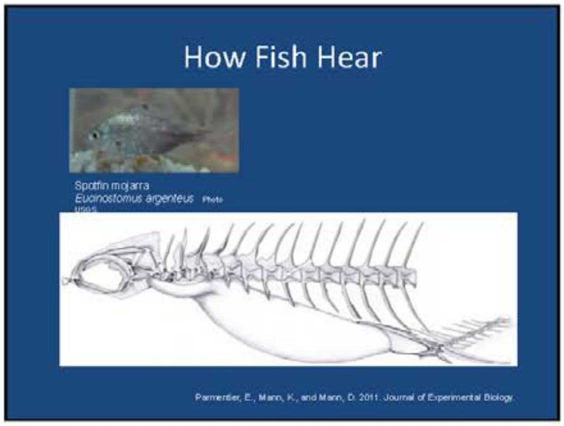

Some Unknowns
6 kHz, diurnal sound
Frequency (Hz)
Time (s)

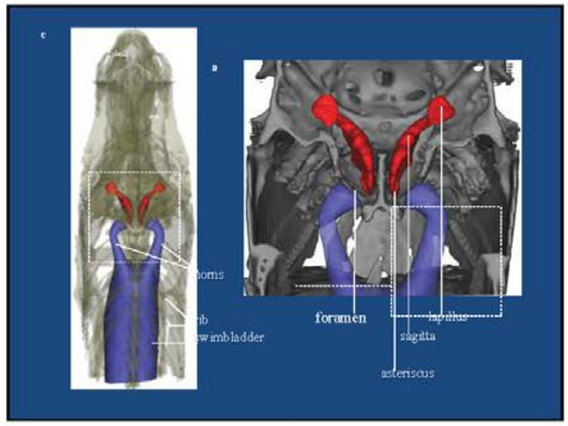

Glider Deployment
• July 14 - 21, 2009
– 20 sec / 5 min
– 2020 acoustic files
Start 7/14
End 7/21
50m
40m
30m
20m

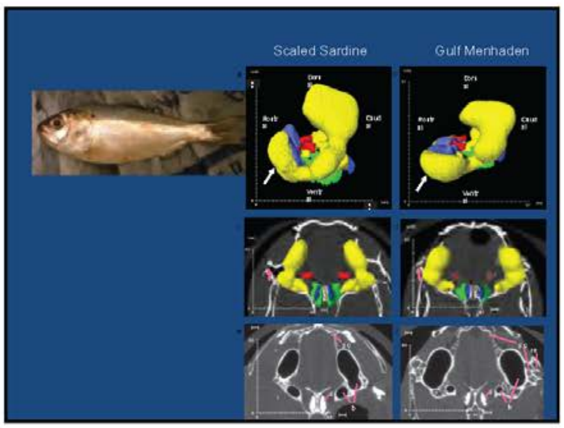

Glider Deployment
Toadfish
Red grouper
400 Hz FM harmonic
300 Hz harmonic
6 kHz
50m
40m
30m

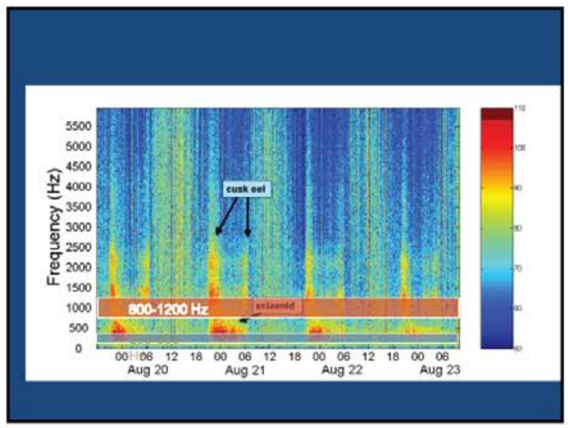

Red Grouper Distribution on West FL Shelf
Tampa Bay
Detections by Hour Count
1 - 2
3 - 4
5 - 6
7 - 9
10 - 12
File Percentage
0.11 - 0.65
0.65 - 1.33
1.33 - 4.92
4.92 - 9.23
9.23 - 16.17
100 m
50 m
40 m
30 m
20 m
10 m
85°W
84°W
83°W
28°N
27°N

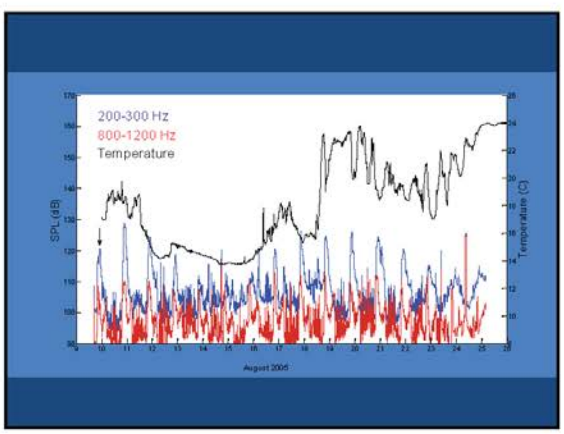

Needs and Data Gaps
David Mann
University of South Florida
Loggerhead Instruments
• Invertebrates: Little is known about how sound is used in communication or hearing sensitivity.
• Library of sounds produced by fishes.
– This hinders use of passive acoustics as tool in determining effects of sound on behavior.
• New methods to identify which species produce which sounds.
– Common tools, such as video, are difficult to use in open ocean environments.
– Develop tags similar to acoustic tags deployed on marine mammals.
• What are impacts of reduced communication range on important behavior, such as spawning?
• Do we care about all fishes?

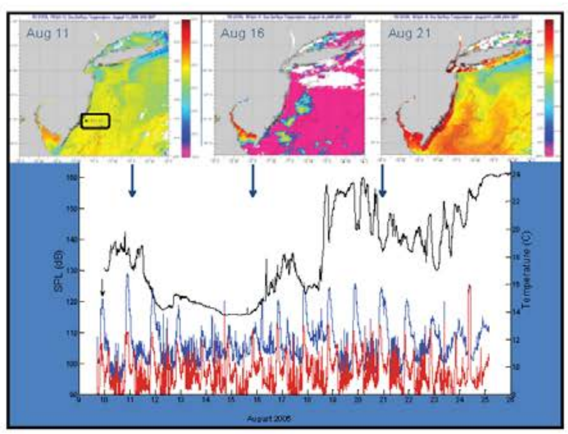

How Fish Hear
Spotfin mojarra
Eucinostomus argenteus
Parmentier, E., Mann, K., and Mann, D. 2011. Journal of Experimental Biology.


foramen
sagitta
asteriscus


Scaled Sardine
Gulf Menhaden


Frequency (Hz)
cusk eel
800-1200 Hz
sciaenid
Aug 20
Aug 21
Aug 22
Aug 23


200-300 Hz
800-1200 Hz
Temperature
SPL (dB)
Temperature (C)
August 2005


Aug 11
Aug 16
Aug 21
SPL (dB)
Temperature (C)
August 2005

Masking and Auditory Scene Analysis: Implications for Fish Behavior and Survival.

Richard R. Fay
Marine Biological Laboratory
Woods Hole, MA

Masking – definition: the reduction in the detectability of a signal of interest due to the presence of another sound – usually noise.

Auditory Scene Analysis (ASA) – definition: the process by which the human auditory system organizes sound into individual, perceptually segregated streams according to their likely sources.
The term was coined to describe human hearing by psychologist Albert Bregman (1990).

These are related concepts that help define the hearing process of human beings and all other animals.

Masking – Originally described aspects of human hearing performance (e.g., Fletcher, 1940)

First applied and developed for human hearing

Simplest case –

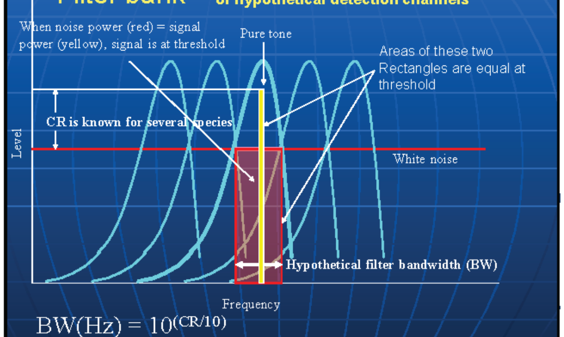
Signal of interest – pure tone
Interfering sound – white noise

Masking assumptions (Fletcher):

- The receiver is the human ear composed of many independent, frequency-selective channels (filters).
- Detection of the signal tone uses a detection channel or filter centered on the signal frequency.
- Detection filters have a finite bandwidth that admits both the tone signal and noise components falling within the filter.
- When the tone is at masked threshold, the noise power equals the signal power within the filter.
- At the detection threshold for the signal, the ratio between tone signal power and noise power (level per Hz) can be specified. This is the S/N at threshold.
- The signal-to-noise ratio in dB at signal threshold is called the Critical Masking Ratio (CR).
- The CR in dB can be used to estimate the width of the detection filter (Bandwidth=$10^{CR/10}$).

Masking Fundamentals and Assumptions

Filter bank of hypothetical detection channels



$$BW(Hz) = 10^{(CR/10)}$$

- For Human listeners, the width of the detection filters increases with center frequency according to a linear function (Glasberg & Moore, 1990).
- Masking will be in effect for all noise levels that can be detected (i.e. from the threshold of hearing the noise).
- Masking is a linear function of noise level (1 dB increment in masking for 1 dB increment in noise level).
- These aspects of masking have been confirmed in a variety of animals (mammals - including marine mammals, birds, amphibians and fishes), including that all ears contain a filterbank of detection channels.
- **It is likely that masking functions similarly in all animals, including sea turtles and invertebrates.**

The usual or "natural" ambient noise already causes masking for most fishes in most environments.

So, any increment in these noise levels by anthropogenic sources will most likely cause additional masking.

Masking effects are analogous to a hearing impairment in that, while the masking noise is present, the thresholds for detecting the usual sources will be raised (i.e., all sources will be harder to detect).

•However, most of what we know about masking applies only to pure tone signals against a flat-spectrum (white) noise masker.

•Real signals and noises are more complex than this, with both signals and noise having arbitrary spectral shapes and bandwidths.

•There has been very little research on this aspect of masking in fishes, and no certain way to make quantitative predictions about the masking effects of arbitrary spectral shapes on arbitrary signals.

•e.g., the masking effect of vibratory pile driving on the detection of communication sounds of the cod cannot be predicted without further research. All we can be sure of is that only the noise levels in the vicinity of the communication sound spectrum cause the masking.

Consequences of masking for the fitness of fishes

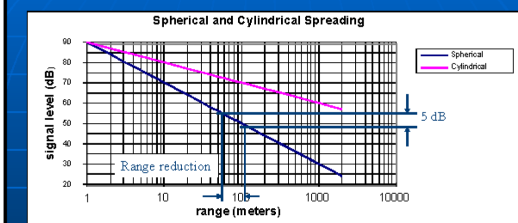
There is no research on this question, so we don't know what effects on fitness and survival might occur caused by anthropogenic noise.

We can guess that extra noise in the environment could interfere with communication (social and reproductive), predator and prey interactions, and orientation to environmental features.

One thing is certain – As noise levels are raised above the "natural" ambient levels, all noise sources may –

- **Render the weakest sounds undetectable**
- **Render all sound sources less detectable**
- **Reduce the distance at which sound sources can be detected.**

Masking Effects on Distance of Source Detection



Any increase in ambient noise reduces the distance at which any source can be detected.

Spherical spreading – **56% distance reduction / 5 dB**

Cylindrical spreading – **32% distance reduction / 5 dB**

There is no threshold – any noise increment = distance reduction

Auditory Scene Analysis

The ability to segregate sounds from different sources, and to assign sounds to independent sources.

Bregman (1990) introduced the notion of Auditory Scene Analysis (ASA) generally, with the focus on human speech and music perception.

"Dividing evidence between distinct perceptual entities (visual objects or auditory streams) is useful because there really are distinct physical objects and events in the world that we humans inhabit. Therefore, the evidence that is obtained by our senses really ought to be untangled and assigned to one or another of them" (Bregman 1990, pg. 13).

Bregman –

2 types of ASA –

PRIMITIVE – Bottom up, involuntary, not dependent on cognition or attention, automatic, and I would say, the ASA shared with all animals.

SCHEMA-BASED – Top down, memory-based, arising from learning and experience.

2 further types –

SEQUENTIAL – Those sensory features that tie together a temporal stream as if from a single source.

SIMULTANEOUS – Features of a sound that distinguish one simultaneous source from another

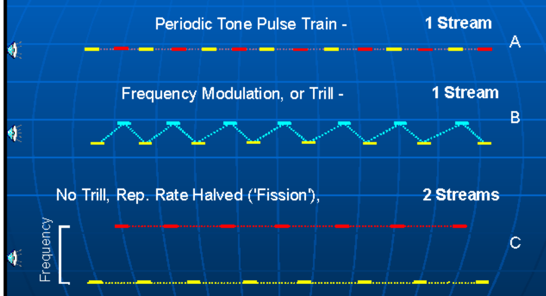
Sequential scene analysis

Principles of Gestalt Psychology (visual analogy), including PROXIMITY and SIMILARITY, - "an automatic tendency of brain tissue," and I would say, one of the primary purposes of the brains of all animals.

ASA in hearing has been classically demonstrated using sequential tones – Miller and Heise (1950)

The question is, "do you hear one source or two?"

Miller and Heise (1950): The 'Trill' Threshold and stream segregation



Simultaneous Scene Analysis –

The "hearing out" two or more sources that operate simultaneously, and assign the acoustic components of each sound to its proper source - E.g., Vibropiling and cod communication sounds. Each source must be analyzed and perceptually segregated for the vocalization to have its intended meaning. Without ASA, this combination of sounds would be a "chimeric" conflation of the 2 simultaneous sounds.

ASA – simultaneous sources

- **Not** the mere recognition of species-specific sounds in noise or distracters.
- **Not** the mere detection of sources in the presence of noise or distracters.
- **Not** dependent on directional hearing – (e.g. as in hearing out individual instruments in an orchestra in a monophonic recording)
- It is the disentangling of acoustic components of one source from those of others, and then the perceptual segregation of these sources.
- It is the determination that the signal in question arises from an independent source.

Acoustic factors that promote segregation: asynchronous onsets and offsets, differences in pitches and timbres, and differences in AM or FM patterns.

Auditory Scene Analysis capacities have been demonstrated so far in:

- Human beings
- Several other mammal species
- Several bird species
- Goldfish

I think we can believe that all vertebrate animals Must have this capacity.

What does this mean for anthropogenic noise effects?

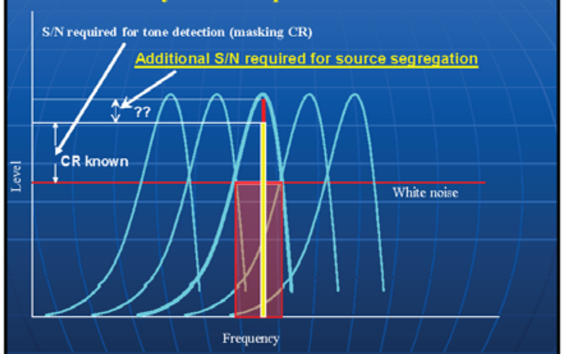
As for the consequences of masking, we don't know – no critical experiments have been done.

One thing we do know, however, is that in order for any sound to be useful as information or perceived properly, it must first be segregated from all simultaneous sounds so that its source can be usefully determined.

And we know that for source segregation to take place against a noise background, the S/N must be higher than that required for mere detection.

In other words, the noise level that interferes with signal detection through masking will be above that required for source segregation – source segregation will be disrupted at lower S/N than signal detection.

Scene analysis assumptions



The additional S/N required for source segregation is not known, but for goldfish the value is about 4 dB greater than the critical masking ratio for tone-in-white noise masking (Fay, 2011).

The point is that the mere detection of a signal is not enough for useful source processing. All effective sources must be above masked threshold by at least 4 dB for the information to be properly used (the source segregated).

Conclusions

- **We know a lot about tone-in-white noise masking in fishes.**
- We know very little about the masking of arbitrary signals by arbitrary noise spectra.
- We know almost nothing about the consequences of masking for fish behavior and survival, except that the distance from a sound source required for detection is reduced by noise levels above ambient.
- **We know that fish are capable of Auditory Scene Analysis.**
- We know that sounds must be segregated to convey all the information about their sources.
- We know almost nothing about the consequences of a failure of ASA for fish behavior and survival, except that the S/N required for segregation is greater than the masking CR.

Behavior of Pelagic Fish in Response to Man-made Sources

John Dalen
Institute of Marine Research, Norway

Effects of Noise on Fish, Fisheries, and Invertebrates
A BOEM Workshop on Data Gaps and Research Needs
San Diego, 20-22 March 2012

INSTITUTE OF MARINE RESEARCH
HAVFORSKNINGSINSTITUTTET

What to include

- **Species**
  True "small" pelagic and mesopelagic ones (no bentho-pelagic ones)
  - herring (*Clupea harengus*)
  - mackerel (*Scomber scombrus*)
  - blue whiting (*Micromesistius potassou*)
  - sandeel (*Ammodytes sp., Hyperoplus sp.,++*)
  - mesopelagic species (Myctophids,++)
  - salmon and trout (xx, *Salmo salar, S. trutta*)

What to include, cont

Sources

- **Only sources producing sound energy within the frequency ranges of hearing in actual fish species, i.e. at low and very low frequencies < 1000 Hz**
  - hammers (piling)
  - fishing gear - trawls
  - explosives – blasting (construction and demolition)
  - sparker (seismic)
  - airgun (seismic)
  - very low frequency sonar (mostly military – a few within geophysics)

What to include, cont

Surroundings and habitats

- free swimming fish – shoals/schools or single specimen
- caged fish have as often undesired and rarely known restrictions in behaviour responses and patterns
  => left out here!

Overall recognition

- **Studying behaviour of free swimming pelagic fish species is a very challenging task with regards to:**
  - **observation methodology**
  - **instrumentation**
  - **data analysis and interpretation**

There is no general fish species in this context!

All impacts from man-made sound on fish and such stimuli leading to changed behaviour must be understood in a species specific, size specific and biological state specific context, and seasonal context!

From hammers - piling

- **All potential relevant studies are either on caged fish and/or on demersal and bentho-pelagic species**

From fishing gear - trawls

2 relevant kinds of trawl

- demersal trawls / bottom trawls
- pelagic trawls

Swimming behaviour of herring during acoustic surveying and pelagic trawl sampling

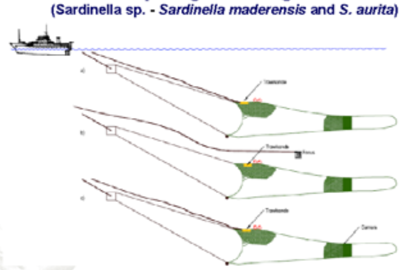
A study showing herring beaviour related to pelagic trawling in the North Sea but the reponses to the trawl are rather difficult to distinguish from the response to the ship – re Alex De Robertis "Responses of Fish to Ship Noise"

- Major findings: The herring avoided the trawl by:
  - increasing the horizontal swimming speed
  - undertook vertical migration towards the bottom

Misund, O.A., & Aglen, A. 1992. Swimming behaviour of fish schools in the North Sea during acoustic surveying and pelagic trawl sampling. ICES J. Mar.Sci. 49: 325-334.

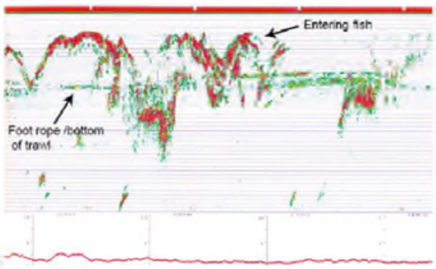
Pelagic Fish Behaviour during Trawl Sampling off Angola

(Sardinella sp. - *Sardinella maderensis* and *S. aurita*)



Kyrkjebø, E. & Misund, O.A. 2011. Pelagic Fish Behaviour during Trawl Sampling off Angola. OpenOceanJour 2011, 5, 22-29.

Pelagic Fish Behaviour - Trawl Sampling - Angola, cont



Echogram from the trawl sonde (echo sounder on the head rope looking downwards) – fish entering the trawl.

Pelagic Fish Behaviour - Trawl Sampling - Angola, cont

Main outcome of shoal behaviour

- Depending on the intensity and type of reactions, the altered behaviour patterns were classified into two categories:
  - *Adjust Reactions*: did not lead to a sudden disintegration of the school organisation but caused the whole school gradually to change swimming direction and move closer to one side or to the bottom of the trawl.
  - *Fright Reactions*: Characterised by a sudden simultaneous mass response, with individual fish swimming in different directions and the collective school organisation collapsing for a few seconds.

From explosives

Most studies are either on caged fish and/or on demersal and bentho-pelagic species

Cited study: Exposing blue whiting to small charges of explosives just behind a fishing vessel to "force" the fish to the bottom to be more exposed/catchable to the bottom trawl (increase catches).

- Depth of fish: 150-200 m
- **Blasting:** The fish concentrated and moved towards the bottom – stayed there for 10-15 min and then lifted again to previous preferred depths
- The blue whiting got habituated after 5-8 blasts with 5-10 min between each stimulation/blast

Dalen, J. 1973. Controlling behaviour of blue whiting in relation to trawling. Experiments in the North Sea. SINTEF Working Report 73-116-K, SINTEF, Div. 48, NTNU.

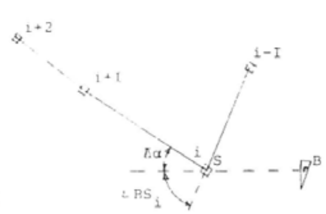
From sparkers (seismic)

Investigations of impacts on herring in a nearly closed bay

The bay holding herring shoal(s), vessel and features of the positioning system

Dalen, J. 1973. Stimulating herring shoals with sound. Report to the Norwegian Research Council of Tevhnology and Natural Sciences.

Investigations of impacts on herring in a bay, cont



Shoal trajector from time/ position i-1 to i+2, response angle α = Δα + BSi: S: shoal B: boat with sonar

Investigations of impacts on herring in a bay, cont

Main results for changes in swimming speed, v, and swimming direction, α, prior to and after stimulation

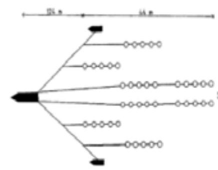
Plot	Average			Variance		
	v [m/s] prior	v [m/s] after	α [°] after	v [m/s] prior	v [m/s] after	α [°] after
1-7	0,37	0,33	51	0,15	0,11	27
8-13	0,41	0,40	50	0,13	0,12	37

- No significant changes in swimming speed
- Significant changes in swimming direction

From airgun(s) - seismic

- **Studies based on 3D seismic surveys**
- **Based on experimental studies**

Pilot study 1984: 3D seismic survey North Sea (SOO)

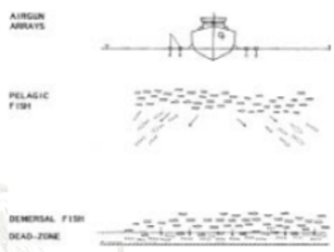


System set-up

Source: 1 airgun array (44 x 57 m); 40 airguns
Towing depth: 6 m
Chamber volume: 77 932 cm^3 (4752 cu.in.)
Source level: 249,9 dB//1µPa re 1 m (calibrated)
Supply pressure: 138 Bar (2000 psi)
Firing interval: 10 s / 25 m

•Dalen, J. & Knutsen, G.M. 1987. Scaring effects in fish and harmful effects on eggs, larvae and fry by offshore seismic explorations. In Merklinger: Proc. Symp. "Progress in underwater acoustics", 1987: 93-99. Halifax 1986.

Pilot study 1984: 3D seismic survey North Sea (SOO), cont



Seismic area: 6 x 9 nautical miles (11 x 17 km)
Observation area: 35 x 18 nautical miles (65 x 33 km)

Estimated SPEL:
210 dB//1 µPa at 100 m 204 dB//1 µPa at 200 m 200 dB//1 µPa at 300 m

Schetch of fish behaviour during seismic blasting

Pilot study 1984: 3D seismic survey North Sea (SOO)

Main outcome: The horizontal and vertical distributions of both pelagic fish and groundfish as observed by hydroacoustic methods and trawling within the observation area surrounding the seismic operations area, were consistently changed after 6 days of airgun operations compared to the distributions prior to the operations.

=> **Blue whiting**: Changes in distribution were observed out to ca. 17 nautical miles from the centre of the seismic area.

=> **Blue whiting**: The echo abundance in the seismic area was reduced by 54 % after 6 days of air gun operations compared to that prior to the operations.

Pilot study: 3D seismic survey North Sea (SOO), cont

Specific observation:

Changes of the fish distributions and behaviour patterns of the fish along the course lines of the seismic vessel from immediately before to just after airgun shooting proved that the fish were affected.

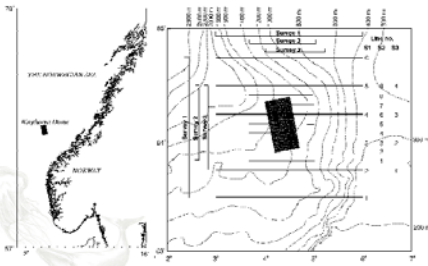
Pelagic fish distribution and abundance in relation to a seismic shooting off the Norwegian west coast (SOO) -1999

System set-up

- Source: 2 airgun arrays, flip-flop operated
- 10 streamers
- Towing depth: 8 m
- Firing interval: 10 s / 25 m
- 51 parallel transect, each 51 km long,
- Adjacent transects separated by 500 m.

Slotte, A., Hansen, K., Dalen, J. & Ona, E. 2003. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. FishRes 67 (2004) 143–150.

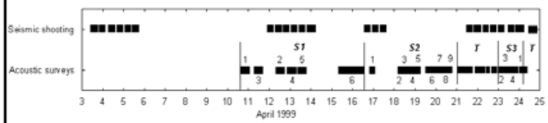
Pelagic fish and seismic shooting off the Norwegian west coast (SOO), cont.



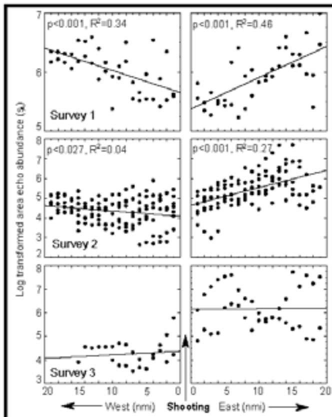
Ringhorne Dome. Survey lines and bathymetry of the surrounding area.

Seismic area Ringhorne Dome off the Norwegian west coast.

Pelagic fish and seismic shooting off the Norwegian west coast (SOO), cont.



Time lines of seismic blasting and the three acoustic surveys (S1–S3). S1: 6 lines, S2: 9 lines, S3: 4 lines



Pelagic fish and seismic shooting off the Norwegian west coast (SOO), cont.

Area echo abundance (S_A) of pelagic fish inceased significantly both in western and eastern direction from the shooting in survey 1 (6 days / 6 lines), survey 2 (4½ days / 9 lines), but not in survey 3 (1½ day / 4 lines)

Pelagic fish and seismic shooting off the Norwegian west coast (SOO), cont.

Main outcome

- The study indicates there could be a long term effect of the seismic shooting: i.e. that highly migratory fish like herring and blue whiting tends to leave and/or avoid seismic blasting areas.
- The fish distribution were found at larger depths during seismic blasting than with no blasting.
- The study indicates that the fish distributions may turn back to “normal” within some days after the blasting ceases.

Fishermen’s stories (anecdotal expressions)

- **Mackerel**
- When a seismic vessel comes into the area the fish "gets wild" (echo sounder observations):
  - => more difficult to catch by purse-seining
  - => for trolling the catches are strongly reduced and stay low as long as the seismic
- **Sandeel**
- When a seismic vessel comes into the area the catch rates are strongly reduced

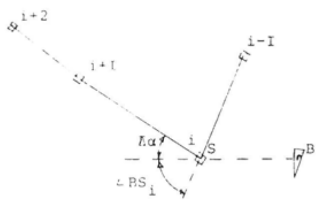
Experimental studies: From airguns

Investigations of impacts on herring in a nearly closed bay

The bay holding herring shoal(s), vessel and features of the positioning system

Dalen, J. 1973. Stimulating herring shoals with sound. Report to the Norwegian Research Council of Tevhnology and Natural Sciences.

Investigations of impacts on herring in a bay, cont



Shoal trajector from time/ position i-1 to i+2, response angle α = Δα + BSi: S: shoal B: boat with sonar

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Impacts on herring in a bay, cont

Main results of changes in swimming speed, v, and swimming direction, α, prior to and after stimulation

Plot	Average			Variance		
	v [m/s] prior	v [m/s] after	α [°] after	v [m/s] prior	v [m/s] after	α [°] after
1-4	0,58	0,80	75	0,06	0,20	26
5-9	0,32	0,59	99	0,11	0,24	37

- **Significant changes in swimming speed**
- **Significant changes in swimming direction**

Dalen, J. 1973. Stimulating herring shoals with sound. Report to the Norwegian Research Council of Technology and Natural Sciences.

Knowledge gaps

- Perform studies on "seismics and herring":
  => impact distances, behaviour studies, impact on catching effort,
  "prior to – during – after the seismic activity"
- Perform studies on "seismics and mackerel":
  => impact distances, behaviour studies, impact on catching effort,
  "prior to – during – after the seismic activity"
- The studies should **not** be undertaken in relation to seismic surveys of opportunity

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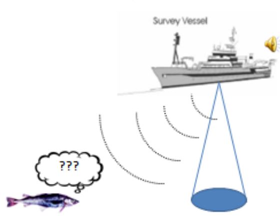
Responses of Fish to Ship Noise

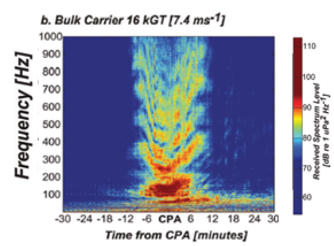
(A perspective from fisheries acoustics)



Alex De Robertis
Alaska Fisheries Science Center, NOAA

Ships are loud
Their sounds propagate long distances

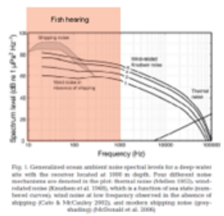
167 m,
16000 tons
9100 HP



Closest point of approach (CPA) = 3 km

McKenna et al. 2012

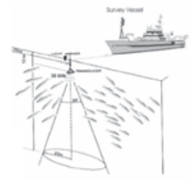
Ships can dominate low frequency noise

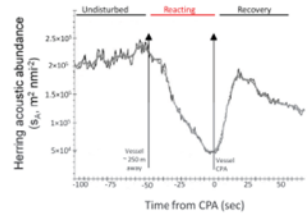


This is a major concern for auditory masking.

Fish react to approaching vessels.

Strength of the response is highly variable
Responses are stereotyped
- •dive towards seafloor
- •acoustic abundance deceases
- •depth-dependent





Fish movement consistent with vessel directivity

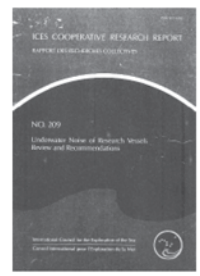
Vessel sound directivity

Propeller shading by hull
Higher frequencies (> 100's Hz)

Swimming direction of fish schools in front of vessel

Atlantic herring and sprat
Misund and Aglen, 1992

The ICES recommendation for research vessel noise

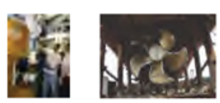


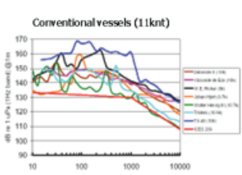
10-1000 Hz– Minimize fish avoidance.

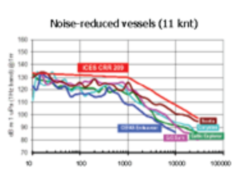
At ranges > 20 m the vessel noise shall not exceed 30 dB above (pressure based) hearing threshold of herring and cod.

(i.e. < 30 dB_{HT} at > 20 m)

Noise reduced vessels emit substantially less sound

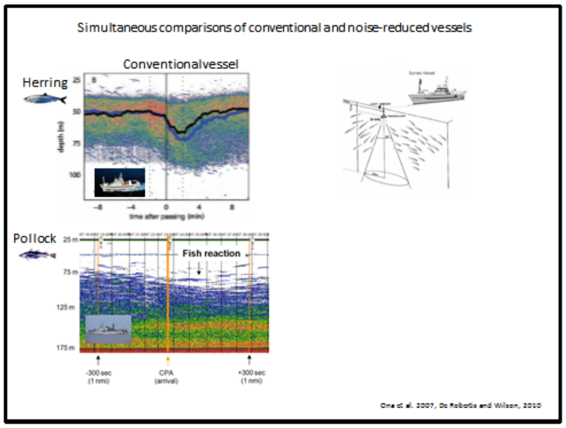


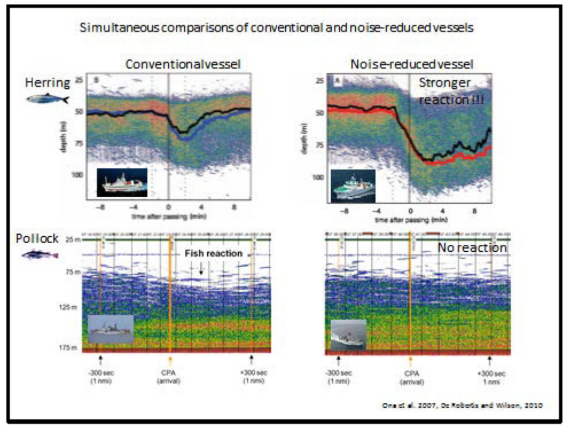


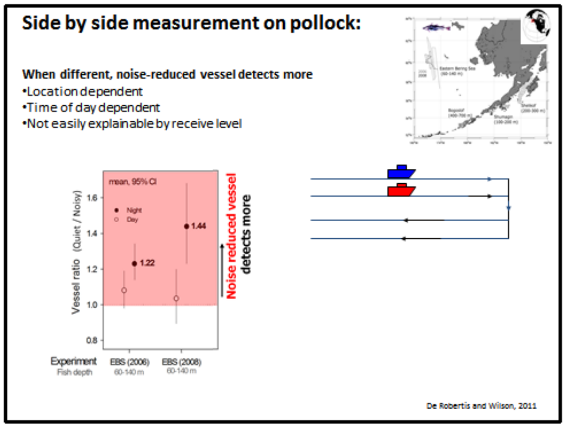


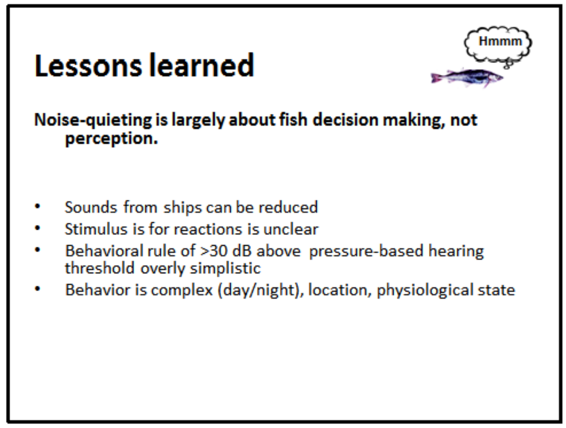
R. Mitson

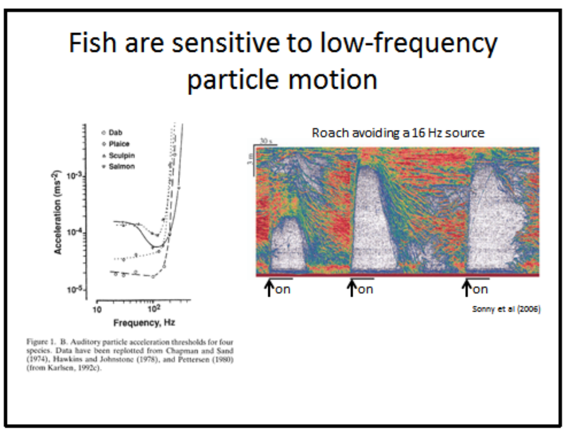
So, what is the impact on fish avoidance ?

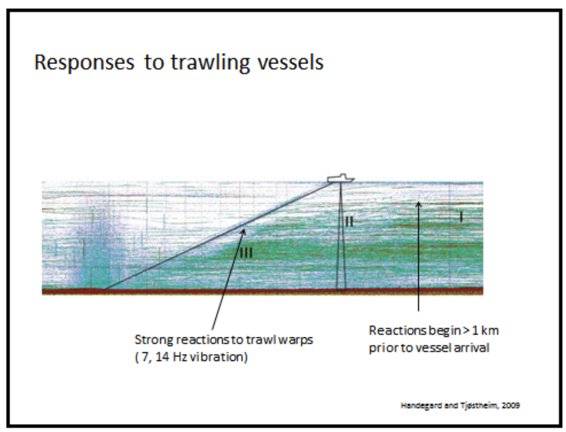

Simultaneous comparisons of conventional and noise-reduced vessels
Conventional vessel
Herring
Pollock
Fish reaction
-300 sec (1 nmi)
CPA (arrival)
+300 sec (1 nmi)
Ona et al. 2007, De Robertis and Wilson, 2010

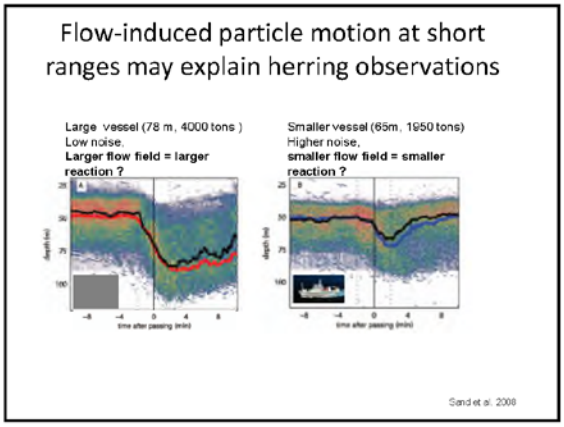

Simultaneous comparisons of conventional and noise-reduced vessels
Conventional vessel
Noise-reduced vessel
Herring
Stronger reaction !!!
Pollock
Fish reaction
No reaction
-300 sec (1 nmi)
CPA (arrival)
+300 sec (1 nmi)
Ona et al. 2007, De Robertis and Wilson, 2010

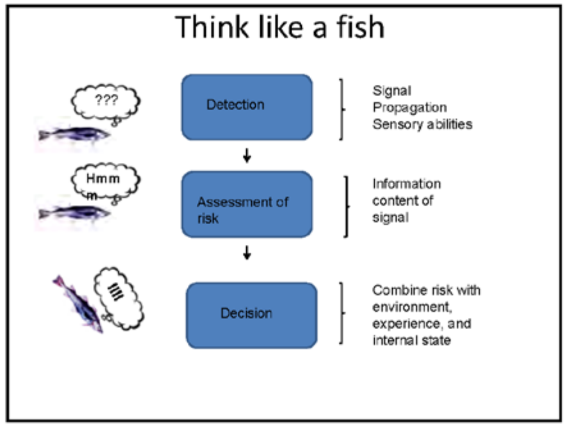

Side by side measurement on pollock:
When different, noise-reduced vessel detects more
•Location dependent
•Time of day dependent
•Not easily explainable by receive level
mean, 95% CI
Night
Day
1.44
1.22
Vessel ratio (Quiet / Noisy)
Noise reduced vessel detects more
Experiment
Fish depth
EBS (2006)
EBS (2008)
De Robertis and Wilson, 2011

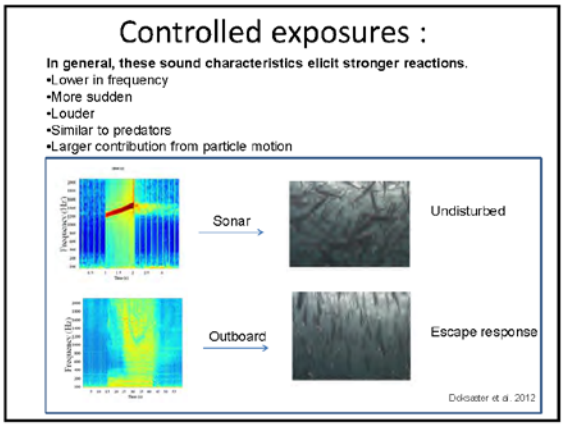

Lessons learned
Hmmm
Noise-quieting is largely about fish decision making, not perception.
• Sounds from ships can be reduced
• Stimulus is for reactions is unclear
• Behavioral rule of >30 dB above pressure-based hearing threshold overly simplistic
• Behavior is complex (day/night), location, physiological state

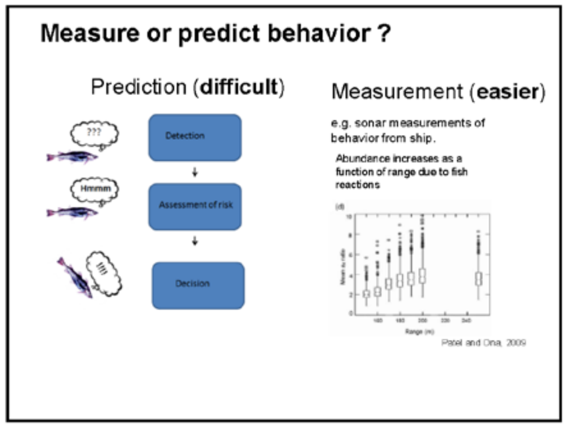

Fish are sensitive to low-frequency particle motion
Dab
Plaice
Sculpin
Salmon
Acceleration (ms⁻²)
Frequency, Hz
Figure 1. B. Auditory particle acceleration thresholds for four species. Data have been replotted from Chapman and Sand (1974), Hawkins and Johnstone (1978), and Pettersen (1980) (from Karlsen, 1992c).
Roach avoiding a 16 Hz source
on
on
on
Sonny et al (2006)

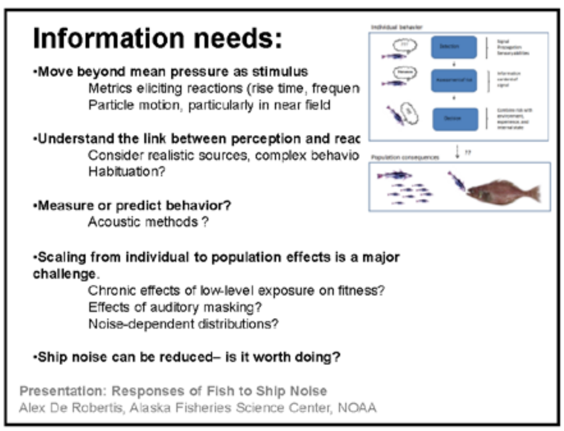

Responses to trawling vessels
III
II
I
Strong reactions to trawl warps (7, 14 Hz vibration)
Reactions begin > 1 km prior to vessel arrival
Handegard and Tjøstheim, 2009


Flow-induced particle motion at short ranges may explain herring observations
Large vessel (78 m, 4000 tons)
Low noise,
Larger flow field = larger reaction ?
Smaller vessel (65m, 1950 tons)
Higher noise,
smaller flow field = smaller reaction ?
Sand et al. 2008


Think like a fish
???
Hmm
Detection
Assessment of risk
Decision
Signal
Propagation
Sensory abilities
Information content of signal
Combine risk with environment, experience, and internal state


Controlled exposures :
In general, these sound characteristics elicit stronger reactions.
•Lower in frequency
•More sudden
•Louder
•Similar to predators
•Larger contribution from particle motion
Sonar
Undisturbed
Outboard
Escape response
Doksæter et al. 2012


Measure or predict behavior ?
Prediction (difficult)
Measurement (easier)
Detection
Assessment of risk
Decision
e.g. sonar measurements of behavior from ship.
Abundance increases as a function of range due to fish reactions
Patel and Ona, 2009


Information needs:
•Move beyond mean pressure as stimulus
Metrics eliciting reactions (rise time, frequen
Particle motion, particularly in near field
•Understand the link between perception and reac
Consider realistic sources, complex behavio
Habituation?
•Measure or predict behavior?
Acoustic methods ?
•Scaling from individual to population effects is a major challenge.
Chronic effects of low-level exposure on fitness?
Effects of auditory masking?
Noise-dependent distributions?
•Ship noise can be reduced– is it worth doing?
Presentation: Responses of Fish to Ship Noise
Alex De Robertis, Alaska Fisheries Science Center, NOAA


Effects of Noise on Catches:
Gear- and species-specific effects of air-gun sounds
HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH
Svein Løkkeberg

Gear-Specific Effects

- Bottom trawls: fish at the bottom
- Longlines: food search behaviour
- Gillnets: swimming activity

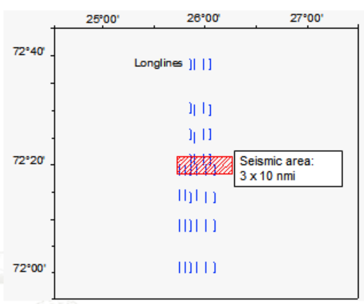
Different catching principles

Species-Specific Effects

- Hearing ability
- Swimming capacity
- Habitat preference/site fidelity
- Predator avoidance behaviour

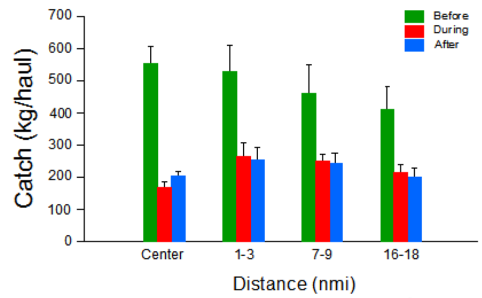
Different behaviour patterns

Trawls and Longlines
Cod and Haddock



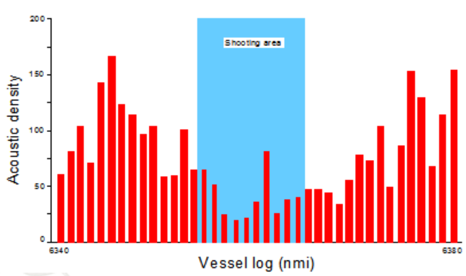
(Engås et al. 1996)

Trawls/Longlines – Cod/Haddock:
Seismic Sounds Cause Catch Reductions



(Engås et al. 1996)

Cod and Haddock:
Seismic Sounds Scare Them Away



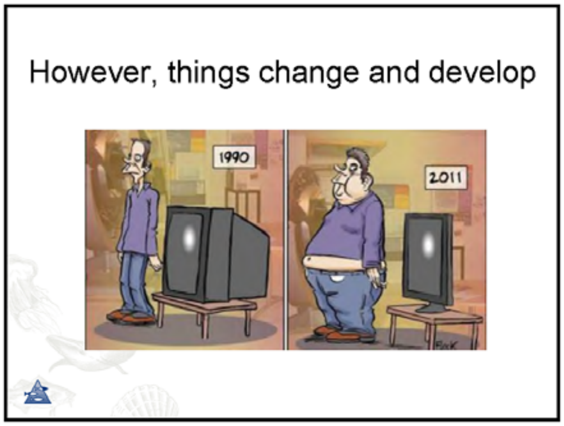
(Engås et al. 1996)

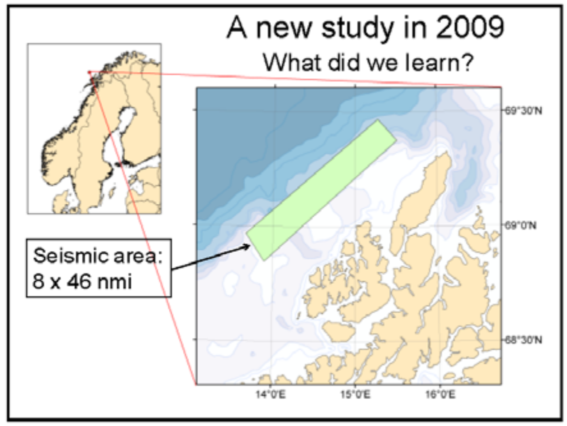
Conclusions:

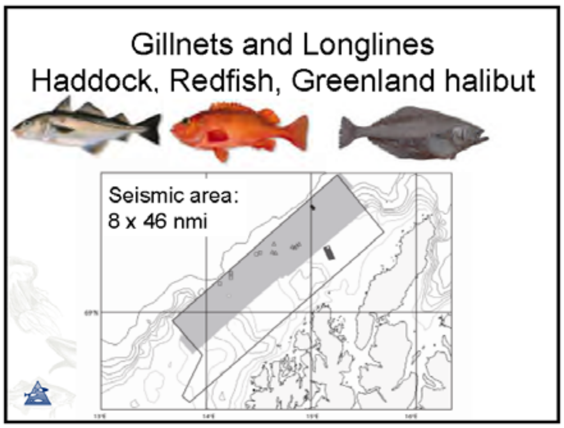
- Trawls and longlines: decreased catch rates
- Cod and haddock: avoidance responses

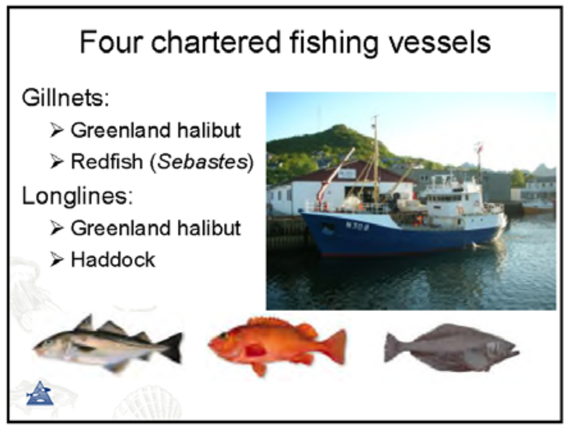
Conclusions supported by three peer review studies:

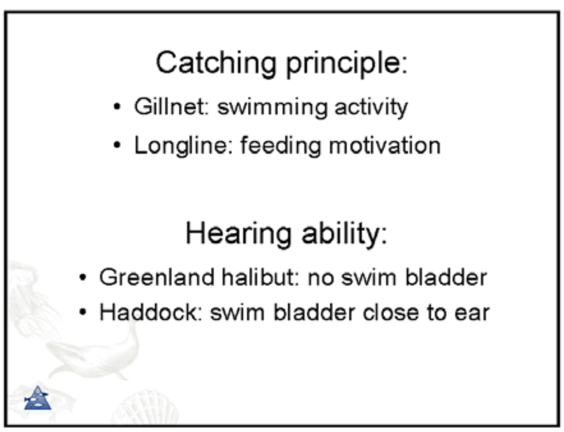
- 50 – 70% for cod and haddock (Engås et al. 1996)
- 55 – 80% for cod (Løkkeborg and Soldal 1993)
- 52% for rockfish (Skalski et al. 1992)

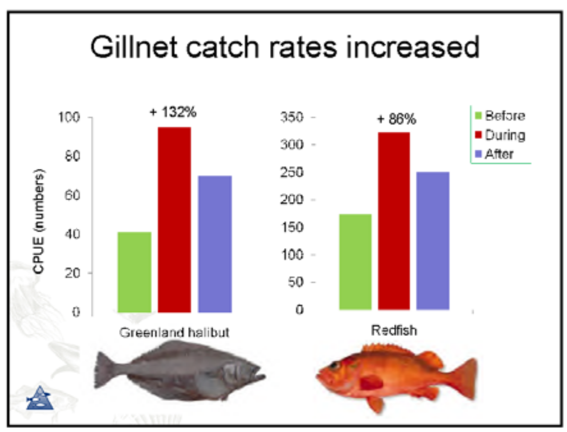

However, things change and develop
1990
2011

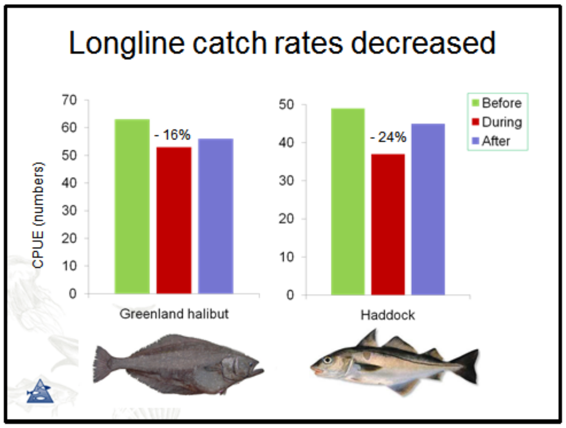

A new study in 2009
What did we learn?
Seismic area:
8 x 46 nmi
69°30'N
69°0'N
68°30'N
14°0'E
15°0'E
16°0'E

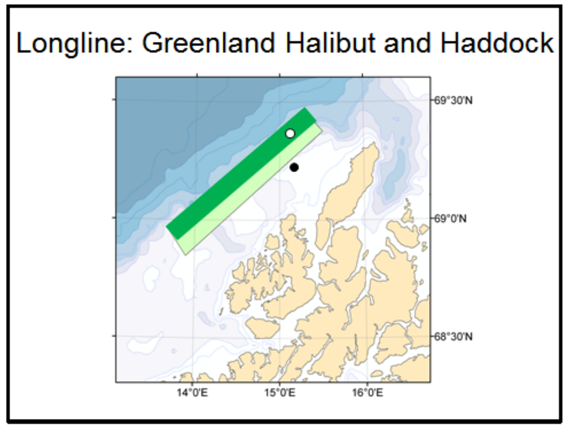

Gillnets and Longlines
Haddock, Redfish, Greenland halibut
Seismic area:
8 x 46 nmi

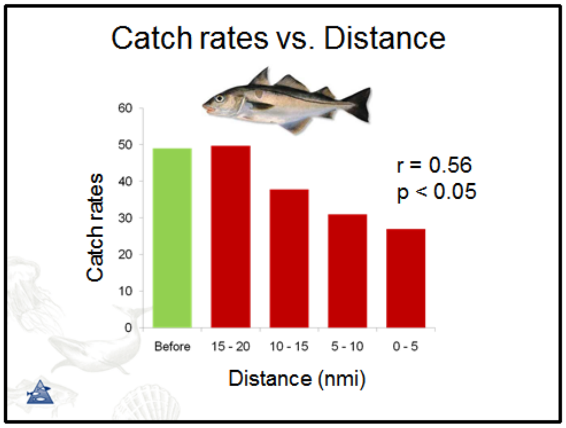

Four chartered fishing vessels
Gillnets:
➢ Greenland halibut
➢ Redfish (*Sebastes*)
Longlines:
➢ Greenland halibut
➢ Haddock

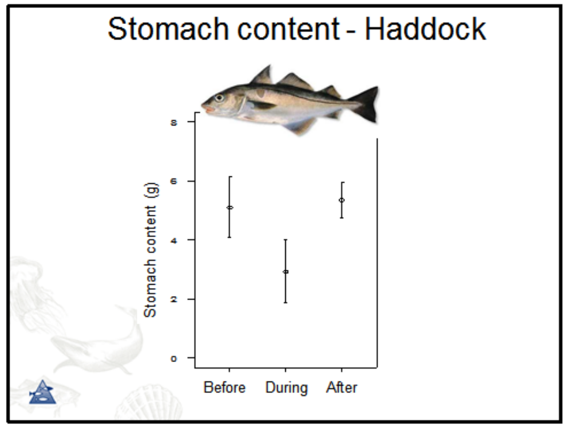

Catching principle:
• Gillnet: swimming activity
• Longline: feeding motivation
Hearing ability:
• Greenland halibut: no swim bladder
• Haddock: swim bladder close to ear

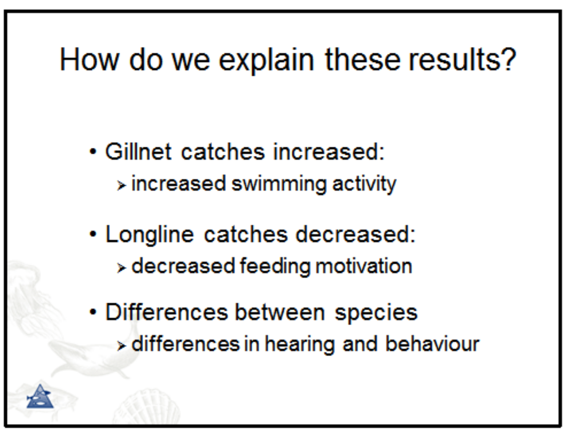

Gillnet catch rates increased
CPUE (numbers)
100
80
60
40
20
0
+ 132%
Greenland halibut
350
300
250
200
150
100
50
0
+ 86%
Redfish
Before
During
After

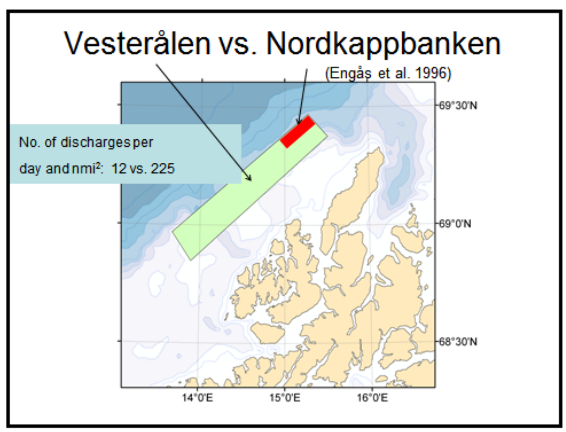

Longline catch rates decreased
CPUE (numbers)
70
60
50
40
30
20
10
0
- 16%
Greenland halibut
50
40
30
20
10
0
- 24%
Haddock
Before
During
After


Longline: Greenland Halibut and Haddock
69°30'N
69°0'N
68°30'N
14°0'E
15°0'E
16°0'E


Catch rates vs. Distance
Catch rates
60
50
40
30
20
10
0
r = 0.56
p < 0.05
Before
15 - 20
10 - 15
5 - 10
0 - 5
Distance (nmi)


Stomach content - Haddock
Stomach content (g)
8
6
4
2
0
Before
During
After


How do we explain these results?
• Gillnet catches increased:
› increased swimming activity
• Longline catches decreased:
› decreased feeding motivation
• Differences between species
› differences in hearing and behaviour


Vesterålen vs. Nordkappbanken
(Engås et al. 1996)
No. of discharges per
day and nmi²: 12 vs. 225
69°30'N
69°0'N
68°30'N
14°0'E
15°0'E
16°0'E

Effects of noise on catches depend on:

- Type of fishing gear – Catching principle
- Fishing ground (topography, depth)

- Hearing ability
- Swimming capasity
- Habitat preference/site fidelity
- Fright/avoidance response (hide or flee)

- Sound source characteristics

Thus: Extrapolation between species, gear and habitats???

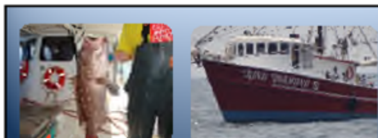
Conclusions:
"Effects of Noise on Catches"
Svein Løkkeborg
Institute of Marine Research, Bergen, Norway

Fish respond to air guns and may show:

- increased swimming
- decreased feeding motivation
- displacement away from fishing grounds
- species-specific differences in behaviour
- decreased longline and trawl catches
- increased gillnet catches

Information needs and data gaps:
"Effects of Noise on Catches"
Svein Løkkeborg
Institute of Marine Research, Bergen, Norway

- Effects on pelagic and schooling species, but also on more demersal species:
  - i.e. species-specific differences
- The impacts of topography and habitat type
- Relationship between sound level and effect
- Effects of different sound sources



The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been cor...

Effects of Sound on Fish Catches: Statistical Approaches & Considerations

BOEM Workshop – Impacts of Marine Noise

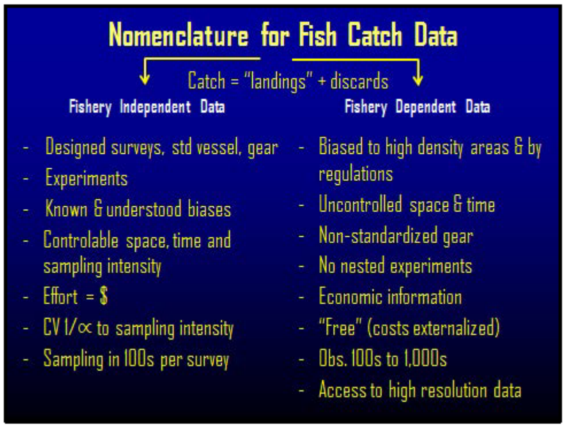
Steve Murawski
University of South Florida
College of Marine Science

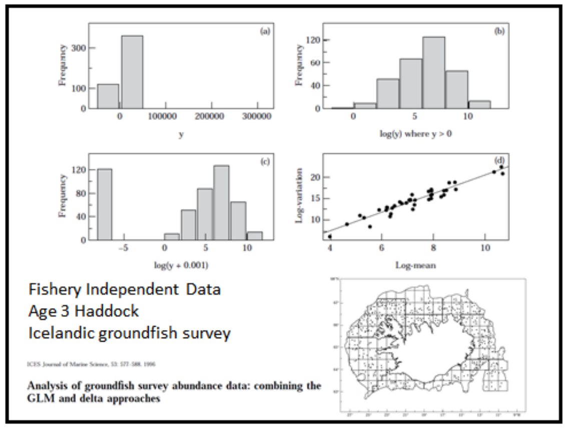
March 21, 2012

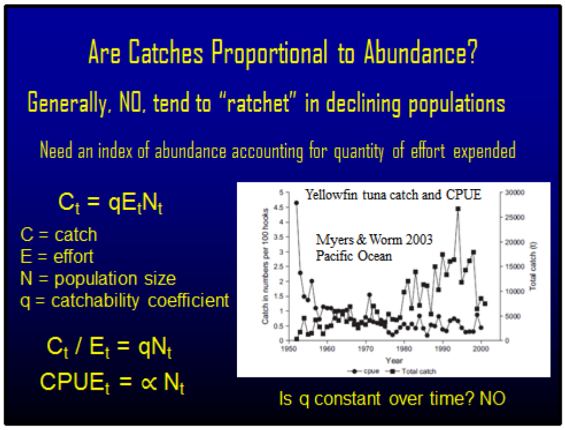
smurawski@usf.edu

Overview

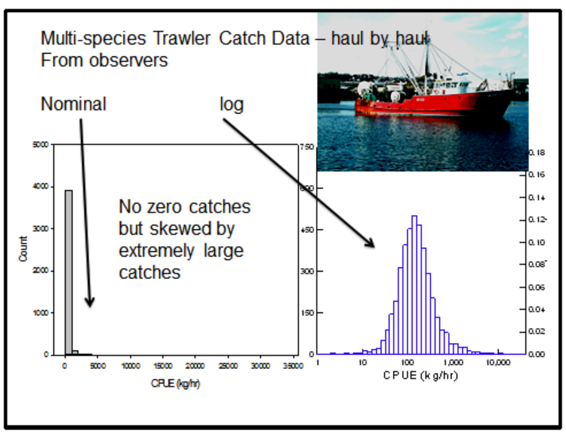
- Definition of terms in analyzing fish catch data
- Collection & statistical properties of catch data
- Some examples of analysis of spatial catch data
- Considerations in the design of studies analyzing

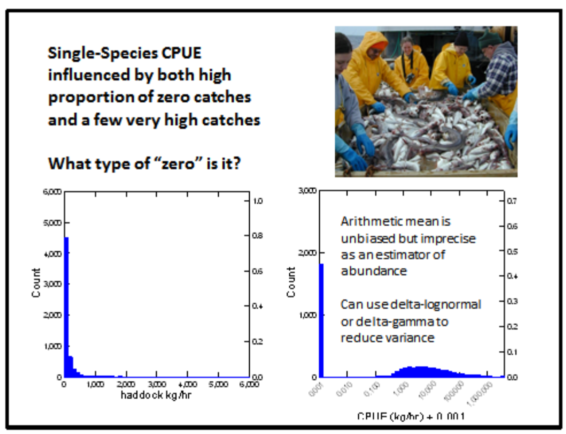

Nomenclature for Fish Catch Data
Catch = "landings" + discards
Fishery Independent Data
Fishery Dependent Data
- Designed surveys, std vessel, gear
- Experiments
- Known & understood biases
- Controlable space, time and sampling intensity
- Effort = $
- CV 1/∝ to sampling intensity
- Sampling in 100s per survey
- Biased to high density areas & by regulations
- Uncontrolled space & time
- Non-standardized gear
- No nested experiments
- Economic information
- "Free" (costs externalized)
- Obs. 100s to 1,000s
- Access to high resolution data

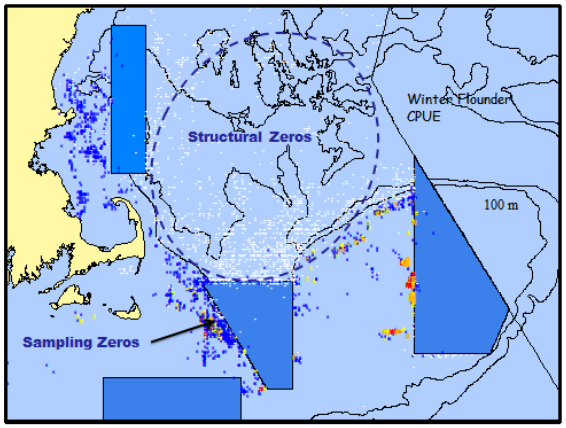

Frequency
y
log(y) where y > 0
log(y + 0.001)
Log-variation
Log-mean
Fishery Independent Data
Age 3 Haddock
Icelandic groundfish survey
Analysis of groundfish survey abundance data: combining the GLM and delta approaches

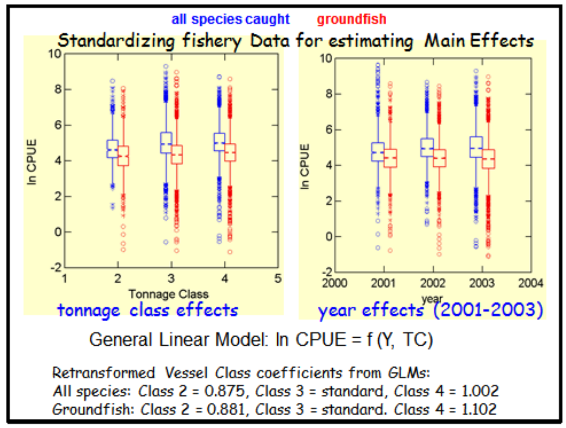

Are Catches Proportional to Abundance?
Generally, NO, tend to "ratchet" in declining populations
Need an index of abundance accounting for quantity of effort expended
$C_t = qE_tN_t$
C = catch
E = effort
N = population size
q = catchability coefficient
$C_t / E_t = qN_t$
$CPUE_t = \propto N_t$
Yellowfin tuna catch and CPUE
Myers & Worm 2003
Pacific Ocean
Catch in numbers per 100 hooks
Total catch (t)
Year
Is q constant over time? NO

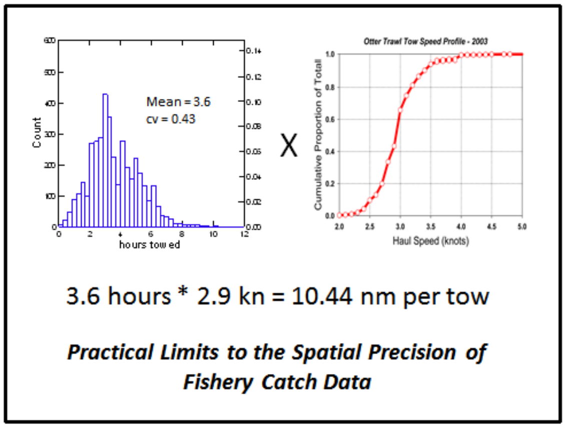

Sources of Fishery Catch & Effort Data
Data From:
- self-reported logbooks
- fish dealer records
- port "agent" interviews
- at-sea observers (the "best")
- recent advent of satellite tracking for effort (high accuracy)
Limits of resolution depend on gear, ability to collect data

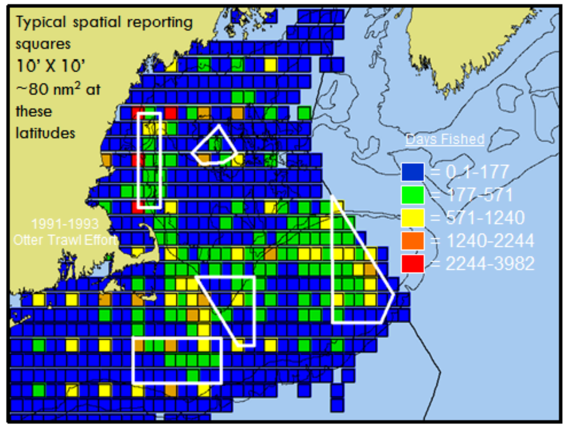

Multi-species Trawler Catch Data – haul by haul
From observers
Nominal
log
No zero catches but skewed by extremely large catches
Count
CPUE (kg/hr)
CPUE (kg/hr)

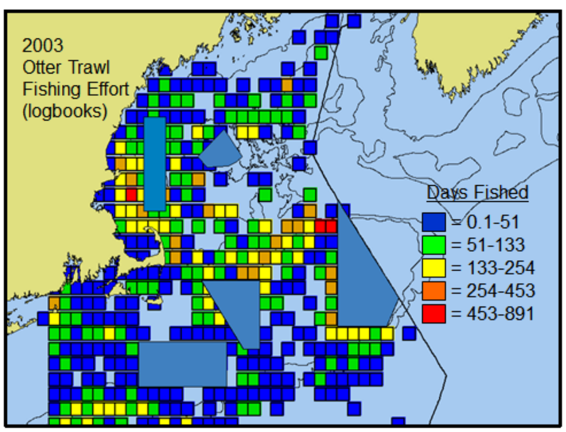

Single-Species CPUE influenced by both high proportion of zero catches and a few very high catches
What type of "zero" is it?
Count
haddock kg/hr
Arithmetic mean is unbiased but imprecise as an estimator of abundance
Can use delta-lognormal or delta-gamma to reduce variance
CPUE (kg/hr) + 0.001

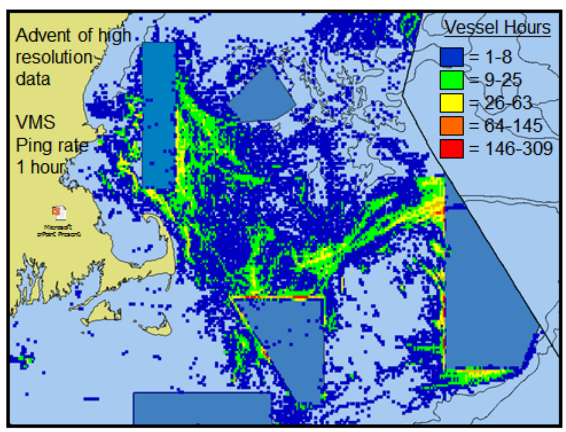

Winter Flounder CPUE
Structural Zeros
100 m
Sampling Zeros

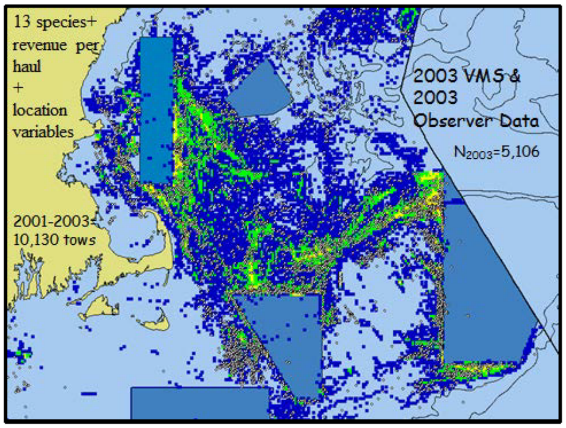

all species caught
groundfish
Standardizing fishery Data for estimating Main Effects
ln CPUE
Tonnage Class
tonnage class effects
year
year effects (2001-2003)
General Linear Model: ln CPUE = f (Y, TC)
Retransformed Vessel Class coefficients from GLMs:
All species: Class 2 = 0.875, Class 3 = standard, Class 4 = 1.002
Groundfish: Class 2 = 0.881, Class 3 = standard. Class 4 = 1.102

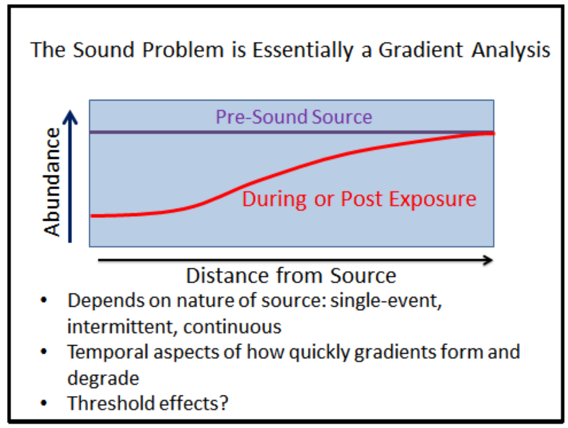

Mean = 3.6
cv = 0.43
Count
hours towed
X
Otter Trawl Tow Speed Profile - 2003
Cumulative Proportion of Total
Haul Speed (knots)
3.6 hours * 2.9 kn = 10.44 nm per tow
Practical Limits to the Spatial Precision of Fishery Catch Data

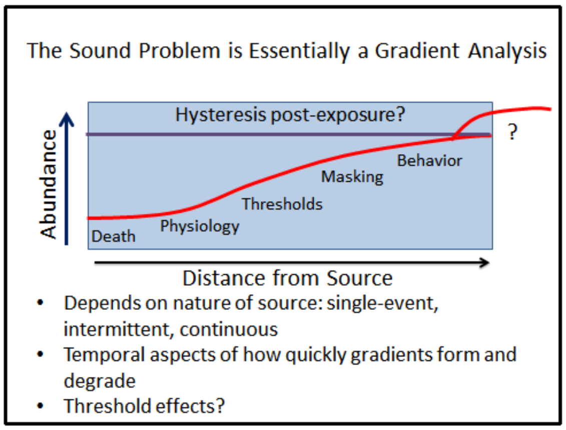

Typical spatial reporting squares
10' X 10'
~80 nm² at these latitudes
1991-1993
Otter Trawl Effort
Days Fished
= 0.1-177
= 177-571
= 571-1240
= 1240-2244
= 2244-3982

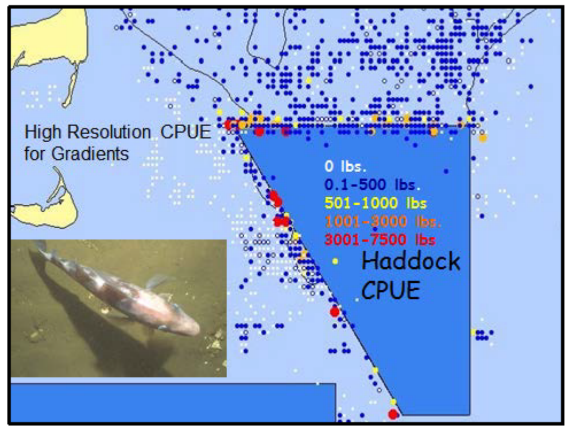

2003
Otter Trawl
Fishing Effort
(logbooks)
Days Fished
= 0.1-51
= 51-133
= 133-254
= 254-453
= 453-891

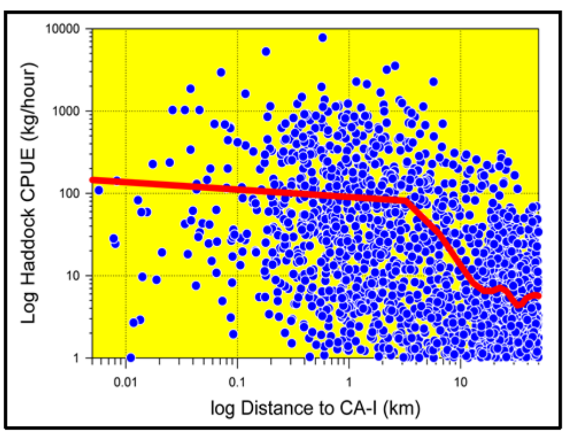

Advent of high resolution data
VMS
Ping rate
1 hour
Vessel Hours
= 1-8
= 9-25
= 26-63
= 64-145
= 146-309

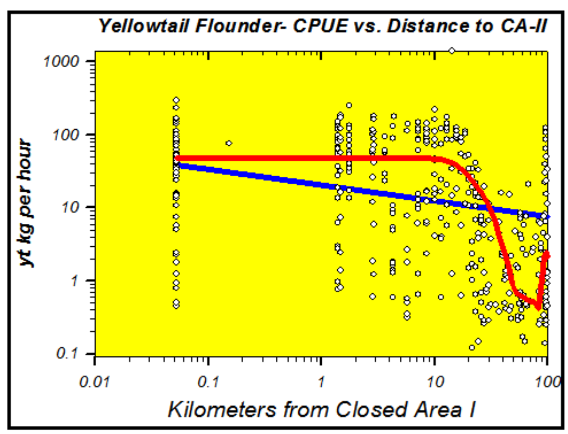

13 species+
revenue per
haul
+
location
variables
2003 VMS &
2003
Observer Data
N_{2003}=5,106
2001-2003
10,130 tows

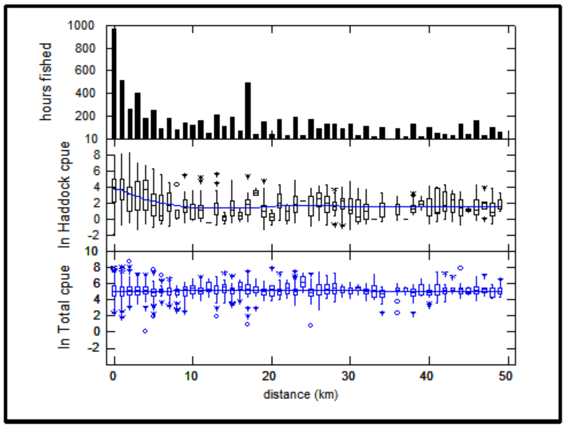

The Sound Problem is Essentially a Gradient Analysis
Pre-Sound Source
During or Post Exposure
Abundance
Distance from Source
• Depends on nature of source: single-event, intermittent, continuous
• Temporal aspects of how quickly gradients form and degrade
• Threshold effects?

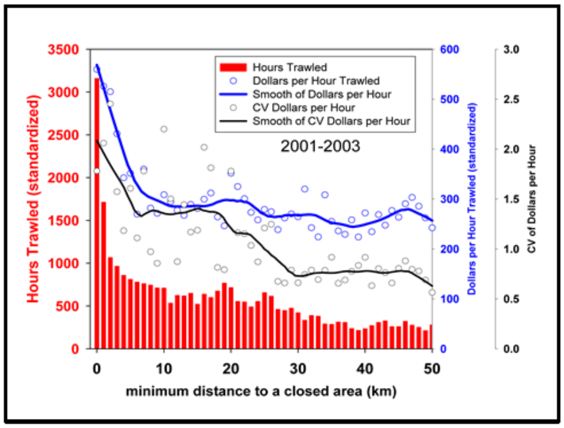

The Sound Problem is Essentially a Gradient Analysis
Hysteresis post-exposure?
?
Behavior
Masking
Thresholds
Physiology
Death
Abundance
Distance from Source
• Depends on nature of source: single-event, intermittent, continuous
• Temporal aspects of how quickly gradients form and degrade
• Threshold effects?

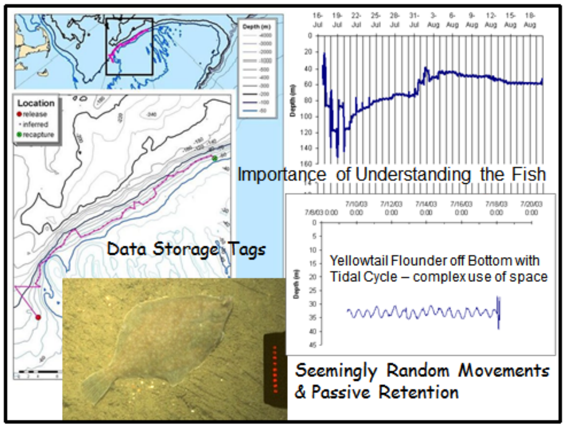

High Resolution CPUE
for Gradients
0 lbs.
0.1-500 lbs.
501-1000 lbs
1001-3000 lbs.
3001-7500 lbs
Haddock
CPUE

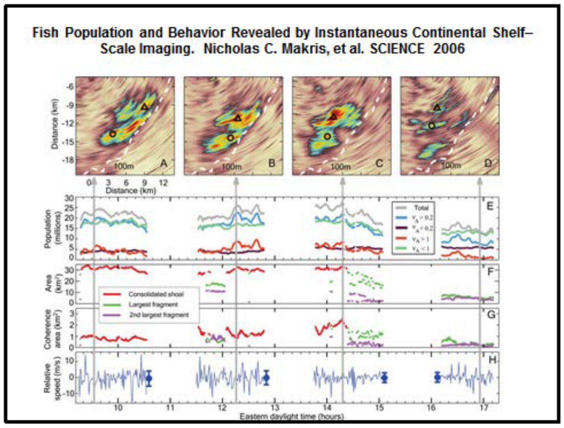

Log Haddock CPUE (kg/hour)
10000
1000
100
10
1
0.01
0.1
1
10
log Distance to CA-I (km)

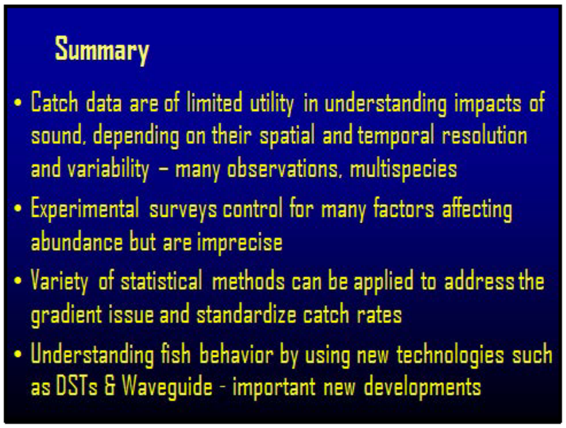

Yellowtail Flounder- CPUE vs. Distance to CA-II
yt kg per hour
1000
100
10
1
0.1
0.01
0.1
1
10
100
Kilometers from Closed Area I

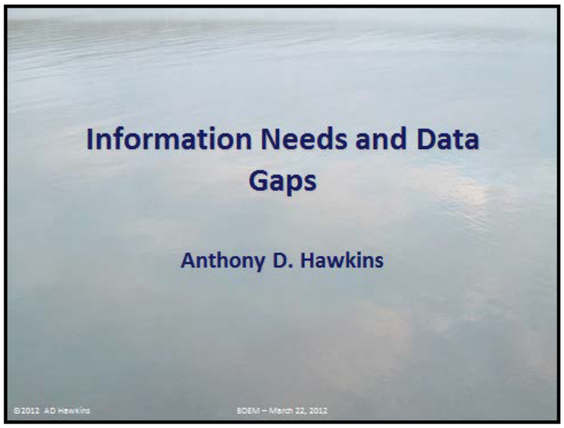

hours fished
ln Haddock cpue
ln Total cpue
distance (km)


Hours Trawled
Dollars per Hour Trawled
Smooth of Dollars per Hour
CV Dollars per Hour
Smooth of CV Dollars per Hour
2001-2003
Hours Trawled (standardized)
Dollars per Hour Trawled (standardized)
CV of Dollars per Hour
minimum distance to a closed area (km)


Importance of Understanding the Fish
Data Storage Tags
Yellowtail Flounder off Bottom with Tidal Cycle – complex use of space
Seemingly Random Movements & Passive Retention


Fish Population and Behavior Revealed by Instantaneous Continental Shelf–Scale Imaging. Nicholas C. Makris, et al. SCIENCE 2006
Eastern daylight time (hours)


Summary
• Catch data are of limited utility in understanding impacts of sound, depending on their spatial and temporal resolution and variability – many observations, multispecies
• Experimental surveys control for many factors affecting abundance but are imprecise
• Variety of statistical methods can be applied to address the gradient issue and standardize catch rates
• Understanding fish behavior by using new technologies such as DSTs & Waveguide - important new developments


Information Needs and Data Gaps
Anthony D. Hawkins
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BOEM – March 22, 2012

Session 1

We established an understanding of the policies and procedures BOEM must follow to implement its mission

Information on the effects of underwater sound is needed to enable BOEM to:

Predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments

The information is used by BOEM to:

- Direct future research
- Assist with NEPA Analyses
- Support BOEM & Other Models
- Develop Mitigation Actions
- Provide Information to Lessees

BOEM also requires information on underwater sound to enable it to:

- Look for conventional energy reservoirs (seismic surveys)
- Survey for sand sources (multi-beam sonar surveys)
- Survey for wind turbine site selection
- Survey for marine archaeological sites
- Regulate activities like:
  - Dredging
  - Pile-driving
  - Explosive removal of platforms

The **Study Program of BOEM** is crucial to taking knowledge forward. It establishes priorities on the basis of:

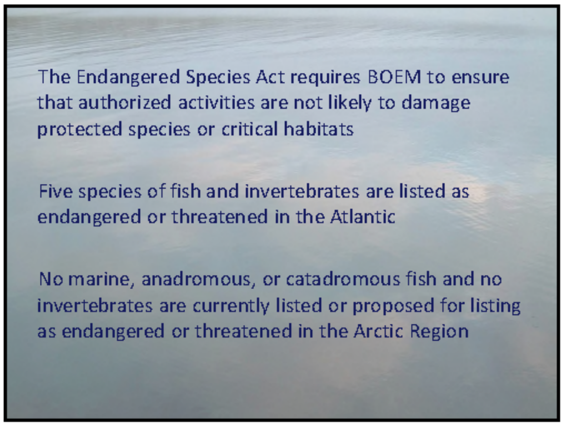
- Mission relevance
- Scientific merit
- Technical feasibility
- Timing
- Applicability

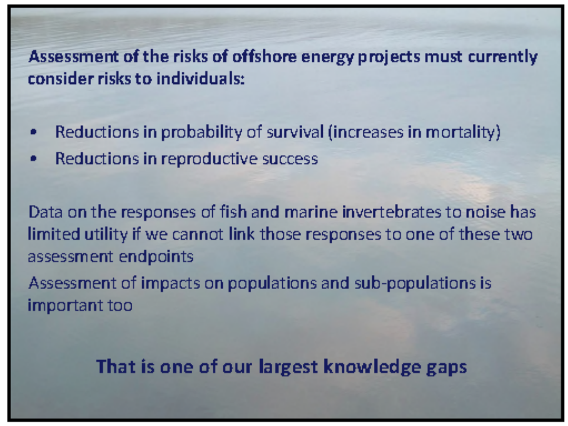
It is already evident to Regulators that:

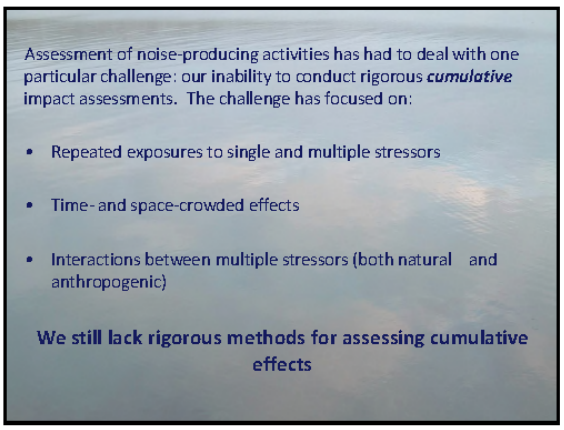
- **Some noise sources will have greater impact than others**
- **Help is needed in deciding which impacts are most important. "This bad, this good"**
- **Uncertainty must be taken into account**
- **Mitigation must be closely examined to ensure that it works. That requires monitoring to be done**

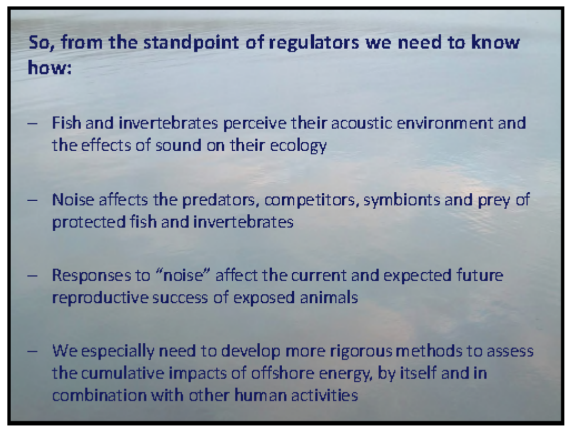
In **Session 2** we tried to define the fish and invertebrate species, habitats and fisheries of concern to regulators, fishery managers and the fishing community

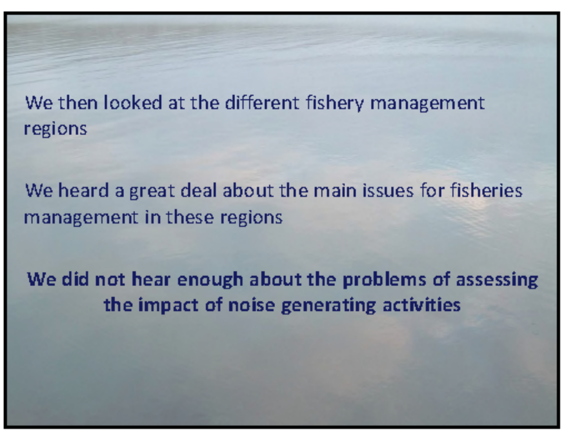
We first considered endangered or threatened species – which are at the top of the list in terms of concern

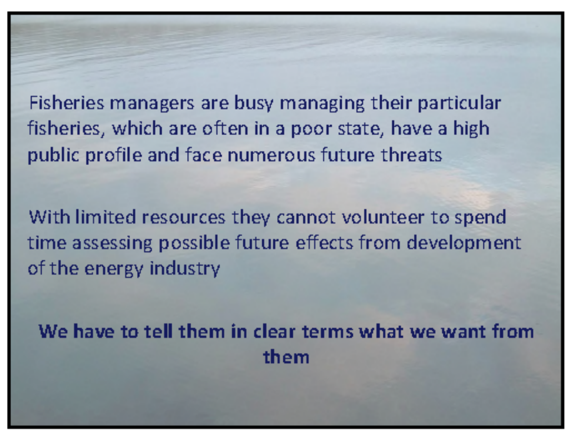

The Endangered Species Act requires BOEM to ensure that authorized activities are not likely to damage protected species or critical habitats
Five species of fish and invertebrates are listed as endangered or threatened in the Atlantic
No marine, anadromous, or catadromous fish and no invertebrates are currently listed or proposed for listing as endangered or threatened in the Arctic Region

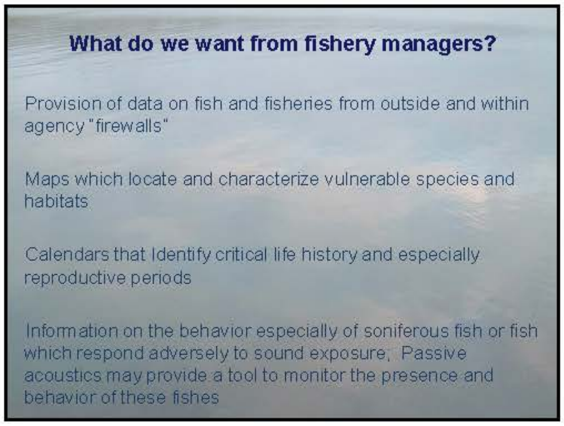

Assessment of the risks of offshore energy projects must currently consider risks to individuals:
Reductions in probability of survival (increases in mortality)
Reductions in reproductive success
Data on the responses of fish and marine invertebrates to noise has limited utility if we cannot link those responses to one of these two assessment endpoints
Assessment of impacts on populations and sub-populations is important too
That is one of our largest knowledge gaps

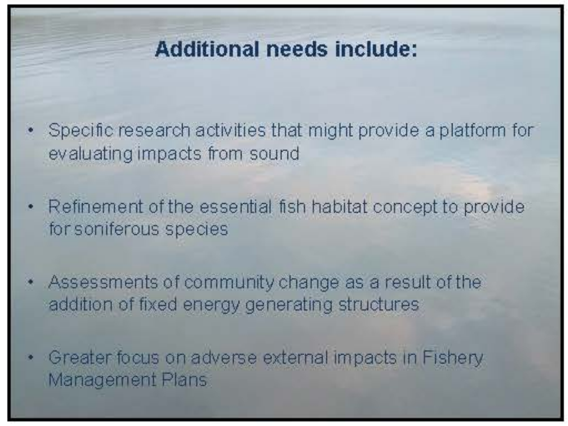

Assessment of noise-producing activities has had to deal with one particular challenge: our inability to conduct rigorous cumulative impact assessments. The challenge has focused on:
Repeated exposures to single and multiple stressors
Time- and space-crowded effects
Interactions between multiple stressors (both natural and anthropogenic)
We still lack rigorous methods for assessing cumulative effects


So, from the standpoint of regulators we need to know how:
Fish and invertebrates perceive their acoustic environment and the effects of sound on their ecology
Noise affects the predators, competitors, symbionts and prey of protected fish and invertebrates
Responses to "noise" affect the current and expected future reproductive success of exposed animals
We especially need to develop more rigorous methods to assess the cumulative impacts of offshore energy, by itself and in combination with other human activities


We then looked at the different fishery management regions
We heard a great deal about the main issues for fisheries management in these regions
We did not hear enough about the problems of assessing the impact of noise generating activities

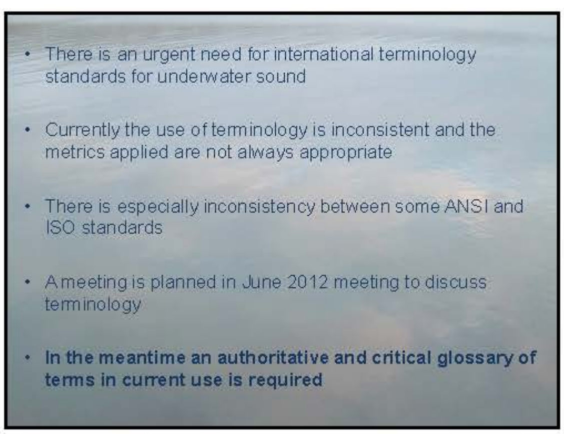

Fisheries managers are busy managing their particular fisheries, which are often in a poor state, have a high public profile and face numerous future threats
With limited resources they cannot volunteer to spend time assessing possible future effects from development of the energy industry
We have to tell them in clear terms what we want from them


What do we want from fishery managers?
Provision of data on fish and fisheries from outside and within agency "firewalls"
Maps which locate and characterize vulnerable species and habitats
Calendars that Identify critical life history and especially reproductive periods
Information on the behavior especially of soniferous fish or fish which respond adversely to sound exposure; Passive acoustics may provide a tool to monitor the presence and behavior of these fishes


Additional needs include:
• Specific research activities that might provide a platform for evaluating impacts from sound
• Refinement of the essential fish habitat concept to provide for soniferous species
• Assessments of community change as a result of the addition of fixed energy generating structures
• Greater focus on adverse external impacts in Fishery Management Plans


In all the fisheries management areas:
• Some species (and life stages) are especially vulnerable to man-made sounds – for example during spawning
• There is potential for energy developments to have adverse effects upon these species and their habitats
• However, these species and habitats have rarely been identified, let alone considered within fishery management plans. The degree of risk to individuals or populations has not been assessed
• More information is needed on these species, their location and their habitat requirements


Session 3 considered Sources and Sound Exposure
We first considered the Terminology for describing Underwater Sounds


• There is an urgent need for international terminology standards for underwater sound
• Currently the use of terminology is inconsistent and the metrics applied are not always appropriate
• There is especially inconsistency between some ANSI and ISO standards
• A meeting is planned in June 2012 meeting to discuss terminology
• In the meantime an authoritative and critical glossary of terms in current use is required


The next topic we addressed was the description of marine soundscapes
There are issues over:
• the description and quantification of soundscapes
• identifying trends in levels and characteristics
• Deciding when soundscapes are adversely affected by man-made sounds
• Presentation of noise budgets can be misleading depending on the units used

Do we have enough descriptions of marine soundscapes?

No!

- Most observations and measurements have been incidental to other activities
- There are few ocean observing stations dedicated to 'ecological' sound measurements. We need a long term commitment to such stations and to surveys of different ocean soundscapes. **More acoustic ecology**
- We need to decide what measurements we require from such stations, how they should be presented, and to whom they should be made available

Individual Man-made Sound Sources

We have a lot of information on some sound sources

For example, the OGP JIP program has characterized an air gun array and ancillary work has examined 'soft starts'

However, some key damaging man-made sources are still poorly characterized – for example pile driving

We need further measurements – based not on the requirements of the sound-makers but on the need to assess impacts on animals (remember particle motion!)

Industry needs to look more closely at alternatives - vibroseis

Additional Points re Sound Sources

What are the important metrics from the standpoint of the biological receivers - rather than the engineers?

How can we reduce those sound characteristics which are especially damaging to marine critters?

How should the relative contributions and the degree of damage likely to be caused by different sources be compared – apples and pears! How do we consider aggregate effects?

What future trends should we expect? Are marine animals doomed to be subjected to larger pile drivers, even more extensive seismic surveys and wider swathes of dredging?

Session 4 – Effects of Sounds

The great diversity of fishes and Invertebrates poses major problems

It is not just diversity of species but also diversity of size and life history status within each species

Can we identify particular "types" which will serve as models for other species and life history stages?

Can we reliably make broad generalizations about effects of sound on such a diverse group of species?

Table 1: Groupings of Fish by Sensitivity to Seismic Sound and Ecological Association

		Ecological Associations					
		Large Pelagic	**Small Pelagic**	**Demersal**	**Reef**	**Shallow/Estuary**	**In River**
Fish Categories Arranged by Sensitivity to Sound	**gas bladder connected to ear**		Herring Sprat Shad	Weakfish Deep-sea cod	Squirrel-fish	Catfish Carp Goldfish	Dace Minnow
	gas bladder close to ear			Cod Haddock Saithe	Red Snapper		
	gas bladder distant from ear	Dorado	Horse Mackerel	Spot	Wrasse	Sand-smelt	Salmon Eel
	no gas bladder	Sharks	Mackerel	Plaice Sole		Flounder	
	fish eggs and larvae	Dorado larvae	Herring Larvae	Cod larvae	Red Snapper larvae	Catfish larvae	Salmon eggs

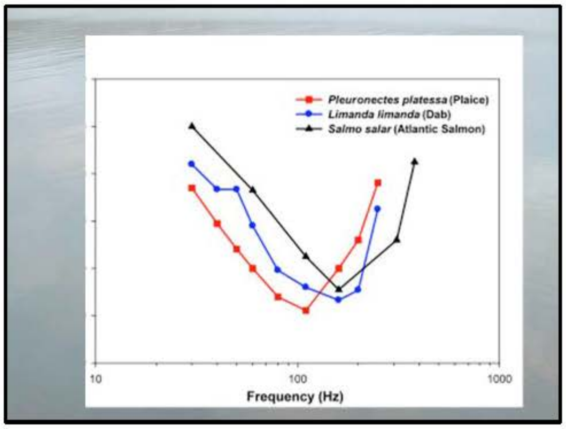
Hearing

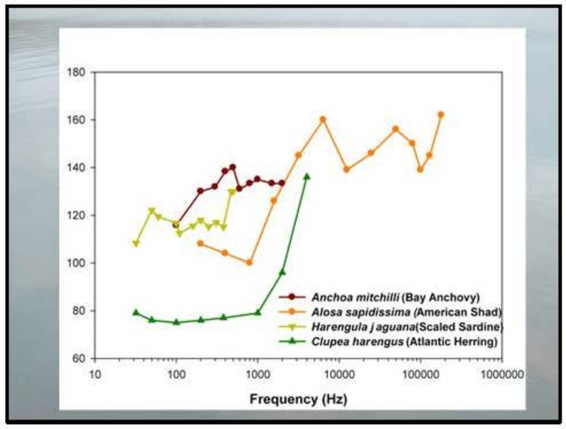
Knowledge of the hearing abilities of fish and invertebrates is not just of academic interest!

Audiograms are already being used in environmental statements to assess whether animals can detect man-made sounds. Metrics like the dBht require reliable measurements of hearing abilities.

Information on the masking of biologically important sounds by 'real' sounds – including man-made sounds is also urgently needed. **Masking is an important potential effect!**

We have very few reliable data on hearing abilities. Valid audiograms are only available for a handful of species





How can we obtain better data on hearing and especially masking?

We need well equipped field sites for examining the hearing abilities of a range of species (and perhaps also their behavior) in the sea, at depth, under quiet ambient noise conditions

Specially designed tanks can also enable precisely controlled sound stimuli to be presented to fish and invertebrates

Instrumentation is urgently needed that will allow us to monitor the particle motion stimuli presented to fish and invertebrates

Then we might examine representative species and obtain valid data applicable to a range of similar animals

Similar principles apply to the evaluation of injury and physiological damage to animals

Michele has shown us what can be achieved using specially designed facilities – and more importantly well defined protocols - in terms of measuring effects

These pioneering techniques can now be rolled out to examine effects both in the laboratory and in the field

It should be possible to look at the effects of different stimuli including sound pressure and particle motion, and to look at factors like rise-time, kurtosis, cumulative effects, recovery and other important aspects of sound exposure

We can then look at:

Thresholds or criteria for the occurrence of different effects

The nature of the effects and how they change with different sound types and levels

The source characteristics that cause detrimental effects; e.g., magnitude, rise time, duration, kurtosis, duty-cycle

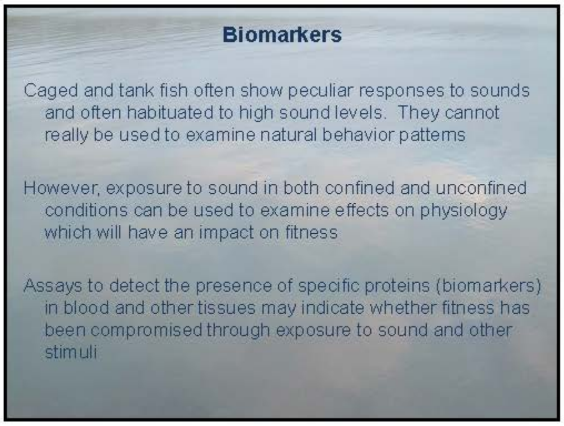
The responses of different types of animal

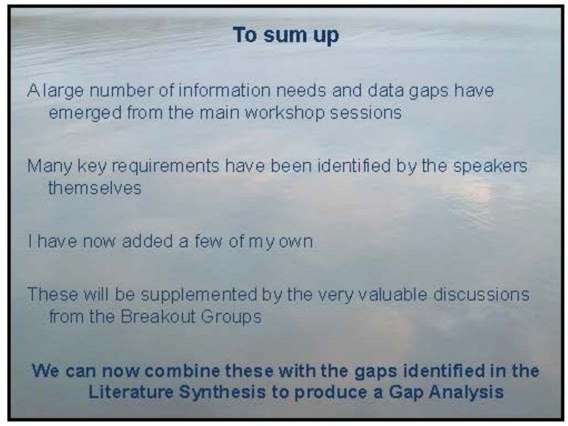
Behavior

Alex, John and Svein showed us what can now be achieved in terms of examining responses of fish in the actual sea. **Fish do react to sounds (sometimes!)**

Sonar and echo-sounding observations, analysis of catches and other techniques like the examination of the tracks of tagged fish and the use of Waveguide can enlarge our knowledge of how fish behave in response to real sounds. **We should be able to define behavioral thresholds from these field experiments**

We still have the problem of deciding which responses are significant in terms of impairing fitness.


Biomarkers
Caged and tank fish often show peculiar responses to sounds and often habituated to high sound levels. They cannot really be used to examine natural behavior patterns
However, exposure to sound in both confined and unconfined conditions can be used to examine effects on physiology which will have an impact on fitness
Assays to detect the presence of specific proteins (biomarkers) in blood and other tissues may indicate whether fitness has been compromised through exposure to sound and other stimuli


To sum up
A large number of information needs and data gaps have emerged from the main workshop sessions
Many key requirements have been identified by the speakers themselves
I have now added a few of my own
These will be supplemented by the very valuable discussions from the Breakout Groups
We can now combine these with the gaps identified in the Literature Synthesis to produce a Gap Analysis


The future
This meeting has demonstrated clearly that there are benefits to be gained from bringing together Regulators, Noise-makers, Environmentalists, Fishery Managers to discuss the effects of underwater sounds
There are also advantages in combining discussion on the effects on different animals. There are even benefits from having marine mammal specialists present for discussions on fish!
How can we ensure that these fruitful contacts are maintained?