Potential Noise Impacts of Current and Advancing Marine Technologies in the Industrialization of the Ocean

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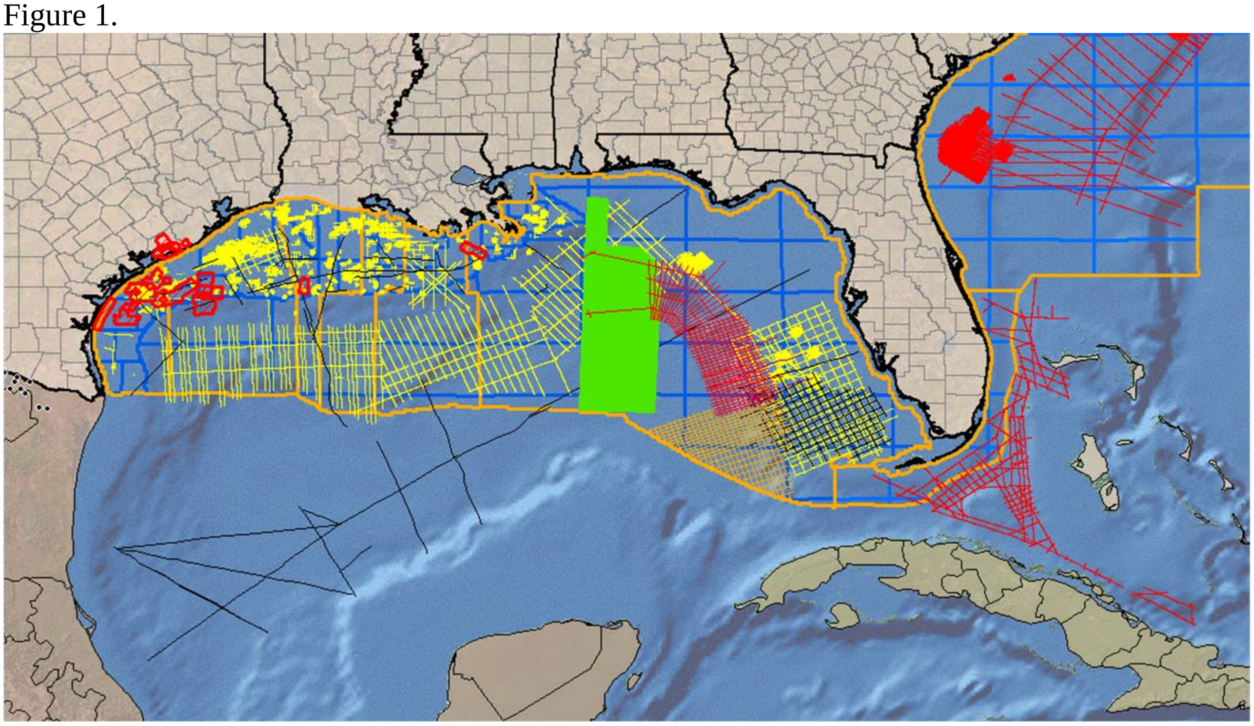
Abstract:

Increasingly technology is opening up hostile and challenging marine environments for industrial exploitation. This is occurring in the energy sector with fossil fuel exploration and extraction operations and developing wind and hydrodynamic energy projects. It is also occurring with the deep-water expansion of other extraction industries such as minerals mining and fishing. All of these operations and enterprises are introducing loud and complex noise sources into marine bioacoustic habitats. This presentation will be an overview examination of existing and developing noise sources that are a consequence of the industrialization of the outer continental shelf and high seas.

Overview:

It has been often said that we know more about the surface of the moon than we do about the ocean. This may have been true twenty years ago, but due to the importance of the ocean for military, commerce, and industry the ocean is getting increasingly explored, plumbed, charted, and mapped.

Figure 1.



Seismic Transects and Pipelines
Gulf of Mexico and South-mid Atlantic

This mapping and exploration is not being done for pure curiosity sake. Much of it is not even being done to expand scientific understanding of the physical ocean and biological habitats. Most of this exploration is being advanced to find extractable resources. Hydrocarbons (fossil fuel, methane hydrates), wind and tidal energy harvesting, minerals mining, and fisheries resources all play into the industrialization of the sea.

Exploitation of these resources in often challenging or hostile environments is being made possible by advancing materials and manufacturing processes that produce equipment that can meet the physical challenges of the deep – with temperature extremes (below 0°C to above 400°C) and pressure extremes found in deep, resource-rich areas. It is also being made possible by the increasing computerization of equipment that can execute complex tasks autonomously or semi- autonomously with minimal human intervention.

In any marine industry the entire process from exploration, to extraction, to processing introduces acoustical energy into the ocean – which is habitat for marine animals, many of which depend on sound to communicate, navigate, hunt, feed, avoid predators, and procreate. Thus the potential for industrial noise interference with critical biological processes can be pretty high.

Looking for Resources

Before ocean resources are extracted they need to be located. Where there are some broad-brush and non-invasive reconnaissance technologies such as magnetic gravimetry, most ocean and seafloor mapping is done using sound, with the low-frequency impulsive seismic surveys (Airguns, sparkers, boomers:1Hz -4kHz), chirp seafloor profiling system (500Hz -100kHz), side-scan sonar (100kHz-500kHz), sub-bottom profilers (1kHz – 12kHz), single-beam bathymetry (3kHz-200kHz), and multi-beam "swath" profilers (10kHz-+300kHz).[1]

With the exception of seismic surveys few of these technologies have come under any regulatory scrutiny. [2] This is likely a product of a number of factors, including the typical short pulse length, narrow transmission beam, "ultra-sonic"(above human auditory detection) frequencies, and the gradual introduction of commercial and industrial SONAR (SOund NAvigation and Ranging) over decades with no apparent deleterious effects on marine life.

In most cases it is probably true; exposures to short duration high frequency acoustical pulses are either outside of the hearing systems of most marine animals, or in the case of odontocetes, easy enough to for the animals to localize, identify, and avoid if required. It was only recently when a 12kHz multibeam sonar survey that a sonar mapping system was implicated in a mass stranding.[3] This incident has not seemed to raise any regulatory flags yet. There were some common benthic profile components in this incident that have been associated with Mid Frequency military sonar strandings – such as a steep shelf-break. This similarity may have singled out this incident as

[1] For a reasonable overview on ocean mapping technologies see: http://woodshole.er.usgs.gov/operations/sfmapping/index.htm

[2] As seismic surveys are under continuous and ongoing public and regulatory scrutiny we will not dive into this technology herein.

[3] Southall, B.L., Rowles, T., Gulland, F., Baird, R.W. and Jepson, P.D. (2013) *Final report of the Independent Scientific Review Panel investigating the potential contributing factors to a 2008 mass stranding of melon headed (Peponocephala electra) in Antsohihi, Madagascar* International Whaling Commission

being an anomaly. But the frequency, amplitude, and the density of the signal source alone should trigger regulatory scrutiny. (see Table 1)

Table 1: Kongsberg EM120 Multi-Beam Echo Sounder (MBES)

Output carrier frequency	12kHz
Pulse duration	2ms, 5ms, or 15ms
Pulse rate	≤5Hz
Transducer beam-width	1° or 2°
Output source level (RMS SPL)	236 to 244 dB (re 1μPa @ 1 m)
SEL per pulse (calculated for 15ms pulse, 5Hz)	218-224 dB (re 1μPa^2·s @ 1m)
Number of beams	191
Across-track beam fan width	150°

It is easy to assume that because these MBESs cut a narrow and focused swath (1° or 2° beam width x 150° track width) that there is no sound outside of the beam. But the specification is a transducer specification, not a propagation specification. At 12kHz and at source levels of 236-244dB(re: μPa @ 1 m) the acoustical artifacts of this equipment would impose a 180dB SEL Level A take on marine mammals[4] at 5km from the source.

Calculating Impacts:

Any acoustical signals will attenuate over distance. There are two components of sound attenuation from the signal source: propagation energy losses due to the distance from the source, and sound absorptivity in water due to frequency dependent chemical “relaxation” or “elasticity” characteristics of Boric acid and Magnesium sulphate components in seawater. (See Appendix A for calculation details).

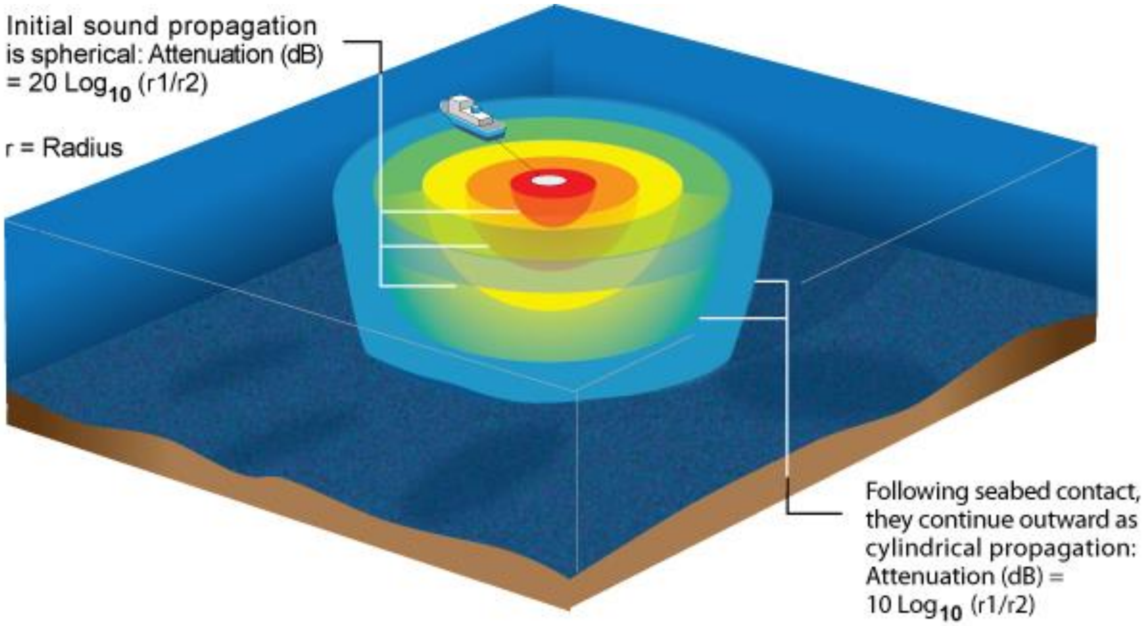
The propagation losses are spherical up to a distance approximately two times the depth of the water ($20\log_{10}(r1/r2)$ where “r” is the radius of the propagation) at which point the sound begins to propagate at a cylindrical propagation-loss factor of 10log10(r1/r2). (See Figure 2).

[4] Under the 1994 Amendments to the Marine Mammal Protection Act (MMPA), harassment is statutorily defined as, any act of pursuit, torment, or annoyance which--

(Level A Harassment) has the potential to injure a marine mammal or marine mammal stock in the wild; or,

(Level B Harassment) has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild.

Figure 2:



Using the SEL at 224dB as the source level it would require 44dB of signal dissipation to bring the signal down to the MMPA Level A impact 180 dB SEL isopleth. The frequency dependent chemical absorptivity coefficient at 12kHz is approximately 1.5dB/km

Factoring in cylindrical propagation loss and frequency dependent absorption losses, the 180dB isopleth would be at 4.75 km:

Propagation loss: $10\log_{10}$ (1m/4.75km) =	36.8 dB
Absorption: 4.75km*1.5dB*km-^{1} =	7.1 dB
Total transmission loss:	43.9 dB

But at 4.75km the sound would typically be more of a continuous noise due to reverberation, imposing a Level B take (120dB continuous noise) and requiring an additional 60dB attenuation for a total required attenuation of 104dB to comply with regulatory standards, which would be met at 38.75km:

Propagation loss: $10\log_{10}$ (1m/38.75km) =	45.9 dB
Absorption: 38.75km*1.5dB*km-^{1} =	58.1 dB
Total transmission loss at 38.75 km:	104.0 dB

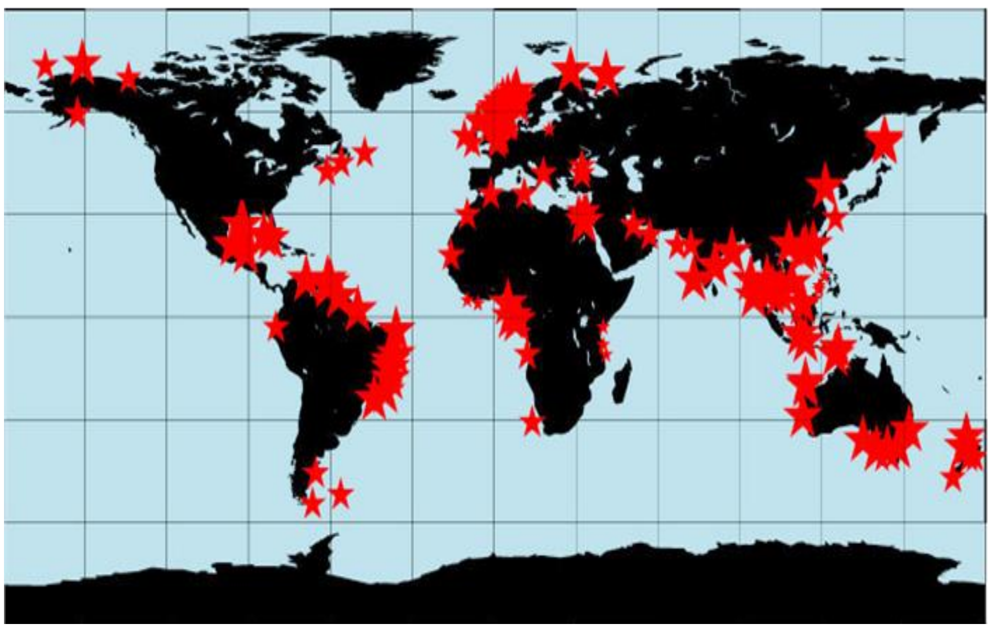
While in this instance this one piece of equipment was used in unregulated national waters off Madagascar, if used in US national waters it would require regulatory review and permitting.

So while this particular and unusual event in Madagascar has not been known to be repeated, it is clear that the equipment exceeds current MMPA Level A Take threshold[5] and should be deployed in conformance with regulatory guidelines in determining marine mammal takes – and applying for authorizations and permits as required.

Industrialization of the Outer Continental Shelf (OCS) and High Seas

Surveys using the MBES and other seafloor and subsea profiling systems are occurring world-wide as businesses look for minerals, energy harvesting sites, fish aggregations, methane hydrates, and fossil fuel deposits. Seafloor minerals extraction and offshore energy harvesting (hydrocarbon, wind, and tidal energy) leading the charge – fossil fuel exploration, extraction, and production being at the head of the pack.

Figure 3:



Global Ongoing Seismic Survey Locations for Fossil Fuel (2010)

Increasingly as the technologies are advancing to meet the challenge offshore oil and gas extraction and production (E&P) operations are being developed on the global Outer Continental Shelf (OCS). From a geological standpoint this makes sense; tens of millions of years of marine biological materials falling to the seafloor containing solar energy has been transformed and subducted into rich deposits of extractable hydrocarbons.

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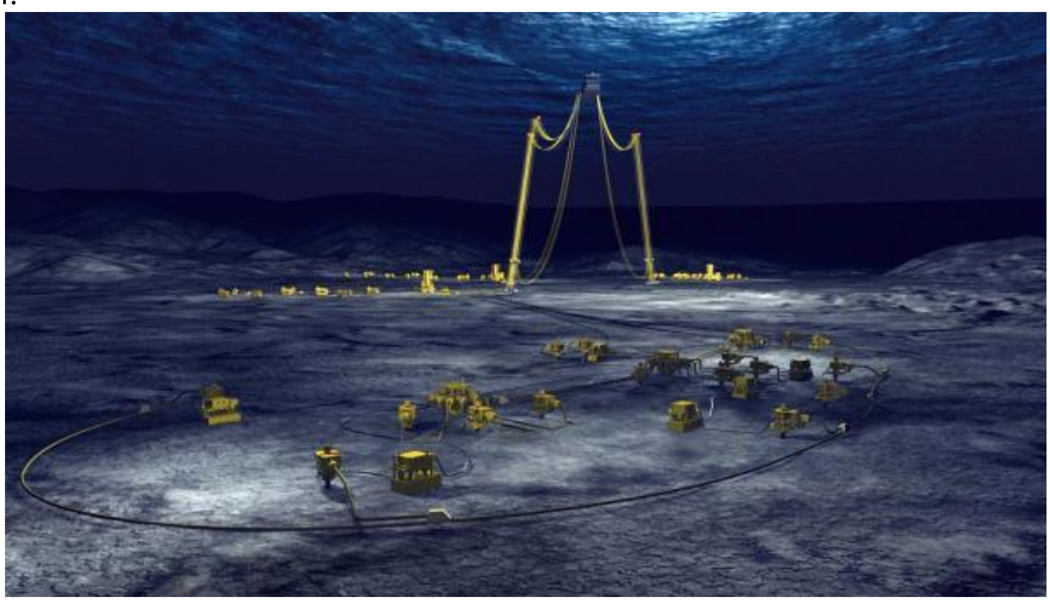
[5] Marine Mammal Protection Act Level A take at 180dB (re: 1µPa) Level B Behavioral disruption for pulse or discontinuous noise is 160dB (re: 1µPa). For non-pulse noise: 120dBrms(re: 1µPa), broadband, non-characterized continuous noise.

From a socio-economic (and regulatory) standpoint is also makes sense, as increasingly terrestrial-based hydrocarbon operations are chafing against opposition from human populations who are increasingly less inclined to absorb the environmental and social costs of oil and gas operations in their communities and habitats. Offshore operations, while technically challenging offer potentially robust deposits largely out of the reach of human interference. While it is not clearly stated in the recent Bureau of Ocean Energy Management (BOEM) Mid-Atlantic Geophysical and Geological DEIS[6] why the surveys are set back 50 miles from the shore, the regional conversation included keeping these industrial operations beyond the coastal viewshed and other intersecting impacts on coastal community's recreational and commercial interests.

Deepwater Hydrocarbon Extraction and Production

What is alarming about this advance of technologies and industrial enterprise is that the equipment used in the Madagascar incident outlined above is being increasingly deployed around the world. Data from these surveys – along with data from seismic and other seafloor and subsea surveys are being used to develop complex seafloor and subsea extraction and processing factories – refineries built on the ocean floor to handle the materials pre-processing required to successfully extract hydrocarbons from deepwater wells.

Figure 4:



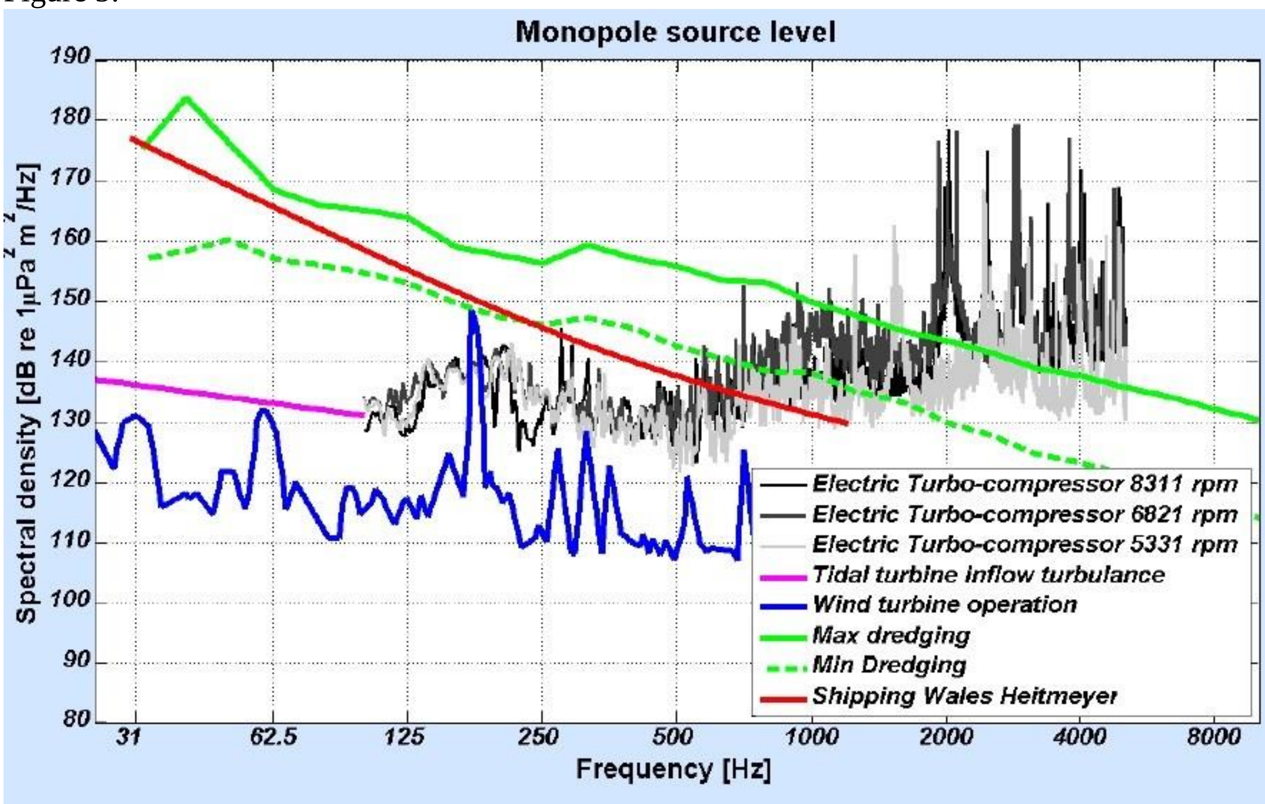
PazFlor Oilfield Layout - Angola

Once a potentially productive deposit is located the field is drilled and developed. A typical operation involves piping into the deposit and extracting a mix of substances which includes oil, gas, brine, sand, mud, and other solids. What is valuable in this (oil, and sometimes gas) needs to be brought to the surface, what is not valuable (gas, brine, sand, mud, and other solids) needs to be dispensed with. In terrestrial and shallow-water settings gas is flared, brine, sand and mud are either poured into settling ponds, or reinjected back into the well.

[6] Atlantic OCS Proposed Geological and Geophysical Activities Mid-Atlantic and South Atlantic Planning Areas Final Programmatic Environmental Impact Statement. BOEM 2014-001

In deepwater settings this all happens at the seafloor by way of processing equipment: seafloor separators, multi-phase pumps, reinjection pumps, and other seafloor handling equipment. All of this is happening under extremely high pressures. The static water pressure is 11.3 kPa/m (1/2psi/ft.), below grade the product pressure can be ~ 22.6 kPa/m (1 psi/ft.). While there are some countervailing pressures and the force of gravity at play it is not uncommon to have a well-head over pressure of thousands of lbs./in^2. For the sake of informing this discussion; the Deepwater Horizon/Macondo wellhead pressure was approximately 13,000psi. Under these pressures the equipment generates noise. (See Figure 5)

Figure 5:



Subsea compressor noise –from Bas Binnerts, TNO

As a continuous noise source the single compressor modeled in Figure 5 would generate a 120dB "Level B Take" isopleth at 550 m – assuming a required attenuation of 55dB, a spherical propagation loss factor of $20\log_{10}$ (d1/d2) and a HF roll-off at 4kHz of .25dBkm.

Propagation loss:$20\log_{10}$ (1m/500m) =	54.8 dB
Absorption: 0.5km*1.5dB*km-^{1} =	0.1 dB
Total transmission loss:	54.9 dB

This 500m Level B isopleth in and of itself does not seem too extreme, but this is only one (unregulated) pump in an array of other equipment required for a complete subsea processing

operation which would likely include seafloor separators, reinjection pumps, multi-phase and multi-stage materials handling pumps and compressors.

Due to the depths of these deepwater operations the drilling and extraction processes are not performed from derricks built up from the sea floor, rather they are executed on floating drilling ships[7] and production platforms (floating Production, Storage, and Offloading or "FPSO")[8] which are dynamically positioned with continuously running thrusters. (See Appendix B for West Auriga and Sevan Brasil) Four to eight 5000kW thrusters driving 3m diameter high-thrust propellers are not uncommon. In calm waters these thrusters are idle, but in any seas the platform needs to maintain position within 1m on x, y, and z axis requiring significant energy input, and consequent cavitation and gearbox noise.

Keeping position on these platforms is assisted by the use of one to three acoustical positioning beacons operating in the 20kHz to 75kHz range (detailed below).

High frequency beacons, transponders, altimeters, and Doppler current sensors

Due to extreme hydrostatic pressures of these environments it is not safe or practical to send human operators into the subsea field to manage the equipment. So all of these installations on the seafloor are managed by way of remote controlled and autonomous vessels (ROVs and AUVs). These working vessels are adjusting valves, connecting pipes and hoses, replacing parts, and maintaining the safe mechanical operations of the equipment.

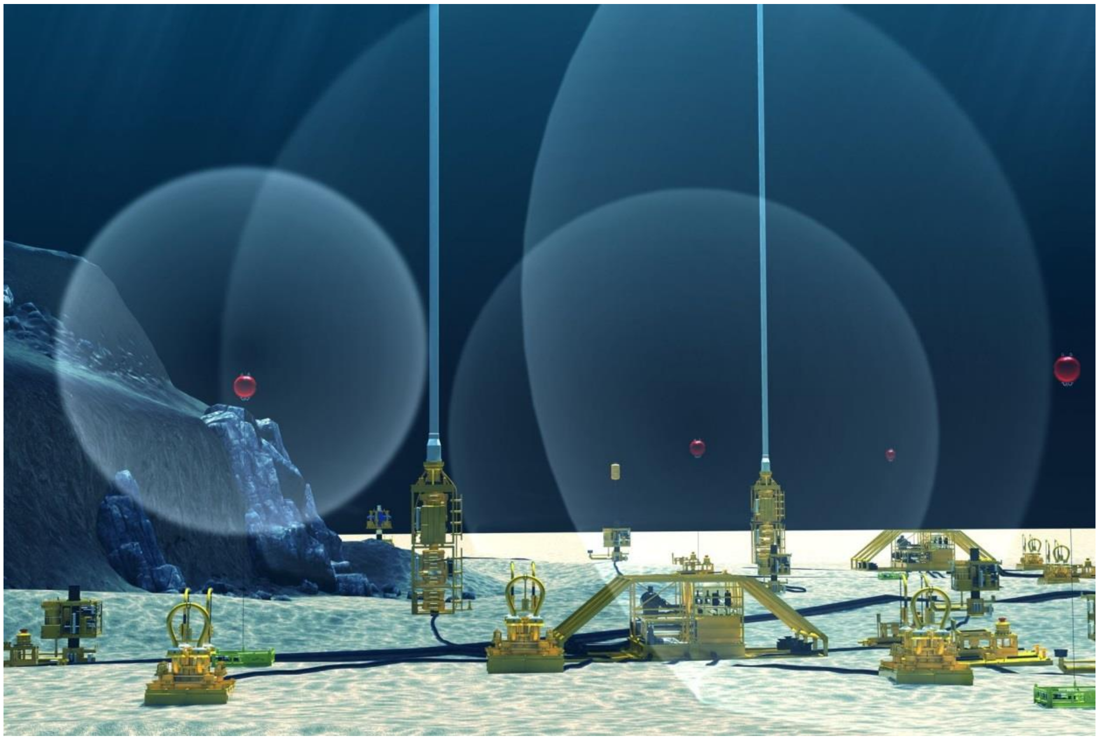
Heretofore many of these Remotely Operated Vessels (ROVs) have been controlled using cabled umbilicals carrying power and communications. The cables in the presence of drive propellers

[7] See Appendix B for West Auriga Drillship specifications
[8] See Appendix B for Sevan Brasil FPSO specifications

and obstacles are a continuous entanglement concern, so increasingly these ROVs are becoming autonomous – carrying their own power, communicating over acoustical communications networks. These task vessels attend to seafloor mounted equipment (with their own acoustical condition beacons) and navigate by triangulation within an acoustical navigation array. The equipment field is thus in continuous acoustical communication with all other equipment and the surface on a multi-nodal communications network.

Prominent manufactures of this communication equipment include Teledine, Kongsberg, Nautronix, and Sonardyne. The operating frequency bands are selected for data density and transmission range, with higher frequencies above 200kHz relegated to short distance (<1km) high density (video) data. Given the high absorption at these frequencies the transmission distance is limited. Due to the distance constraint most mechanical task oriented acoustical communications equipment operates in a lower (20kHz – 75kHz) frequency range suitable for up to a 10km operating range.

Figure 6:



Nautronix acoustical communication networks.

Transponders in these networks can be used for equipment management and maintenance, but are also deployed in various configurations for acoustical altimeters, Doppler current flow monitors, and dynamic positioning beacons. So in any given field there may be dozens of these acoustical transponders operating on their various frequency bands, informing the field operators about the conditions, locations, and dispositions of the equipment in the field, and allowing the operators to manage the field equipment form topsides.

Breaking this down to one typical device, a Kongsberg cNODE Transponder (see Appendix B for cNODE data sheet) operating at 30kHz, 206dB re:1uPa would need 86dB attenuation to meet Level B take 120dB isopleth for continuous noise:[9]

Propagation loss: $20\log_{10}$ (1m/2500m) =	68.0 dB
Absorption: 2.5km*7.25dB*km-^{1} =	18.1 dB
Total transmission loss:	86.1 dB

This translates into a 120dB isopleth at 2500 meters from the source– for a single piece of equipment that is operated in transponder arrays of four to a dozen devices. What this means is that these devices are creating huge fields of acoustical smog that directly overlaps the bio-sonar vocalization and hearing range of odontocetes (dolphins, sperm whales, porpoises) and pinnipeds (seals and sea lions), and some clupeiforme fishes (herring, shad, menhaden).

So without any regulatory oversight (or much biological research) these technologies are colonizing large tracts of marine habitat using signals that are aggravating to some marine mammals and possibly to some fish. Kastelein et.al (2005) determined that various common communication signals induce avoidance behavior in harbor porpoises at levels between 97dB and 113dB (re 1uPa) depending on signal type.[10] This situation is expanding rapidly and should be examined before the empirical evidence of cumulative impacts of these networks become incisively clear.

Noise from wind farms

Seismic and other benthic surveys need to occur to locate and install shallow-water windfarms, but given that the subsea depths for anchoring wind turbine masts are measured in tens of meters rather than the kilometers used in offshore fossil fuel surveys, the seismic surveys for placement of wind farms use significantly less energy. Where the noise is introduced in wind farming is during the pile-driving required to anchor the masts.

Unmitigated pile driving noise can cause significant disruptions to marine animals. In one case harbor porpoise (*Phocoena phocoena*) avoidance setback was 20km.[11] Some mitigation strategies have been designed to attenuate this noise, including bubble curtains and arrays of acoustic resonators[12] deployed around the pile driving operation. In deeper-water turbines the masts are floating and teathered in place, obviating any concern for pile driving noise.

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[9] The transmission model is slightly complicated by the fact that some of these devices broadcast omni-directionally, others are focused beams.

[10] R.A. Kastelein, W.C. Verboom, M. Muijsers, N.V. Jennings, S. van der Heul. *The influence of acoustic emissions for underwater data transmission on the behavior of harbour porpoises (Phocoena phocoena) in a floating pen* Marine Environmental Research 59 (2005) 287–307

[11] Michael Dahne, Anita Gilles, Klaus Lucke, Verena Peschko, Sven Adler, Kathrin Krugel, Janne Sundermeyer, and Ursula Siebert (2013) *Effects of pile-driving on harbor porpoises (Phocoena phocoena) at the first offshore wind farm in Germany* Environ. Res. Lett. 8 (2013) 025002 (16pp) doi:10.1088/1748-9326/8/2/025002

[12] *AdBm Demonstration at Butendiek Offshore Wind Farm with Ballast Nedam* AdBm Butendiek Demonstration Report, © 2014 AdBm Corp

Once installed, windfarm noise is dominated by two sources – tip vortices from the propellers and gearbox noise. These are continuous noises with no consistent marine mammal response recognized. In one case harbor porpoises avoided returning to an area after a wind farm had been installed.[13] In another case the a harbor porpoises seem to prefer the windfarm site – perhaps due to the wind farm exclusion zone providing shelter from fishing boats and ship traffic, and the "reef effect" of prey fish aggregating around the piles.[14]

But as these offshore wind farms are in the early years of development it is too soon to establish any predictors of noise impacts. Marine mammals may habituate or avoid the noise, which are both noticeable behaviors. But the continuous noise may impact marine invertebrates in unpredictable ways,[15,16] disrupting the trophic structure and causing long-term impacts which would be less noticeable unless their habitat engagement was observed in a thorough baseline study.

Shipping Noise

The increase in broadband and low frequency noise[17] from ships has long been known.[18] Long-term impacts from shipping noise is not well understood because there were few biological baselines taken with respect to shipping noise before the expansion of global trade through mechanized shipping. In the 50 years this expansion and the consequent noise has become so pervasive that with few exceptions it would be difficult to gain a comprehensive understanding of shipping noise impacts on actual marine habitats over time. But there is ample evidence that shipping noise has many deleterious impacts on a broad range of marine life.

In-habitat impacts on great whales include elevated stress,[19] interference with vocalizations,[20] area avoidance,[21] and foraging disruptions.[22] Lab studies and in-situ research on fish and marine

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[13] Jonas Teilmann and Jacob Carstensenn (2012) *Negative long term effects on harbor porpoises from a large scale offshore wind farm in the Baltic—evidence of slow recovery* Environ. Res. Lett. 7 (2012) 045101 (10pp) doi:10.1088/1748-9326/6/2/025102

[14] Meike Scheidat, Jakob Tougaard, Sophie Brasseur, Jacob Carstensen, Tamara van Polanen Petel, Jonas Teilmann, and Peter Reijnders (2011) *Harbour porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea* Environ. Res. Lett. 6 (2011) 025102 (10pp) doi:10.1088/1748-9326/7/4/045101

[15] Pine MK, Jeffs AG, Radford CA (2012) "*Turbine Sound May Influence the Metamorphosis Behavior of Estuarine Crab Megalopae.*" PLoS ONE 7(12): e51790. doi:10.1371/journal.pone.0051790

[16] Martin Solan, Chris Hauton, Jasmin A. Godbold, Christina L. Wood, Timothy G. Leighton & Paul White *"Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties*" Nature: Scientific Reports 6:20540 |DOI: 10.1038/srep20540

[17] Wenz, G.M. (1962). "Acoustic ambient noise in the ocean: Spectra and sources." JASA v.34.

[18] Ross, D., (1976) *Mechanics of Underwater Noise* Pergamon Press

[19] Rosalind M. Rolland, Susan E. Parks, Kathleen E. Hunt, Manuel Castellote, Peter J. Corkeron, Douglas P. Nowacek, Samuel K. Wasser and Scott D. Kraus (2012) Evidence that ship noise increases stress in right whales. Proc. R. Soc. B doi:10.1098/rspb.2011.2429

[20] Melco´n ML, Cummins AJ, Kerosky SM, Roche LK, Wiggins SM, et al. (2012) Blue Whales Respond to Anthropogenic Noise. PLoS ONE 7(2): e32681. doi:10.1371/journal.pone.0032681

[21] I. Campana, R. Crosti, D. Angeletti, L. Carosso, L. David, N. Di-Meglio, A. Moulins, M. Rosso, P. Tepsich, A. Arcangeli, (2015) *Cetacean response to summer maritime traffic in the Western Mediterranean Sea* Marine Environmental Research 109 (2015) 1e8 http://dx.doi.org/10.1016/j.marenvres.2015.05.009

[22] Pirotta E, Milor R, Quick N, Moretti D, Di Marzio N, et al. (2012) *Vessel Noise Affects Beaked Whale Behavior: Results of a Dedicated Acoustic Response Study*. PLoS ONE 7(8): e42535. doi:10.1371/journal.pone.0042535

invertebrates has indicated a broad range of impacts including disruption of normal predator-prey relationships,[23]compromise in nesting/dwelling behavior,[24]and communication masking.[25] While Wenz (1962) implicates shipping noise as being largely a low frequency noise source, there is a natural correlation between high frequency energy and proximity, so that in close range ships generate a significant amount of high frequency energy.[26]

This punctuates the fact that any ocean industry will be accompanied by ships, so while there are a lot of ship noise data associated with commercial shipping and cargo traffic, any offshore industrial activities will be characterized by local concentrations of vessel activity, and increased port-to-site vessel traffic.

Acoustical complexity of industrial noise in marine habitats.

One of the broadest challenges of monitoring the impacts of industrial noises in the ocean is that industry is introducing noises that are new to marine habitats. The frequencies, bandwidth, and signal characteristics[27] all have various effects on the biological interaction with the noise. Many mechanical noises are broad-band and thus pose a masking threat to animals in any masked acoustical niche. Or the signal may put an animal on alert and this under stress, causing behavioral compensations or adaptations at some biological expense.

We are now aware that the ocean is not just the home for countless individual species of marine animals, it is habitat and ecosystem where synthetic disruptions from new noises will have asymmetrical impacts on marine life. Some animals may be hyper sensitized to particular noises that other animals might not even perceive. Predators may advantage the masking aspects of noise, where foragers might be wary of predation in a masking soundscape. Even the specific noise quality may disrupt some animals and not others.

The reach of industrialization also complicates understanding impacts because industrialization introduces an array of noises associated with the industrial activity, not necessarily one specific noise. Any enterprise will include noises from vessels, acoustic communication, and operations, all across a broad frequency band, with various characteristics and amplitudes. Typically regulatory evaluation of any introduced noise source is done in the context of the specific noise. With the expansion of offshore industry the noise impacts need to be considered in the context of how all of the introduced noises impact the natural marine soundscape.

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[23] Stephen D. Simpson, Andrew N. Radford, Sophie L. Nedelec, Maud C.O. Ferrari, Douglas P. Chivers, Mark I. McCormick & Mark G. Meekan Anthropogenic noise increases fish mortality by predation Nature Communications 7:10544 DOI: 10.1038/ncomms10544

[24] Martin Solan, Chris Hauton, Jasmin A. Godbold, Christina L. Wood, Timothy G. Leighton & Paul White (2016) *"Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties*" Nature: Scientific Reports 6:20540 |DOI: 10.1038/srep20540

[25] Codarin, A., Lidia E. Wysocki, Friedrich Ladich , Marta Picciulin (2009) *Effects of ambient and boat noise on hearing and communication in three fish species living in a marine protected area (Miramare, Italy).* Mar. Pollut. Bull. (2009), doi:10.1016/j.marpolbul.2009.07.011

[26] Scott Veirs, Val Veirs, Jason D. Wood *Ship noise extends to frequencies used for echolocation by endangered killer whales* PeerJ (2016) DOI 10.7717/peerj.1657

[27] Michael Stocker (2013) *Signal kurtosis as a predictor of biological impacts from noise exposure* IEEE*Explore* 2013 OCEANS - San Diego

Appendix A:
Equations for frequency-dependent sound absorption in seawater.[28,29,30]

Frequency dependent sound absorption coefficient in seawater is largely influenced by the chemical "relaxation" processes of the medium due to the concentration of Boric acid (BH_3O_3) and Magnesium sulphate $MgSO_4$ such that:

Total absorption coefficient (α) = BH_3O_3 contribution +$MgSO_4$ contribution + pure water contribution:

$$\alpha = \frac{A_1 P_1 f_1 f^2}{f_1^2 + f^2} + \frac{A_2 P_2 f_2 f^2}{f_2^2 + f^2} + A_3 P_3 f^2$$

The first term is the BH_3O_3 contribution, the second term the $MgSO_4$ contribution, and the third term the contribution of pure water.

α = Absorption coefficient in dB/km

A_1, A_2 and A_3 are empirically derived absorption constants:

$A_1 = (8.86/c)\text{x}10^{(0.78\text{pH}-5)}$ in dB km^{-1} kHz^{-1} (varying with pH)
$A_2 = (2/c)(\alpha\lambda)_{35}(S/35)(8686)(10^3)$ (increasing with salinity and slightly with temperature)
8686 converts Np/m to dB/km. 10^3 converts to kHz
$A_3 \approx 25\text{x}10^{-15}$Np m^{-1} Hz^{-2} @ 20°C (decreasing with increasing temperature)

P_1, P_2 and P_3 are pressure dependencies at depth in atmospheres.

f_1 = the relaxation frequency of BH_3O_3 in kHz → $f_1 = \sqrt{(35/S)}e^{(T/26)}$

f_2 = the relaxation frequency of $MgSO_4$ in kHz → $f_2 = 42e^{(T/17)}$

f = System transmission frequency.

where:
c = velocity of sound in water
λ = wavelength
S = salinity at 35ppt
T = Temperature in C°
e = Euler's constant 2.71828…

[28] Francois R. E., Garrison G. R., *Sound absorption based on ocean measurements: Part I:Pure water and magnesium sulfate contributions*, Journal of the Acoustical Society of America, 72(3), 896-907, 1982.
[29] Francois R. E., Garrison G. R., *Sound absorption based on ocean measurements: Part II: Boric acid contribution and equation for total absorption*, Journal of the Acoustical Society of America, 72(6), 1879-1890, 1982.
[30] Ainslie M.A, McColm J.G. *A simplified formula for viscous and chemical absorption in seawater.* Journal of the Acoustical Society of America 1998;103(3):1671-1672.

Appendix B:

Equipment data sheets:

1. **West Auriga**
2. **Sevan Brasil**
3. **Kongsberg cNODE Transponder**

West Auriga

West Auriga is a 6th generation drillship under construction at Samsung in Korea, with planned delivery Q1 2013. The design is based on Seadrill's existing Samsung drillships.

Further information: Tel: +47 51 30 90 00 • seadrill.com

GENERAL

Design	SHI S10000
Built/year	SHI / 2013
Flag	Panama
Classification	ABS
Class notations	AMS, ACCU, DPS-3, NBLES, DLA, CDS

MAIN DIMENSIONS/TECHNICAL

Length x breadth	228 x 42 m
Design water depth	3 600 m
Min. water depth	500 m
Drilling depth	11 400 m
Variable load	18 000 mt (drilling)
Propulsion	6 x 4 500 KW thrusters
Transit speed	12 knots
Helideck	Boeing Chinook
Accommodation	200 persons

STORAGE CAPACITIES

Fuel	6200	m3
Drill water	2600	m3
Potable water	1450	m3
Liquid mud	2060	m3
Base oil	500	m3
Brine	500	m3
Barite/Bentonite	450	m3
Cement	530	m3

DRILLING EQUIPMENT

Derrick	1 x 1250 st (main) 1 x 1000 st (aux)
Drawworks	NOV 1250
NOV	1000
Racking capacity	260 std. 6 5/8" DP + 110 std 5 7/8" DP
Top drive	1 x 1250 TDX
1	x 1000 HPS
Rotary table	75 ½" and 60 ½"
Iron roughneck	2 x Hydratong MPT 200
Motion compensation	NOV active/passive
Riser tensioner	8 dual x 225 Kips

WELL CONTROL

BOP	Shaffer - 18 3/4" - 15K 7 Ram
Diverter	Shaffer - 500 psi
C&K manifold	RB PipeTech - 15K

RISER SYSTEM

Type	Shaffer FT-H
Length of joints	90 ft.
Min. ID	19 ¼"
K&C lines	4 ½" ID - 15K

BOP/RISER HANDLING

BOP crane	2 x 220 mt gantry crane
Riser crane	40 mt gantry crane
BOP skid	480 mt
Xmas tree crane	85 mt (deck crane)
Xmas tree skid	700 mt

MUD SYSTEM

Mud pumps	4 x NOV 14-P-220
Pressure rating	7500 PSI
Shale shakers	6 x Brandt VSM 300

POWER

Main engines	6 x STX MAN V16
Total power	42 MW
Emergency power	STX Cummings

STATION KEEPING

DP class	DP 3
DP control system	Kongsberg
Anchor chain	N/A
Anchors	N/A

LIFTING EQUIPMENT

Deck crane	4 x NOV Knuckle boom
Deck crane rating	85 mt
Auxiliary crane	1 x helideck service
Pipe handling crane	Deck crane

Sevan Brasil

The construction of the UDW Sevan Brasil took place at the Cosco Quidong Shipyard. Sevan Brasil is of the same design as Sevan Driller.

Sevan Brasil is contracted to Petrobras S.A. on a six year contract for drilling operations offshore Brazil.

The Rig was accepted by Petrobras on 24 July 2012 and spudded it's first well on the 31 August in Santos basin at a water depth of 1 800 m.

Petrobras S.A is a national oil company founded in 1953 by the Brazilian government. Petrobras has been ranked as the world's 3rd largest public energy company and 8th largest company in the world in market value, and closed 2010 with a production of 2.2 million bpd of oil and LNG and 0.4 million boepd of gas.

1 / 12 Start Stop

Key data MAIN TECHNICAL DATA - HULL DRILLING PARTICULARS

Water depth	3,000 m (10,000 ft, upgradable to 12,000 ft)
Drilling depth	12,000 m (40,000 ft)
LOA (Length)	86 m
Breadth	75 m (at waterline)
Depth	24.5 m
Displacement	55,800 mT at 12.5m draft
Variable deck load	20,000 mT
Diesel generators	8 x 5,535 kW
Thrusters	8 x 3,800 kW
Station keeping	DP3
Living quarters	150 persons
Helicopter deck	Sikorsky S92 and S-61N, Superpuma AS332L2, EC225 and EH-101

TOTAL HP =
8 x 5535 x 1.341
= 59,380 HP

cNODE® Transponders
Maxi and Midi - Medium Frequency, 4000 m

KONGSBERG

Introduction

cNODE® is a family of transponders for underwater acoustic positioning and data link and operates with both HiPAP®, HPR and cPAP® transceivers.
The Medium frequency (MF) cNODE® family consists of the following types, each with a separate product specification sheet:

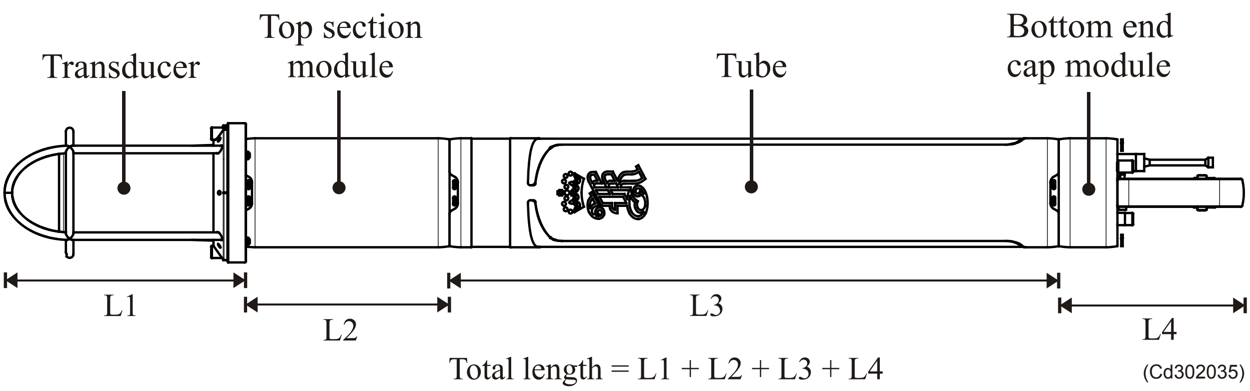
- cNODE® Maxi and cNODE® Midi (Medium frequency, 4000 m)
- cNODE® Mini (Medium frequency, 4000 m)

cNODE® operates with either the HiPAP/HPR 400 channels and telemetry or with the new Cymbal® acoustic protocol.
The cNODE® design is very modular and covers a large range of applications with its variety of different transducers, internal and external sensors, housing materials and other add-on functions.
Both new configurations and software can easliy be downloaded from the Transponder Test and Configuration unit (TTC30) without opening the transponder.
The floating collar and release design make the launch/recovery operation safe and easy. Spare parts for cNODE® are based on the main modules.

Maxi 34-30V30H-R (Left)
Midi 34-180 (Right)

Common for all cNODE® transponders

- Operates together with HiPAP®, HPR and cPAP® transceivers.
- Compatible with both Cymbal® acoustic protocol for positioning and data link, and HiPAP®/HPR 400 channels and telemetry.
- SSBL positioning.
- LBL positioning.
- Range measurement between transponders (typical, 1 σ standard deviation):
  - — Range accuracy: 0.02 m.
  - — Repeatability: 0.01 m.
- Acoustic data link for command and data transfer.
- Both transponder and responder functions.
- Internal tilt sensor ± 90°. Accuracy ± 2°.
- Pressure relief valve and vent screw (safety devices).
- External connector for transponder configuration and software update via serial line (TTC30).
- Modular design such that the transducer, transponder electronics, battery pack and optional add-ons can be replaced individually.



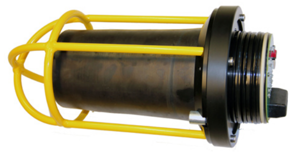
cNODE® modular design

Specifications for all Maxi and Midi transponders, Medium frequency

Frequency band: Medium frequency 21-31 kHz
Depth rating: 4000 m
Operating temperature: - 5 °C to + 55 °C

- Aluminium (Alu) transponders can only consist of Aluminium modules
- Stainless steel (St) transponders can only consist of Stainless steel modules

Transducers

	TD180	TD30V	TD30V30H
			
Beam width:	180°	30° vertical	30° vertical/30° horizontal
Receiver sensitivity:	100 dB	85 dB	85 dB
Source level - max:	190 dB	206 dB	206 dB/190 dB
Dimensions (L x dia):	169.5 x Ø166	169.5 x Ø166	316 x Ø184
Models (material):	Aluminium and Stainless steel	Aluminium and Stainless steel	Aluminium and Stainless steel
P/N:	319750 (Alu) and 320877 (St)	320662 (Alu) and 320077 (St)	313455 (Alu) and 359429 (St)

TDR - Remote transducers for Split transponders (S)

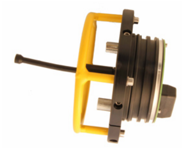
	TDR 30H	TDR 180	TDR 40V	TDR 30V
				
Beam width:	30° horizontal	180° horizontal	40° vertical	30° vertical
Receiver sensitivity:	100 dB	100 dB	90 dB	85 dB
Source level - max:	194 dB	190 dB	203 dB	206 dB
Dimensions (L x dia):	262.4 x Ø77	209.8 x Ø88	218.6 x Ø100	279.5 x Ø166
Models (material):	Aluminium and Stainless steel	Aluminium and Stainless steel	Aluminium and Stainless steel	Aluminium and Stainless steel
P/N:	345773 (Alu) and 375359 (St)	349742 (Alu) and 375361 (St)	349743 (Alu) and 375360 (St)	333445 (Alu) and 370447 (St)

Transducer cable (6m)

P/N: 345772
Connectors: Subconn MCILF and MCIL4M

Top end caps

Split transponder (S) for remote transducer



Dimensions (L x dia): 62 x Ø166
Model (material): Aluminium and Stainless steel
P/N: 320949 (Alu) and 322375 (St)

Top section modules

Depth sensor (Dx)

High accuracy depth sensor
Accuracy: 0.01% FS (FS = 400 bar)
Dimensions (L x dia): 272 x Ø144
Model (material): Aluminium
P/N: 350211

Multi Sensor Module (Msm)

The module includes the following high accuracy sensors:

- Depth: 0,01% FS (FS = 400 bar)
- Inclinometer: 0.05°
- Sound velocity: ± 0.02 m/s

Dimensions (L x dia): 184 x Ø144
Model (material): Aluminium
P/N: 358791