Overview on Seismic Survey Research and Main Literature

Background

During the NWWAC meetings in Madrid 2018 an action point arose from Working Group 2 based on the NWWAC Executive Committees' concern regarding oil and gas exploration in North Western waters. Irish representatives during this meeting commented that recent research has shown the detrimental effects of seismic exploitation on e.g. zooplankton and fish distribution and recommended the AC should follow up further.

This document comprises an overview of research on seismic surveys and examples of the main literature with abstracts for information. Further work would be beneficial such as a critical review of the scientific literature on impacts of seismic sounds or effectiveness of mitigation options. A workshop or focus group could be set up to explore how tolerances for ecological impacts could be addressed according to the MSFD, Good Environmental Status descriptors.

MSFD Descriptor 11: Energy including underwater noise[1]

"Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment"

The introduction of energy is quite difficult to explain and grasp. It changes the physical systems. Simply put, when we speak about introduction of energy, we refer to light, electricity, heat, noise, electromagnetic radiation, radio waves or vibrations. Building the foundations of an offshore platform using pile driving for instance is the source of a lot of energy releases, whether in the form of noise or vibrations.

Although energy is a natural process, it does not always have a positive effect on other natural processes. Human activities can take a disproportional amount of energy out of a system or add to it. This can have a negative impact on the marine environment.

What kind of damage does underwater noise cause?

Attention has been raised on the topic of underwater noise and its effects on marine life. Yet, the effects of underwater noise are not fully understood. One reason for this is that only for a few species of mammals and fish, tests have been performed to identify hearing range and sensitivity.

But even if an individual hears the noise, we are not sure how it will react or what damage will be done. It could avoid the source and be chased out of important areas, for example spawning grounds. It might influence its ability to detect food. Its hearing could get damaged at close ranges with further effects on communication about food, danger and reproduction. Research proved that marine fauna certainly do experience effects from noise exposure. It has been established for example that stranding incidents in beaked whales were caused by underwater noise from military activities.

Some underwater noise can be heard by marine life over distances of dozens of kilometres. For example pile driving sound can be as loud as 250 decibels* at the source and can potentially be picked up by a harbour porpoise over distances of at least 80 km under certain circumstances.

[1] http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-11/index_en.htm

*relative to 1 micropascal

What are the main sources of energy in the marine environment?

Human sources of energy in the marine environment are commonly related to transport, mining and fishing and construction. The effects of recreation and industries can also be experienced in coastal waters.

Sources of energy include:

- Shipping for trade or tourism, like ferries or cruise ships, recreation boats and fishing boats, which all produce noise;
- The use of sonar systems by all kinds of vessels;
- Construction (especially through piling) of offshore oil and gas platforms and wind parks;
- Dredging for shipping lanes, sand mining and for laying pipes and cables;
- Operation of platforms and their lights;
- Cable connections between offshore activities, the main land and between power stations, causing electromagnetic radiation;
- Cooling water systems for industry, which raise water temperature;
- Military activities, which produce noise.

Monitoring underwater energy of marines waters

The adoption of the Marine Directive (MSFD 2008/56/EC) and specifically of Descriptor 11 has given a great impulse to the market of underwater sound equipment, engineering and advice. There is also more interest for research in this field and governments, companies and institutes have already performed a great amount of studies on the topic.

As a follow up to the Commission Decision on criteria and methodological standards on good environmental status (GES) of marine waters (Commission Decision 2010/477/EU), the Marine Directors requested the Directorate-General for the Environment (DG ENV) in 2010 to establish a technical subgroup under the Working Group on GES (WG GES) in relation to the Marine Strategy Framework Directive 2008/56/EC (MSFD) for further development of Descriptor 10 Marine Litter and Descriptor 11 Noise/Energy. For practical reasons the work was carried out by two separate groups. The reports compile the recommendations regarding Descriptor 10 (Marine Litter) and Descriptor 11 (Noise).

Monitoring impacts of individual public and private projects

The Environmental Impact Assessment (EIA) Directive (2011/92/EU) is applicable at the level of individual public and private projects. Development consent (e.g. permission/approval/authorisation) for projects, which are likely to have significant effects on the environment, should be granted once the environmental impact assessment has been carried out.

The EIA Directive distinguishes between projects requiring a mandatory EIA (so-called Annex I projects) and those where Member State authorities must determine, in a procedure called "screening", if projects are likely to have significant effects, taking into account criteria in Annex III of the Directive (so-called Annex II projects). Under both the mandatory EIA and the screening procedures, depending on the type of project, a number of project's characteristics including nuisances and/or noise should be considered.

In addition, recital 12 of Directive 2014/52/EU amending Directive 2011/92/EU further focuses on the protection of the marine environment and urges Member States to take into account during the EIA and screening procedures particular characteristics of projects with regard to technologies used such as seismic surveys using active sonars.
You can access here the new EIA Directive (applicable as of 16 May 2017) and the current EIA Directive.

ICES Data portal[2]

The EU's Marine Strategy Framework Directive (MSFD) lists input of energy including underwater noise as descriptor 11 in its list of Descriptors, which can be used to describe what the marine environment will look like when good environmental status (GES) has been achieved. The ICES underwater noise data portal will not record all sounds in the seas, just the human caused impulsive noise that occur due to activities such as pile driving, seismic surveys, controlled explosions and from some naval operations.

The ICES impulsive noise data portal assembles data supplied by OSPAR (North East Atlantic) and HELCOM (Baltic Sea) and will register noise events collated nationally from registers of licenced events.

As there is currently inadequate knowledge on the effects of underwater sound and the effects of impulsive noise especially to quantify effects on ecosystem and population levels, the data portal aims to increase our knowledge of trends in these sounds.

The ICES underwater noise data portal is available through the ICES Data Centre.

Bibliography

McCauley, R., Swadling, K., Fitzgibbon, Q., Watson, R., Semmens, J. 2017.**Widely used marine seismic survey air gun operations negatively impact zooplankton**. Nature Ecology & Evolution volume 1, Article number: 0195 (2017) doi:10.1038/s41559-017-0195

Zooplankton underpin the health and productivity of global marine ecosystems. Here we present evidence that suggests seismic surveys cause significant mortality to zooplankton populations. Seismic surveys are used extensively to explore for petroleum resources using intense, low-frequency, acoustic impulse signals. Experimental air gun signal exposure decreased zooplankton abundance when compared with controls, as measured by sonar (~3–4 dB drop within 15–30 min) and net tows (median 64% decrease within 1 h), and caused a two- to threefold increase in dead adult and larval zooplankton. Impacts were observed out to the maximum 1.2 km range sampled, which was more than two orders of magnitude greater than the previously assumed impact range of 10 m. Although no adult krill were present, all larval krill were killed after air gun passage. There is a significant and unacknowledged potential for ocean ecosystem function and productivity to be negatively impacted by present seismic technology.

[2]ICES Data portal http://www.ices.dk/news-and-events/news-archive/news/Pages/ICES-launches-underwater-noise-data-portal.aspx

Carroll, A.G.,Przeslawski, R. Duncan, A., Gunning, M., Bruce, B., **A critical review of the potential impacts of marine seismic surveys on fish & invertebrates** Marine Pollution Bulletin Volume 114, Issue 1, 15 January 2017, Pages 9-24 https://doi.org/10.1016/j.marpolbul.2016.11.038

Marine seismic surveys produce high intensity, low-frequency impulsive sounds at regular intervals, with most sound produced between 10 and 300 Hz. Offshore seismic surveys have long been considered to be disruptive to fisheries, but there are few ecological studies that target commercially important species, particularly invertebrates. This review aims to summarise scientific studies investigating the impacts of low-frequency sound on marine fish and invertebrates, as well as to critically evaluate how such studies may apply to field populations exposed to seismic operations. We focus on marine seismic surveys due to their associated unique sound properties (i.e. acute, low-frequency, mobile source locations), as well as fish and invertebrates due to the commercial value of many species in these groups. The main challenges of seismic impact research are the translation of laboratory results to field populations over a range of sound exposure scenarios and the lack of sound exposure standardisation which hinders the identification of response thresholds. An integrated multidisciplinary approach to manipulative and in situ studies is the most effective way to establish impact thresholds in the context of realistic exposure levels, but if that is not practical the limitations of each approach must be carefully considered.

Løkkeborg, S., and Soldai, A. V. 1993. **The influence of seismic exploration with airguns on cod (*Gadus morhua)* behaviour and catch rates.** - ICES mar. Sei. Symp., 196: 62-67.

Analyses of catch records showed that geophysical activity with airguns significantly influenced the catch rates of cod (*Gadus morhua*) in long-line and trawl fisheries. Catch reductions of 55-80% were observed for long lines set within a seismic survey area, and the by-catch of cod in shrimp trawl was reduced by about 80-85%. The bycatch of cod in trawl fishery for saithe, however, was observed to increase threefold and to return to normal immediately after the seismic work ended. The predominant frequencies of airgun sound spectra match the most sensitive auditory band of cod.
The reductions in catch rates are undoubtedly due to behavioural responses of cod to airgun sound. The fish probably avoided the approaching geophysical vessel by swimming away from the sound source, and the amount of fish available to any fishing gear used in this area was thereby reduced. The results from the trawl fishery for saithe were explained by the short duration of the sound emissions during this particular seismic survey.
Svein Løkkeborg and A u d Void Soldai: Institute o f Marine Research, Fish Capture Division, PO Box 1870 Nordnes, N-5024 Bergen, Norway.

A review of the effects of seismic surveys on marine mammals. / Gordon, Jonathan Charles David; Gillespie, D ; Potter, J ; Frantzis, A ; Simmonds, M P ; Swift, R ; Thompson, D . In: Marine Technology Society Journal, Vol. 37, No. 4, 2003, p. 16-34. **DOI:** https://doi.org/10.4031/002533203787536998

This review highlights significant gaps in our knowledge of the effects of seismic air gun noise on marine mammals. Although the characteristics of the seismic signal at different ranges and depths and at higher frequencies are poorly understood, and there are often insufficient data to identify the appropriate acoustic propagation models to apply in particular conditions, these uncertainties are modest compared with those associated with biological factors. Potential biological effects of air gun noise include physical/physiological effects, behavioral disruption, and indirect effects associated

with altered prey availability. Physical/physiological effects could include hearing threshold shifts and auditory damage as well as non-auditory disruption, and can be directly caused by sound exposure or the result of behavioral changes in response to sounds, e.g. recent observations suggesting that exposure to loud noise may result in decompression sickness. Direct information on the extent to which seismic pulses could damage hearing are difficult to obtain and as a consequence the impacts on hearing remain poorly known. Behavioral data have been collected for a few species in a limited range of conditions. Responses, including startle and fright, avoidance, and changes in behavior and vocalization patterns, have been observed in baleen whales, odontocetes, and pinnipeds and in some case these have occurred at ranges of tens or hundreds of kilometers. However, behavioral observations are typically variable, some findings are contradictory, and the biological significance of these effects has not been measured. Where feeding, orientation, hazard avoidance, migration or social behavior are altered, it is possible that populations could be adversely affected. There may also be serious long-term consequences due to chronic exposure, and sound could affect marine mammals indirectly by changing the accessibility of their prey species.

A precautionary approach to management and regulation must be recommended. While such large degrees of uncertainty remain, this may result in restrictions to operational practices but these could be relaxed if key uncertainties are clarified by appropriate research.

Implementation of Seismic Surveys on the Norwegain Continental Shelf
http://www.npd.no/Global/Engelsk/5-Rules-and-regulations/Guidelines/Guidelines-Seismic-Surveys.pdf

How are fish and the fishing industry affected by seismic acquisition?
5.1 How are fish stocks affected by seismic surveys? The sound waves transmitted through the water during the acquisition of seismic data can affect marine organisms directly (physiologically) or indirectly (behavioural influence).

5.1.1 Direct effects - fish, eggs, larvae and fry
Fish exposed to sound waves from seismic acquisition will attempt to swim away from the source. Except for the metres closest to the sound source, adult fish are not directly injured by seismic sound waves. Eggs, larvae and fry do not have the same ability as large fish to escape the sound source. The sound energy from seismic activity can injure or kill larvae and fry near (less than five metres) the source by causing injuries to hearing and the kidneys, heart and swim bladder. 20 metres away there is very little likelihood that fry suffer damage. The natural mortality of larvae and fry is so high that the negative effect of seismic activity is small in comparison, and the consequences at the population level are considered insignificant and the uncertainty is negligible. On this basis, no restrictions are placed on seismic surveys out of consideration to injuries to fish eggs, larvae and fry.

5.1.2 Indirect impact - spawning production
Fish react to sound in various ways. The weakest form of behavioural response is small changes in swimming activity where the fish changes direction and increases swimming speed, while the most powerful form of behaviour in response to sound is a quick flight reaction. The success of spawning could conceivably be affected if, during migration to spawning grounds or during spawning, the fish change behaviour due to acquisition of seismic data. The spawning migration pattern may change

and spawning may be more or less displaced in time and space. Consequently, the larvae may miss the time window of optimal biological conditions for survival and growth. Restrictions on seismic activity have therefore been implemented in areas with important spawning grounds and in areas when concentrated spawning migrations take place. Time and area restrictions are block specific and are stipulated in the the individual licensing round announcements.

Guidelines

- Regulation of seismic activity : According to the Petroleum Act, none other than the State may conduct petroleum activities without authorisation. This means that anyone who acquires seismic data in connection with petroleum activities must be authorised pursuant to the Petroleum Act. Such permission may be either an exploration or a production licence.
- Coexistence with other industries : Section 10-1, second paragraph, first sentence of the Petroleum Act reads:
  The petroleum activities must not unnecessarily or to an unreasonable extent impede or obstruct shipping, fishing, aviation or other activities, or cause damage or threat of damage to pipelines, cables or other subsea facilities.
- Time and area restrictions: Seismic has little effect on eggs, larvae and fry, but can affect fish behaviour and migration patterns, adversely affecting spawning production. Time limits have therefore been introduced for seismic activity in areas with important spawning grounds and in areas where there are concentrated spawning migrations.
- Safe distance – Section 5, first subsection of the Resource Management Regulations : Section 5, first subsection of the Resource Management Regulations, reads:
  "Vessels carrying out seismic surveys shall maintain a safe distance from vessels carrying out fishing activities and from fixed and floating fishing gear. Particular attention must be exercised when an accumulation of fishing vessels is observed."
  This means that the seismic vessels shall keep such good distance to fishing vessels that no ongoing fisheries are unduly affected or that deployed fishing gear is physically destroyed.
- Marine Resources Act: The Act relating to the management of wild living marine resources (Marine Resources Act) aims to ensure sustainable and socio-economically profitable management of wild living marine resources and associated genetic material, and to contribute to securing employment and settlement in coastal communities.
  Section 24 of the Act deals with the rules of due care by the following: *"Any person arriving at harvesting grounds where gear has been set shall acquaint himself with the location of such gear. All persons shall conduct themselves in such a way that fishing gear is not damaged or unnecessarily endangered. It is prohibited to impede harvesting or spoil harvesting opportunities by means of shooting, noise or other improper conduct. The Ministry may adopt further provisions on the manoeuvring of vessels and conduct on harvesting grounds."*

Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals

https://pdfs.semanticscholar.org/860e/3b7fbd59198cafb146194f9c717dd997cbb3.pdf

DFO, 2004. Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals. DFO Can. Sci. Advis. Sec. Habitat Status Report 2004/002.

Summary
From the evidence available, it can be concluded that seismic sounds in the marine environment are neither completely without consequences nor are they certain to result in serious and irreversible harm to the environment. In the huge range of effects between those extremes, however there are many potential detrimental consequences. In general risks of these consequences are poorly quantified, often unknown, and likely to be variable with both conditions of the environment and of the organisms exposed to the sounds. The long and widespread history of seismic surveys globally in marine environments with no documented fish or invertebrate kills, and only circumstantial evidence of associations with infrequent strandings of marine mammals and giant squid, suggest that seismic surveys with fairly routine mitigation measures in place are unlikely to pose high risk of mortality of marine organisms. However, this suggestion must be qualified, because sublethal or longer-term effects could have occurred and not have been detected by the monitoring programs typically in place.

The following reports have been made available by **Subacoustech** for download. For the latest publications by Subacoustech, check the website.

- Nedwell J, Turnpenny A (2003) '*Measurements of underwater noise during piling at the Red Funnel Terminal, Southampton, and observations of its effect on caged fish*'. Subacoustech Report Reference: 558R0207, October 2003
- Nedwell J, Edwards B (2002) '*Measurements of underwater noise in the Arun River during piling at County Wharf, Littlehampton*', Subacoustech Report Reference: 513R0108, August 2002
- Nedwell J, Needham K (1995) '*Noise Hazard in the Diving Environment*'. Published in Proceedings of the international conference: SUBTECH '95: Addressing the Subsea Challenge.
- Nedwell J (1994) '*Underwater Spark Sources: Some experimental information*'. Subacoustech Report Reference: 440R0102, December 1994

Government and Industry guidelines

DRAFT Guidelines for Seismic Surveying and Submission of Seismic Data to Exploration and Mining Division, DCCAE October 2016. http://www.mineralsireland.ie/files/Seismic_Guidelines_DRAFT.pdf

Exploration and Mining Division (EMD) must be notified in writing at least three calendar months prior to the commencement of a seismic survey. The notification should include the exact location of the proposed survey (coordinates and maps should be provided), survey acquisition parameters, the proposed start date, expected survey duration and proximity to Natura 2000 sites. A Screening for Appropriate Assessment Report may be required if the Seismic Survey is planned to be acquired in close proximity to a European Site. A reduced notification timeframe will be considered. However all seismic surveys need prior approval from EMD. Such requisite licences or permissions that are additionally required must be obtained by the commissioner of the Survey from the relevant authorities, such as local authorities, Transport Infrastructure Ireland (TII) etc.

A “Seismic Survey Report” is required for each seismic survey. This report should be lodged with EMD on a confidential basis within one year from the date of survey acquisition completion i.e. the ‘Lodgement Date’ is one year after ‘Completion Date’. It should include details of the survey

acquisition and data processing, along with all the raw and processed data. Format and Content of Seismic Data Submission to EMD - 3 - An Interpretation Report to accompany each survey should be submitted within two years of the 'Completion Date'. In addition to the 'Seismic Survey Report' and the 'Interpretation Report', the digital images of the processed seismic data and resulting interpretations relevant to individual PL areas should be referenced in individual PLA and PLA Block Reports.

JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys August 2010.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/50005/jncc-seismic-guide.pdf

Guidance before and during seismic activity

- Pre-shooting search
- Delay if marine mammals are detected within the mitigation zone (500 metres)
- The soft-start
- Soft-start requirements for site survey or Vertical Seismic Profiling (VSP)
- Soft-starts and airgun testing
- Line change
- Seismic surveys with an airgun volume of 500 cubic inches or more
- Seismic surveys with an airgun volume of 180 cubic inches or less
- Undershoot operations