MÜLLER-BBM

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo)

Phase 3

Abschlussbericht

Dr. Andreas Müller, Müller-BBM GmbH

Auftraggeber:
Bundesamt für Seeschifffahrt und Hydrographie
Federal Maritime and Hydrographic Agency (BSH)
Hamburg and Rostock, 2022

Forschungs- und Entwicklungsprojekt, Auftragsnr. 10036955

Inhaltsverzeichnis

1 Einleitung

Das o. g. FuE-Vorhaben hat am 1. Juni 2019 mit der Bearbeitung der vereinbarten Aufgaben begonnen. Die Bearbeitungsschritte wurden stets mit dem BSH abgestimmt. In diesem Berichtszeitraum sind Arbeiten partiell für das Arbeitspaket 2 und für das Arbeitspaket 3, „MSRL“, angefallen.

2 Kurzfassung der Ergebnisse

2.1 Allgemeines

Das Projekt umfasst drei Arbeitspakete, siehe auch [1]:

- Die Evaluierung und Fortschreibung der BSH-Vorschriften (AP 1),
- die Prüfung und Bewertung historischer und aktueller Daten (AP 2) und
- Arbeiten im Rahmen der MSRL (AP 3).

2.2 AP 1, Evaluierung der BSH-Vorschriften

Vor neun Jahren wurde die Messvorschrift für Unterwasserschallmessungen für Offshore-Windparks [2] entwickelt. Die Vorgehensweise für die messtechnische Untersuchung wurde bei den Betriebsschallmessungen an die Basisaufnahme (Voruntersuchungen vor Baubeginn) angepasst. Zusätzlich wurde ein Messpunkt in 100 Metern von einer Windkraftanlage definiert, da man schon zu dieser Zeit einschätzte, dass die Schallabstrahlung der bis dato bekannten Anlagen eine eher untergeordnete Bedeutung verglichen zu den Umgebungsgeräuschen hatte, siehe hierzu exemplarisch den Abschlussbericht [13], Seite 10.

Es hat sich in der Praxis gezeigt, dass die Interpretation der Messergebnisse, siehe hierzu die Dokumente [3], [4] und [5], einige Schwierigkeiten birgt und eine Überarbeitung der Vorgehensweise zur Diskussion steht.

In einer kurzen Notiz wurden Fragestellungen während des letzten Berichtszeitraumes zusammengefasst, siehe Dokument [12], und mit dem BSH diskutiert. Die Interpretation der Messungen birgt Herausforderungen, da es zwar eine recht eindeutige Vorgabe für die Messungen gibt, siehe [2], die Auswertemethodik jedoch eine Klarstellung und weitere Detaillierung erfordert.

Im Dokument [17] sind Auswertungs- und Darstellungsvorgaben dargestellt, um für die Übergangszeit bis zur Evaluierung der Messvorschrift notwendige Hinweise für die Berichtsdokumentation nutzen zu können.

Aktuelle Arbeiten aus dem AP 3 (MSRL) beschäftigen sich weiterhin mit der Interpretation von impulshaften- und kontinuierlichen Schalleinträgen. Insbesondere die Diskussionen und ggf. Festlegungen zur Beurteilung der kontinuierlichen Schallbeiträge können unterstützend bei der Bewertung von Betriebsschall sein. Die Evaluierung der BSH-Vorschriften wird zu einem späteren Zeitpunkt fortgeführt.

2.3 AP 2, Prüfung und Bewertung der aktuellen Datenlage

In diesem Berichtszeitraum wurden insbesondere Berichte zu Explosionen betrachtet. Es besteht teilweise Unklarheit, wie der Quellpegel von Explosionen zu bewerten ist, da dieser sich aus Schockwellen und lineare akustische Wellen (Blasengeräusche) zusammensetzt, die im Nahfeld und Fernfeld unterschiedlich gewichtet sind. National wird die Thematik des Assessments und der „richtigen" Prognose von Schallbeiträgen diskutiert. Bei einzelnen Fragestellungen hat Müller-BBM unterstützt, auch bei der Diskussion zur richtigen Beschreibung von Ausströmvorgängen in Abhängigkeit von der Tiefe, wie man sie bei Blasenschleiern kennt, siehe [41].

2.4 AP 3, Arbeiten im Rahmen der Meeresstrategierichtlinie

Drei große Themenblöcke wurden im Rahmen des Projektes bearbeitet. Eine Thematik befasste sich mit der Überarbeitung der „TG Noise Guidance" [6], [14]. Bei der Sitzung der TG Noise am 14./15. Oktober 2019 wurde die bisherige Arbeit vorgestellt und diskutiert. Die Harmonisierung der Klassifizierung (Hammerenergie) mit der schon eingeführten Vorgehensweise, das Verhältnis zwischen Spitzenpegel und Schallereignispegel sowie die Einführung einer unteren Grenze zur Meldung von Schallereignissen wurden im Nachgang der Sitzung in einer Arbeitsgruppe kontrovers diskutiert und schließlich eine gemeinsame Vorgehensweise festgelegt. Das finale Ergebnis wurde im Rahmen der TG Noise Sitzung Anfang Juni 2020 vorgestellt. Dieser Themenblock ist soweit abgeschlossen, muss aber weiterhin verfolgt werden, da die Überarbeitung der TSG Noise Guidance von 2014 und somit die Integration der Arbeiten noch nicht abgeschlossen ist.

Der zweite große Themenblock beschäftigte sich mit der Fragestellung, welche Bewertungsgrundlagen für impulshafte Schallereignisse geschaffen werden können. Dies wurde letztes Jahr in einem Technischen Bericht der TG Noise festgehalten, siehe hierzu [8]. Müller-BBM hat gemeinsam mit dem BSH bei Teilaspekten des Dokumentes unterstützt. Im Laufe der Bearbeitung stellte sich heraus, dass die etablierte Vorgehensweise bei der Festlegung von Grenzwerten in Deutschland nicht richtig akzentuiert wurde. Im Rahmen der TG-Noise am 15./16.Oktober 2019 wurde seitens des BfNs und BSHs darauf hingearbeitet, hierzu Abhilfe zu schaffen. Das Dokument wurde im Rahmen eines TG Noise Workshops am 7. Oktober 2020 [27], [28] nochmals vorgestellt und final diskutiert. Es ist nun derart allgemein gehalten, dass „alle" möglichen Assessmentmethoden dargestellt sind. Um ein besseres Verständnis für das international vorgeschlagene Assessment zu erzielen, wurde im Rahmen dieses Projektes eine Studie [22], [25] erarbeitet, die bei der Anwendung der Methodik den Lebensraum der Schutzgüter betrachtet. Neben technischen Fragen, welchen Einfluss beispielsweise die zeitliche und räumliche Auflösung auf die Ergebnisse hat, wurde auch untersucht inwiefern schallgeminderte Schallereignisse abgebildet werden können.

Um ein konkretes Beispiel zu untersuchen, wurden die an OSPAR übermittelten Schalldaten von den Rammarbeiten des Jahres 2018 für die Nordsee verwendet. Beispielhaft wurde das deutsche Schallschutzkonzept für die Nordsee angewendet. Es zeigt sich, dass neben dem „Exposure Index“ weitere Schwellwerte sinnvoll für die Bewertung eines Seegebietes sein können. So könnte die prozentuale räumliche, aber auch zeitliche Einschränkung eine sinnvolle Zusatzinformation bieten. Die Arbeit wurde zunächst national bei Vertretern des BfN und UBA vorgestellt, mit den erlangten Impulsen überarbeitet und soll in den Gremien der TG Noise, der EN Noise und ICG Noise als Diskussionsgrundlage für das gemeinsame Verständnis eines Assessments verteilt werden. Bei der TG Noise wurde die Studie schon angekündigt. Bei der ICG Noise wurde die Studie am 16. Juni 2020 vorgestellt. Die dargelegte Vorgehensweise wurde von den Sitzungsteilnehmern begrüßt und der Wunsch geäußert, dass das Konzept auf die OSPAR-Region angewendet werden soll um eine bessere Vergleichsmöglichkeit mit dem Assessment bezogen auf die Populationsdichten von Schweinswalen zu haben.

Im Rahmen einer Besprechung (BSH und Müller-BBM, [26]) am 23. Juni 2020 wurde die weitere Vorgehensweise besprochen. U. a. wurden Studien für die Baltische See und OSPAR-Regionen definiert. Erste Analysen wurden für beide Seegebiete durchgeführt. Am 9. Dezember 2020 fand ein vorbereitendes Meeting der ICG Noise zum Assessment impulshaltiger Geräusche statt, bei dem die Ergebnisse der Studie vorgestellt wurden. Unter anderem wurde der Mehrwert einer Betrachtung von MPAs (Marine Protection Areas) herausgearbeitet. Am 22. Januar 2021 wurde die ICG-Noise-Sitzung mit u. a. zwei großen Themenblöcken zu kontinuierlichen und impulshaften Geräuschen abgehalten. Im Januar wurde der Entwurf zum vorläufigen „EIHA Dokument“ zum Assessment impulshafter Geräusche kommentiert und zwischen BSH, BfN und Nathan Merchant vor der ICG Noise Sitzung am 22. Januar 2021 besprochen.

Während der Sitzung erklärte Nathan Merchant, dass die wesentlichen Inhalte zum Habitat-Ansatz übernommen wurden und er eine überarbeitete Version verteilen würde. Diese liegt mit dem Dokument [33] seit dem 2. Februar 2021 vor. Das Assessment, impulshafter Geräusche mit dem Ansatz MPAs zu betrachten, wird auch strategisch bei der HELCOM verfolgt. Es soll im Assessment „HOLAS III“ umgesetzt werden.

Bei der EN Noise ist das BSH gestaltend für die Entwicklung des Assessments beteiligt, Müller-BBM unterstützt. Während der ICG Noise Sitzung am 30.06.2021 wurde wieder das Assessment impulshafter Geräusche für die OSPAR II Region vorgestellt. Leider wurden in dem Assessment nicht alle abgestimmten Änderungen übernommen. Insbesondere sind die Erläuterungen zu dem „Flächenansatz“, z. B. Nutzung geeigneter Naturschutzgebiete für das Assessment, untergegangen und der Hinweis der OSPAR Marine Mammal Expert Group (OMMEG), dass die Nutzung von Populationsdichten zum jetzigen Zeitpunkt noch nicht valide genug sei, nicht klar formuliert. Es gab in der Diskussion von diversen Mitgliedern Support bei der Einschätzung, dass der Habitatansatz einen sinnvollen Mehrwert bieten kann. Es wurde sich darauf geeinigt, dass Deutschland bei der Integration des Assessments unter Verwendung des Habitatansatzes unterstützt.

In der gemeinsamen Sitzung zwischen EN Noise und ICG Noise am 24. August 2021 sowie der ICG Noise-Sitzung am 17. September wurden wiederholt diverse Diskussionen zum Assessment durchgeführt und Textbeiträge angeboten [40]. Von Nathan Merchant wurde zwischenzeitlich eine flächenhafte Analyse Integriert. Müller-BBM hat diesen Prozess mit Textbeiträgen und Analysen zur OSPAR II Region in den Jahren 2015 – 2019 unterstützt.

Der dritte große Bearbeitungsblock ist das Assessment von kontinuierlichen Schalleinträgen. Dieser hat aufgrund auferlegter Abgabetermine seitens der TG Noise eine besondere Dynamik entfaltet, siehe Müller-BBM Dokumente [27], [28], [29] und [30]. Am 4. Dezember fand ein weiterer TG Noise-Workshop statt, um die offenen Fragen zum Assessment zu besprechen.

Der Teilnehmerkreis des Workshops am 29. Oktober 2019 wurde aufgefordert, Beispiele für die nächste Sitzung vorzubereiten. Es wurde ein Beispiel mit der Diskussion der einzelnen akustischen Metriken in dem Dokument [31] festgehalten, um ein besseres Verständnis für die einzelnen Konzepte zu erhalten.

Am 21. Januar 2021 fand das TG Noise-Seminar zum Themenkreis der Bewertung kontinuierlicher Geräusche statt. Im TG Noise-Seminar wurden einzelne Beispiele und Konzepte vorgestellt und diskutiert. Die Erkenntnisse sollten in dem Assessment-Strategiepapier für kontinuierliche Geräusche der TG Noise [32] berücksichtigt werden.

Während der ICG-Noise-Sitzung am 22. Januar 2021 wurde das geplante OSPAR-Assessment der Niederlande vorgestellt. Es basiert im Wesentlichen auf den Ergebnissen des JOMOPANS-Projektes. Einige kontrovers diskutierte Aspekte wurden thematisiert, die insbesondere die Frage nach der „richtigen“ akustischen Metrik beinhalten. Es fanden diverse Diskussionen zwischen BSH, BfN und Müller-BBM statt, um die Assessmentstrategien geeignet einschätzen zu können.

Am 12. März 2021 wurde eine zusammenfassende Präsentation [34] zu den Diskussionspunkten vorgestellt und bei der Skizzierung der Hauptkritikpunkte unterstützt, um den deutschen Teilnehmern der EIHA transparente Argumente zur Verfügung zu stellen.

Am 11. Mai 2021 fand die 18. TG Noise-Sitzung, siehe Protokoll [35], statt. Diese Sitzung wurde online abgehalten. Sie war als Folgeveranstaltung zu den Diskussionen über den „Draft Deliverable 3 (DL3), Assessment framework for threshold values for continuous noise" auf der Sitzung der Arbeitsgruppe WG GES am 23. April 2021 zu verstehen. Ziel dieses Treffens war es, die Einwände einiger Mitgliedsstaaten zu dem DL3 zu erörtern, bevor das Dokument auf der nächsten Sitzung der Marine Strategy Coordination Group (MSCG) am 28. Mai 2021 vorgestellt wurde.

Am 30 Juni 2021 fand das ICG Noise Meeting [38] statt. Nils Kinneging hat die Ergebnisse des JOMOPANS-Projekts vorgestellt und mitgeteilt, dass das Projekt zunächst um ein Jahr verlängert wurde. Dieses Projekt dient als Basis für das geplante OSPAR-Assessment. Die deutschen Vertreter haben die kritischen Aspekte zum Assessment benannt, siehe [37].

Am 24. August fand das Joint Meeting der EN Noise und ICG Noise und am 17. September 2021 eine weitere ICG Noise-Sitzung statt [40]. Die Bereitschaft von Nils Kinneging, das Assessment zu ergänzen, ist sehr gering. Es wurde sich darauf geeinigt, dass von deutscher Seite ein Vorschlag für eine Erweiterung des Assessments in Textform eingebracht wird. Bei Helcom wurde bereits ein Assessment von absoluten Schalldruckpegeln sowie von Schalldruckpegeln relativ zum Hintergrundgeräusch als sinnvolle Ergänzung akzeptiert. Zwischen August bis Oktober wurde des Weiteren in der TG Noise das Dokument „Assessment framework for threshold values for continuous sound and setting of threshold values” in Arbeitsgruppen während des wissenschaftlichen TG Noise-Workshops am 13. September 2021 bearbeitet, bei der Sitzung am 26.10.2021 finalisiert und am 18.11.2021 publiziert [43]. Die unterstützenden Arbeiten zu den Gremien wurden national zwischen BfN, BSH und Müller-BBM abgestimmt. Die nationale Position zur Bewertung kontinuierlicher Geräusche wurde im Oktober nochmals evaluiert, siehe [42]. Dieser Abstimmungsprozess inklusive der gemeinsamen Kommentierung von Dokumenten zur ICG Noise Sitzung sowie Vorbereitung zur EIHA wurde im Jahr 2022 weitergeführt.

3 Sonstige für das Projekt unterstützende Tätigkeiten

Es werden stets die aktuellen Normungsaktivitäten der ISO-TC43-SC3-WG1, WG2 und WG3 (Schiffsmessungen, Terminologie und Messungen im Offshore-Bereich) beobachtet und in ihrer Konsequenz diskutiert. Weiterhin wurde in Abstimmung mit dem BSH und dem DIN zugestimmt, die DIN SPEC 45653:2017-04 (D/E), „Offshore wind farms -In-situ determination of the insertion loss of control measures underwater“ als Vorlage für einen internationalen Standard ISO zu verwenden. Während des Berichtszeitraums wurde ein Entwurf der ISO 7447 „Underwater acoustics—Measurement of radiated underwater sound from percussive pile driving — In-situ determination of the insertion loss of barrier control measures underwater” erstellt und im Rahmen einer Arbeitsgruppensitzung (WG3) am 30. September 2021 präsentiert [44]. Im Rahmen dieser Sitzung wurde vereinbart, dass das Dokument nach kleinen Überarbeitungen der Terminologie als Komiteeentwurf (CD) im Januar 2022 verteilt wird. Dieser Entwurf ist zwischenzeitlich zur Abstimmung an die Mitglieder der ISO versendet worden.

Die Ergebnisse und Aufgabenstellungen aus den nationalen Arbeitskreisen wie die ErBeM-Fach-AG sowie die internationalen Arbeiten bei der TG Noise und ICG Noise werden bei der Bearbeitung der Arbeitspakete berücksichtigt.

4 Ergebnisse des Vorhabens

Das Gesamtvorhaben hat die Ziele, die in dem ursprünglichen Antrag gesetzt wurden, vollumfänglich erreicht. Im Anhang A sind sämtliche Berichte des Vorhabens aufgelistet. Die Ergebnisse des Vorhabens wurden während der Projektlaufzeit unmittelbarer nach der Generierung entweder durch das BSH veröffentlicht oder im Auftrag des BSH in internationalen Gremien und Arbeitsgruppen eingespeist. Eine Auswahl der Dokumente ist dem Anhang C beigefügt.

Dr. rer. nat. Andreas Müller

Berichterstatter

Anhang A

Dokumenten- und Aktivitätenliste zu Projekt M146361

Müller-BBM: M146361

Nr.	Dokument	Datum	Betreff	Verteiler	Status
1	Bericht	19.06.2019	BEMO III, Einbeziehung von Lärmminderungs-maßnahmen in die Berichterstattung an das Impulsschallregister	BSH	abgeschlossen
2	Notiz	19.06.2019	FINO 1 und FINO 3, Datenhandling akustischer Daten	BSH	abgeschlossen
3	Notiz	19.06.2019	BEMO III, Auftaktbesprechung am 23. Mai 2019	BSH	abgeschlossen
4	Notiz	19.06.2019	BEMO III, JOMOPANS, Datenhandling und Kalibrierung	BSH	abgeschlossen
5	Notiz	27.06.2019	Betriebsschall und Umgebungsschall bei Offshore-Genehmigungsverfahren: Dokument als Diskussionsgrundlage	BSH	abgeschlossen
6	Bericht	23.08.2019 Version 2E 25.5.2020	Revision of the “TG Noise monitoring guidance“ Part 1: sound exposure levels of pile-driving noise with/without noise protection measures Background paper	BSH	abgeschlossen
7	Notiz	11.09.2019	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
8	Notiz	22.10.2019	Testing CEAF in SEANSE case studies TNO report, Remark on prediction uncertainties	BSH	abgeschlossen
9	Notiz	01.11.2019	Betriebsschall und Umgebungsschall bei Offshore-Genehmigungsverfahren Konkretisierung zur Auswertung	BSH	abgeschlossen
10	Notiz	18.12.2019	Arbeitsbeschreibung zur Kurzstudie „Transfer der deutschen Grenzwerte im europäischen Kontext“	Müller-BBM intern	abgeschlossen
11	Notiz	18.11.2019	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
12	Notiz	19.03.2020	Dual level statistics (SEL und L_{peak})	BSH	abgeschlossen
13	Report	03.04.2020 Version 2E 22.04.2020 Version 3E 27.04.2020	Pile Driving - Classification and assessment of impulsive noise with and without noise mitigation measures – Exposure Index	BSH	abgeschlossen
14	Notiz/Memo	30.04.2020	EN-Noise 3-2020, HELCOM impulsive noise indicator	BSH	abgeschlossen
15	Notiz	04.06.2020	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen

Nr.	Dokument	Datum	Betreff	Verteiler	Status
16	Bericht	18.05.2020	Pile Driving - Classification and assessment of impulsive noise with and without noise mitigation measures – Exposure Index	BSH	abgeschlossen
17	Notiz		BEMO III, Anstehende Aufgaben, Besprechung am 23.06.2020	BSH	abgeschlossen
19	Notiz	13.10.2020	Sechzehnte TG Noise Sitzung und Workshop am 06. Und 07. Oktober 2020	BSH	abgeschlossen
20	Notiz	22.10.2020	Aufgaben aus der sechzehnten TG Noise Sitzung und der Workshop am 6. und 7. Oktober 2020	BSH	abgeschlossen
21	Notiz	22.10.2020	JOMOPANS Einschätzung der Umsetzungsmöglichkeit	BSH	abgeschlossen
22	Notiz	03.11.2020	TG Noise: Workshop zum Themenkreis der kontinuierlichen Schalleinträge und deren Bewertung, Abgabe DL3, am 29. Oktober 2020	BSH	abgeschlossen
23	Kurzbericht	25.11.2020	TG noise workshop on 4th December 2020 An example to discuss the assessment methodologies	BSH	abgeschlossen
24	Notiz	26.11.2020	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
25	Notiz	4.02.2021	TG-Noise-Seminar und ICG-Noise-Treffen im Januar 2021/ Entwicklungen beim Assessment kontinuierlicher und impulshafter Geräusche	BSH	abgeschlossen
26	Bericht	7.05.2021, Version 2E	HARMONIZE Report A3.I2, Data acquisition, Towards the cross-regional unification and harmonization of applicable assessment approaches for D11 on impulsive noise, in regard of special requirements from EU regions and subregions	BSH	abgeschlossen
27	Notiz	19.5.2021	18. TG Noise-Sitzung Diskussion der Kommentare zu DL3, kurze Zusammenfassung	BSH	abgeschlossen
28	Notiz	5.07.2021	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
29	Notiz	07.07.2021	JOMOPANS	BSH	abgeschlossen
30	Notiz	07.07.2021	ICG Noise Sitzung vom 30.6.2021, Skizzierung der nächsten Arbeitsschritte	BSH	abgeschlossen
31	Notiz	08.07.2021	Tätigkeitsbericht: AP 3, Projekt HARMONIZE Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
32	Brief/Notiz	11.09.2021	Die Bedeutung des Massenstroms für den Blasenschleier	BSH	abgeschlossen

Nr.	Dokument	Datum	Betreff	Verteiler	Status
33	Notiz		EN/ICG Noise, ICG Noise Treffen, TG Noise Workshop und TG Noise Treffen im August bis Oktober, Kurze Zusammenfassung	intern	abgeschlossen
34	Notiz	29.11.2021	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen
35	Notiz	21.6.2022	Tätigkeitsbericht: AP 1, AP 2, AP 3 Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3	BSH	abgeschlossen

Aktivitätenliste Gremien

	Dokument	Zeitraum	Kurzbeschreibung	Gremien	Status
1	NWIP ISO 7447	Mai-September 2021	Beantragung eines neuen ISO Projekts zur inhaltlichen Übernahme der DINSPEC 45653 Im September 2021 wurde der Antrag von den Mitgliedern der ISO angenommen. Die Bearbeitung findet in der	DIN/ISO	abgeschlossen
2	ISO/WD 7447	August 2021	Erstellung der ISO 7447 “Offshore wind farms — In-situ determination of the insertion loss of control measures underwater” als Arbeitsunterlage für die Arbeitsgruppe	ISO	abgeschlossen
3	ISO/WD 7447	September 2021	Vorstellung des Entwurfs der ISO 7447 bei der Arbeitsgruppe *ISO/TC 43/SC 3/WG 3.*	ISO	abgeschlossen
4	ISO/AWI 7605	September/Oktober 2021	Arbeitsgruppenmitglied bei der neu gegründeten Arbeitsgruppe, Teilnahme an der Sitzung: ISO/TC 43/SC 3/WG 5 "Measurement and modelling of underwater ambient sound"	ISO	abgeschlossen
5	ISO/CD 7447	Oktober-November 2021	Überarbeitung des Entwurfs der ISO 7447 (im Wesentlichen Terminologie) zur Einreichung der ISO im Januar 2021 als Komiteeentwurf.	ISO	abgeschlossen

	Dokument	Zeitraum	Kurzbeschreibung	Gremien	Status
6	DL3	August-September 2021	Unterstützung mit diversen Textbeiträgen und nationalen Besprechungen (BfN, BSH, Müller-BBM zum Dokument Technical Group on underwater noise (TG Noise) Sigray,P., Borsani, J.F., Le Courtois, F., Assessment Framework for EU Threshold Values for continuous underwater sound, TG Noise Recommendations Editorial coordination : Maud Casier, DG Environment, European Commission, 18.11.2021	TG Noise	abgeschlossen
7	Dokument	Januar 2020-Oktober 2021	Unterstützung der nationalen Position mit Textbeiträgen und Analysen von OSPAR II Schallregisterdaten von 2015-2019 für das Dokument: "OSPAR Common Indicator assessment of risk of impact from impulsive noise for Region II"	ICG Noise	abgeschlossen
8	Präsentation	30.06.2021	Präsentation der Fragestellungen zum vorgestellten Assessment von kontinuierlichen Geräuschen.	ICG Noise	abgeschlossen
9	Dokument	Januar-Oktober 2021	Unterstützung der nationalen Position mit Textbeiträgen und Prinzip-Analysen für das Dokument: "Assessment of the Common Indicator for the pressure from ambient noise"	ICG Noise	abgeschlossen
10	Dokument	Juni-August 2021	Diskussionen im Rahmen von Meetings. Textbeiträge zu dem geplanten Assessment kontinuierlicher Geräusche, die zu einer Betrachtung von absoluten Schalldruckpegel und relativen Schalldruckpegeln geführt hat. 4J-78 Proposal on the assessment methodology for continuous noise in HOLAS III	EN Noise	abgeschlossen
11	Steckbrief	Mai 2021, Oktober 2021	Unterstützung bei der Zusammenfassung der diskutierten Punkte zu kontinuierlichen und impulshaften in den jeweiligen Gremien. (BSH, BfN, Müller-BBM) Überblick und Zusammenfassung zur DE Position gegenüber dem aktuell in Gremien diskutierten Bewertungsrahmen für Umgebungsschall (Ambient Noise) und Impulsschall (Impulsive Noise) Aktualisierung des DE Fachpositionspapiers: Stand Oktober 2021	national	abgeschlossen
12	Email, Abbildungen	November 2021	Unterstützung bei der Bewertung unterschiedlicher „Sealscarer" Konfigurationen im Kontext mit Sprengungen	national	abgeschlossen

	Dokument	Zeitraum	Kurzbeschreibung	Gremien	Status
13	Leitfaden	Januar-März 2022	Unterstützung bei der Konzeption und Berechnung der Schallausbreitung von Explosionen für ein nationales Dokument	national	abgeschlossen

Anhang B

Zusammenstellung von Unterlagen

Unterlagen

[1] Projektantrag, „Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore Genehmigungsverfahren, Raumordnung und MSRL, Bewertungsansätze für Schallmonitoring und Umweltprüfung (BeMo III)“, Müller-BBM vom 16.01.2019

[2] Offshore Windparks, Messvorschrift für Unterwasserschallmessungen, Aktuelle Vorgehensweise mit Anmerkungen, Anwendungshinweise, BSH, Oktober 2011

[3] Messung des Hintergrundschalls im Baugebiet Borkum Riffgrund 2, Itap 14. März 2019, dritte Version, per E-Mail von Carina Juretzek am.12. Juni 2019

[4] Kombinierte Messung des Unterwasserschalls am Windpark Veja Mate und des Unterwasser-Hintergrundschalls für den Windpark Deutsche Bucht, Itap 30. Januar 2019 (Version 2), per E-Mail von Carina Juretzek am 12. Juni 2019

[5] Messung des im Betrieb des Windparks Borkum Riffgrund 1 entstehenden Unterwasserschalls., Itap, 16. Januar 2019 (Version 2), per Mail von Carina Juretzek am 12. Juni 2019

[6] Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications, ACTIONS and REVISIONS PLANNED, November 2018.

[7] MSFD Common Implementation Strategy Technical Group on Underwater Noise,TG-NOISE, Providing research and scientific support to the implementation of the Marine Strategy Framework Directive Management and monitoring of underwater noise in European Seas, Overview of main European-funded projects and other relevant initiatives, 2nd Communication Report, 2019

[8] MSFD Common Implementation Strategy Technical Group on Underwater Noise (TG-NOISE), Towards thresholds for underwater noise Common approaches for interpretation of data obtained in (Joint) Monitoring Programmes Technical report DRAFT version May 2019, (To be presented at WG GES meeting 19 September 2019 Brussels).

[9] MBBM Report M127311/09, “Revision of the “TG Noise monitoring guidance“, Part 1: source levels of pile-driving noise with/without noise protection measures”, A. Müller, Müller-BBM, Sept. 2017

[10] MBBM Bericht M146361/01, BEMO III, Einbeziehung von Lärmminderungsmaßnahmen in die Berichterstattung an das Impulsschallregister, Juni 2019

[11] Müller-BBM Notiz M146361/04, BEMO III, JOMOPANS, Datenhandling und Kalibrierung, Juni 2019

[12] Müller-BBM Notiz M146361/05, Betriebsschall und Umgebungsschall bei Offshore-Genehmigungsverfahren, Juni 2019

[13] Müller-BBM Bericht Nr. M88607/13 Unterwasserschall bei Offshore- Windkraftanlagen – Harmonisierung der Verfahren und Bewertung im Hinblick auf bedarfsorientierte Zielgrößen, Abschlussbericht, Dezember 2011

[14] Müller-BBM Report M146361/6, Revision of the “TG Noise monitoring guidance“ Part 1: sound exposure levels of pile-driving noise with/without noise protection measures
Background paper, September 2019

[15] Müller-BBM Notiz M146361/07, Tätigkeitsbericht: AP 1, AP 2, AP 3, Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3, September 2019

[16] Müller-BBM Notiz M146361/08, Testing CEAF in SEANSE case studies, TNO report, Remark on prediction uncertainties, October 2019

[17] Müller-BBM Notiz M146361/09, Betriebsschall und Umgebungsschall bei Offshore-Genehmigungsverfahren
Konkretisierung zur Auswertung, November 2019

[18] Müller-BBM Notiz M146361/10, Arbeitsbeschreibung zur Kurzstudie "Transfer der deutschen Grenzwerte im europäischen Kontext", interne Notiz

[19] Müller-BBM Report M146361/06, Revision of the “TG Noise monitoring guidance“
Part 1: sound exposure levels of pile-driving noise with/without noise protection measures
Background paper, Mai 2020, Version 2E

[20] Müller-BBM Notiz M146361/11, Tätigkeitsbericht: AP 1, AP 2, AP 3
Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3, November 2019

[21] Müller-BBM Notiz M146361/12, Dual level statistics (SEL und Lpeak), März 2020

[22] Müller-BBM Report M146361/13, Pile Driving - Classification and assessment of impulsive noise with and without noise mitigation measures – Exposure Index, April 2020, Version 3E

[23] Müller-BBM Memo M146361/14, EN-Noise 3-2020, HELCOM impulsive noise indicator, April 2020, Entwurf

[24] Müller-BBM Notiz M146361/15, Tätigkeitsbericht: AP 1, AP 2, AP 3
Studie zu Bewertungsansätzen für Unterwasserschallmonitoring im Zusammenhang mit Offshore-Genehmigungsverfahren, Raumordnung und MSRL (BeMo) Phase 3, Juni 2020

[25] Müller-BBM Bericht M146361/16, Pile Driving – Classification and assessment of impulsive noise with and without noise mitigation measures – Exposure Index, Mai 2020

[26] Müller-BBM Notiz M146361/17 BEMO III, Anstehende Aufgaben, Besprechung am 23.06.2020, Kurzdarstellung der Erkenntnisse zur Vorbereitung der nächsten Schritte

[27] Müller-BBM Notiz M146361/19, Sechzehnte TG Noise Sitzung und Workshop am 6. und 7. Oktober 2020,

[28] Müller-BBM Notiz M146361/20, Aufgaben aus der sechzehnten TG Noise Sitzung und der Workshop am 6. und 7. Oktober 2020

[29] Müller-BBM Notiz M146361/21 Jomopans, Einschätzung der Umsetzbarkeit

[30] Müller-BBM Notiz M146361/22 TG Noise, Workshop zum Themenkreis kontinuierliche Schalleinträge

[31] Müller-BBM Notiz M146361/23 TG Noise Workshop, an example to discuss the assessment methodologies

[32] Assessment framework for threshold values for continuous sound and setting of threshold values, Recommendations from TG Noise, MSFD Common Implementation Strategy, Technical Group on Underwater Noise (TG-NOISE), Methodology report, DL3-REPORT_v1_2021.docx, Stand 28. Jan. 2021

[33] Entwurf zur Kommentierung: Agenda Item 7: EIHA 21/07/02, Original: English, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Meeting of the Environmental Impact of Human Activities Committee (EIHA), BY WEBEX 15 – 18 March 2021, OSPAR Common Indicator on the risk of impact from impulsive noise, Presented by the Co-convenors of ICG-Noise

[34] Powerpoint-Präsentation, Dauerschallindikator OSPAR (EIHA), Diskussionspunkte, 12. März 2021

[35] Müller-BBM Notiz M146361/27, 18. TG Noise-Sitzung
Diskussion der Kommentare zu DL3, kurze Zusammenfassung, 19.05.2021

[36] Müller-BBM Notiz M146361/29, JOMOPANS, kurze Zusammenfassung, 07.07.2021

[37] Müller-BBM Präsentation, ICG Noise meeting, Continuous noise assessment, discussion points, 30.06.2021

[38] Müller-BBM Notiz M146361/30, ICG Noise Sitzung vom 30.6.2021,
Skizzierung der nächsten Arbeitsschritte, 07.07.2021

[39] Agenda Item 4.1, ICG-NOISE (2) 21/04/01, OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Meeting of the Intersessional Correspondence Group on Underwater Noise, Assessment of the Common Indicator for the risk of impact from impulsive noise: 2015-2019, 30 June 2021

[40] Müller-BBM Notiz M146361/33, EN/ICG Noise, ICG Noise Treffen, TG Noise Workshop und TG Noise Treffen im August bis Oktober, kurze Zusammenfassung, Müller-BBM intern

[41] Müller-BBM Brief M146361/32, Die Bedeutung des Massenstroms für den Blasenschleier, 10.09.2021

[42] DE Steckbrief: Überblick und Zusammenfassung zur DE Position gegenüber dem aktuell in Gremien diskutierten Bewertungsrahmen für Umgebungsschall (Ambient Noise), Stand Oktober 2021

[43] Technical Group on underwater noise (TG Noise):Sigray,P., Borsani, J.F., Le Courtois, F., Assessment Framework for EU Threshold Values for continuous underwater sound, TG Noise Recommendations Editorial coordination : Maud Casier, DG Environment, European Commission, 18.11.2021

[44] Müller-BBM Presentation, NWIP ISO 7447, Underwater acoustics – Measurement of radiated underwater sound from percussive pile driving – In-situ determination of the insertion loss of barrier control measures underwater

Anhang C

Ausgewählte Berichte

Tabelle 1. Ausgewählte Berichte.

Bericht M146361/01	BeMo III Inclusion of noise-mitigation measures in the reporting to the impulsive noise registry on behalf of Bundesamt für Seeschifffahrt und Hydrographie Bernhard-Nocht-Str. 78 20359 Hamburg
Bericht M146361/06	Revision of the “TG Noise monitoring guidance“ Sound exposure levels of pile-driving noise with/without noise protection measures Background paper
Bericht M146361/12	Dual level statistics (SEL und Lpeak)
Bericht M146361/13	Pile-driving Classification and assessment of impulsive noise with and without noise mitigation measures Exposure Index
Bericht M146361/16	Pile-driving Classification and assessment of impulsive noise with and without noise mitigation measures Exposure Index
Bericht M146361/23	TG noise workshop on 4th December 2020 An example to discuss the assessment methodologies

MÜLLER-BBM

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

Report

Inclusion of noise-mitigation measures in the reporting to the impulsive noise registry

on behalf of

Bundesamt für Seeschifffahrt und Hydrographie
Bernhard-Nocht-Str. 78
20359 Hamburg

Consultant: Müller-BBM GmbH
Dr. rer. nat. Andreas Müller

Bramfelder Str. 110b
22305 Hamburg

Date: 18 March 2019

Client:	Bundesamt für Seeschifffahrt und Hydrographie Bernhard-Nocht-Str. 78 20359 Hamburg
Consultant:	Müller-BBM GmbH Dr. rer. nat. Andreas Müller Bramfelder Str. 110b 22305 Hamburg

Report No.:	M146361/01
Total number of pages:	10 pages
Date:	18 March 2019

This report (Report No. M146361/01) was created under order number 10036955 on behalf of the Federal Maritime and Hydrographic Agency (BSH) as part of the research project "Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive" (BeMo). The authors assume responsibility for the content of this publication.

To be cited as: Müller, A. 2019. Inclusion of noise-mitigation measures in the reporting to the impulsive noise registry. Report on behalf of the Federal Maritime and Hydrographic Agency as part of the research project **"**Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive" (Order Number 10036955).

Table of contents

1 Situation and Task

In recent years, numerous offshore construction projects have been successfully carried out in several riparian states of the North Sea and the Baltic Sea. Underwater sound is being monitored within the context of HELCOM indicators in these regions, for achievement and preservation of GES in accordance with the MSFD framework. Hence, the input of impulsive sound due to pile driving activities during offshore windfarm construction has to be assessed and the impact has to be evaluated. As an important measure for determining the noise impact during pile driving activities, several member states of the European Union (e.g. Belgium, the Netherlands, Germany and Denmark) have initiated acoustic monitoring. Additionally, technical noise mitigation measures have been applied in various countries (Germany, UK, Belgium and Denmark).

In the framework of the TG Noise meeting held in Lisbon on October 19th/20th 2018 (see [4]) it was decreed that the TSG Noise Guidance [1] is to be revised. Chapter 2 of the Guidance addresses the classification of pile driving sources (for the impulsive noise registry). Currently, the sound source is characterized in terms of an auxiliary variable, the proxy of a maximum hammer energy (indeed the capacity of the impact hammer). In current wording the noise measures are not explicitly taken into account. Measures, however, are known to be able to significantly reduce the sound energy radiated to water and to change the spectral composition of the sound event, see Figure 1.

The implementation of technical noise mitigation measures have been a standard requirement at offshore construction sites in the German EEZ since 2011. As of 2018, 18 offshore wind farms (OWPs) are operated in the German Exclusive Economic Zone (EEZ), four OWPs are under construction. The Federal Maritime and Hydrographic Agency (BSH) holds numerous measurements of underwater sound of pile driving activities collected in accordance with the licensing requirements. The data is integrated in the German national noise registry and provides a substantial basis for assessing influencing factors of the generation and transmission of sound, but also of the effectiveness of noise reduction measures. Hence, Germany (BSH) offered to contribute its experience with a proposal for an approach to integrate noise protection measures for the formulation of the source characterization for pile-driving noise.

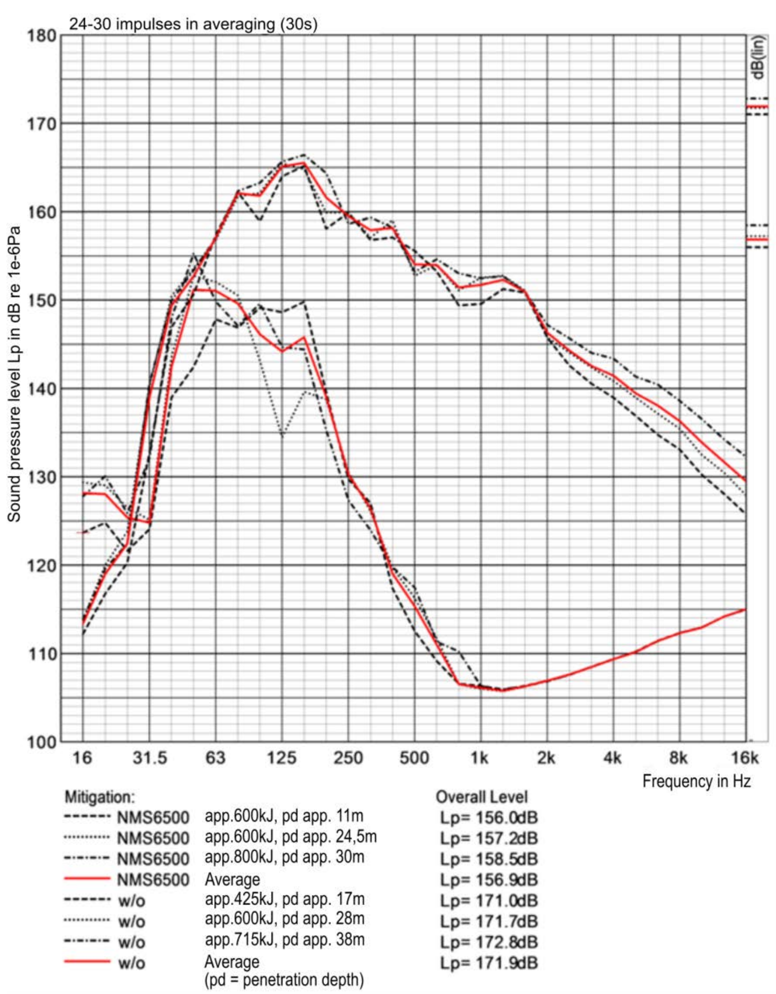


Figure 1: Pile-driving noise: Comparison with / without mitigation.

Numerous member states of the European Union use a distance of approx. 750 m as standard for their acoustic measurements during pile driving activities. National [5] and international standards [2] have adopted this measuring distance and recommend it, which has helped to build up a large data base that is likely to further increase. E.g. OSPAR has introduced this information as non-mandatory entries in the template for reporting to the noise register.

The concrete task is to integrate noise mitigation measures when it comes to formulate source characterization for pile-driving noise. As a first step, available data and possibilities for revising the guidance were collected [8]. Subsequently, a concrete revision was sought. The progress and preliminary results will be presented in the following chapter.

2 Progress

The purpose of the noise registry is to monitor the occurrence of relevant impulsive noise sources on one hand, but also to classify different source types according to their characteristics and potential impact on the marine environment. Ideally, one would prefer to describe the sources as sound power or sound energy, which is an established standard in the field of air acoustics. This would be advantageous, as all noise sources could be assessed consistently. However, for pile driving noise there is no simple equivalent to a source level. In addition, as far as we know, there are neither any standardized measure¬ment procedures nor any published theoretical approaches that are available to doing this. Instead, a practicable approach of performing measurements in the far field at a distance of 750 m from the piling site is typically carried out. The procedure for implementing these measurements is described in an international standard [2]

Therefore, the working team at TG Noise decided to use the measurement distance of 750 m. This distance offers a good source description for the SEL and zero to peak sound pressure level.

In order to assess the pile driving noise with applied noise mitigation measure usually the insertion loss D of a noise barrier (e.g. bubble curtain, cofferdam etc.) is used. This is defined as the (frequency-dependent) decrease of the sound pressure level or the single-value level at the same position by inserting the obstacle with regard to a predefined point of interest.

$$D = L_{E2} - L_{E1}$$

In this equation L_{E1} and L_{E2} stand for the sound exposure level (SEL) at the point of interest with and without sound obstacle, respectively. Usually, the insertion loss D is determined in measurements and given as a frequency-dependent quantity, see [5], [7]. Numerous measurements to determine the insertion loss were carried out within the framework of approval procedures and research projects. Publicly available data can be found in a publication by Bellmann [9] from 2014.

In order to be able to use the already practiced procedure of the noise register on the one hand and on the other hand to design the use as simply as possible, only the insertion loss was added to the existing concept to characterize the ramming processes.

Figure 2 shows the relationship between the sound exposure level SEL at 750 m and hammer energy with and without measures, whereby hammer energy is only a good estimator of the SEL for pile driving without sound insulation measures. When sound insulation measures are used, hammer energy is to be understood as a virtual quantity. Measurements that reach an SEL of 160 dB at 750 m correspond to a virtual hammer energy of 20 kJ.

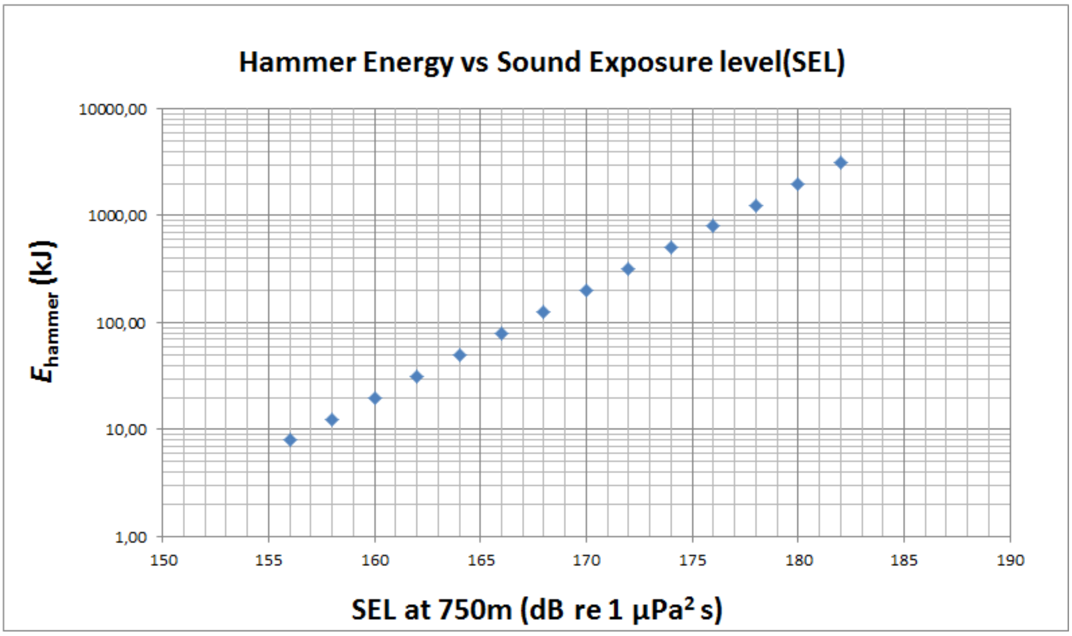


Figure 2: Sound exposure level *SEL* at 750 m, depending on the hammer energy, according to current definition

Categorization of impact pile driver:

If sound measurements are available, these should preferably be used to classify the characterization of the sound source.

If only the hammer energy is available as information and no sound insulation measure is applied, the hammer energy can be used directly for classification. In all other cases, i.e. either measurements are available or no measurements are available, but the hammer energy E and the sound insulation measure (insertion loss D) are known, the hammer energy is replaced by a calculated virtual energy.

Categories	**SEL (750 m) dB re 1µPa^2 s**	**L_{peak} (750 m) dB re 1µ Pa**	**Hammer Energy (kJ)**
1	140 – 149,9	160 – 169,9	0,2 – 1,99
2	150 – 159,9	170 – 179,9	2 – 19,99
3	160 – 169,9	180 – 189,9	20 – 199,99
4	170 – 179,9	190 – 199,9	200 – 1999,99
5	180 – 189,9	200 – 209,9	2000 – 19999,99
6	190 -	210 -	20000 -

Table 1: Current proposal for the categorization of impact pile driver. (Discussion basis)

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_01_BER_3E.DOCX2019-03-18

3 Further procedure

The completion of the contributions for the TG Noise Guidance is scheduled for 2019.

The research project (BMUB R&D ERa Report on Pile Driving Noise, BSH and itap) on systematic data collection and evaluation and thus revision of the findings on the insertion loss of individual measures will be completed at the end of 2019. This provides a tested and citable data set.

4 References

[1] Monitoring Guidance for European Seas, Parts I to III,
MSFD Technical Subgroup on Underwater Noise, 2014

[2] ISO 18406:2017-04: Underwater acoustics –
Measurement of radiated underwater sound from percussive pile driving

[3] ISO 18405:2017-04: Underwater acoustics – Terminology

[4] TG Noise Protocol –
Meeting of the EU Technical Group on Underwater Noise (EU TG-NOISE)
19th – 20th October, Ministry for the Sea, Lisbon, Portugal, November 2016

[5] DIN SPEC 45653:2017-04: Offshore wind farms –
In-situ determination of the insertion loss of control measures underwater

[6] A. Müller, C. Zerbs: “Measuring instruction for underwater sound monitoring – Current approach with annotations, Application instructions”

BSH (Bundesamt für Seeschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2011

[7] A. Müller, C. Zerbs: “Offshore Wind Farms Measuring Specification for the Quantitative Determination of the Effectiveness of Noise Control Systems”

BSH (Bundesamt für Seeschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2013

[8] MBBM Report M127311/9, “Revision of the “TG Noise monitoring guidance“, Part 1: source levels of pile-driving noise with/without noise protection measures”, A. Müller, Müller-BBM, Sept. 2017

[9] Bellmann M: “Overview of existing Noise Mitigation Systems for reducing Pile-Driving Noise”. Proceeding Internoise 2014, Melbourne, Australia, 2014

Dr. rer. nat. Andreas Müller

Müller-BBM GmbH
Branch Office Hamburg
Bramfelder Str. 110 B / 3. Stock
22305 Hamburg

Telephone +49(40)692145 0
Telefax +49(40)692145 11

www.MuellerBBM.de

Dr. rer. nat. Andreas Müller
Telephone +49(40)692145 19
Andreas.Mueller@mbbm.com

2020-05-27
M146361/06 MLR/WNR

Revision of the “TG Noise monitoring guidance“

Sound exposure levels of pile-driving noise with/without noise protection measures

Background paper

Report No. M146361/06

Supporter:	Bundesamt für Seeschifffahrt und Hydrographie Dr. Maria Boethling Carina Juretzek Bernhard-Nocht-Strasse 78 20359 Hamburg
Authors:	Alain Norro Andreas Müller Michael A. Ainslie Nathan Merchant Russell Leaper
Total number of pages:	31 pages in total, thereof 20 pages of text, 6 pages Appendix A and 5 pages Appendix B

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_06_BER_2E.DOCX : 23.08.2019

Müller-BBM GmbH
Branch Office Hamburg
HRB Munich 86143
VAT Reg. No. DE812167190

Managing directors:
Joachim Bittner, Walter Grotz,
Dr. Carl-Christian Hantschk, Dr. Alexander Ropertz,
Stefan Schierer, Elmar Schröder

Content

1 Situation and task

In the framework of the TG Noise meeting held in Lisbon on October 19th/20th 2016 (see [5]) it was decreed that the TSG Noise Guidance [1] is to be revised.

The document at hand will, in that respect, look at impulsive noise from pile driving.

Currently, the sound source is characterized in terms of an auxiliary variable, the proxy of a maximum hammer energy. In current wording the noise protection measures are not explicitly taken into account. Noise protection measures, however, are known to be able to significantly reduce the sound energy radiated to water and to change the spectral composition of the sound event, see Figure 1.

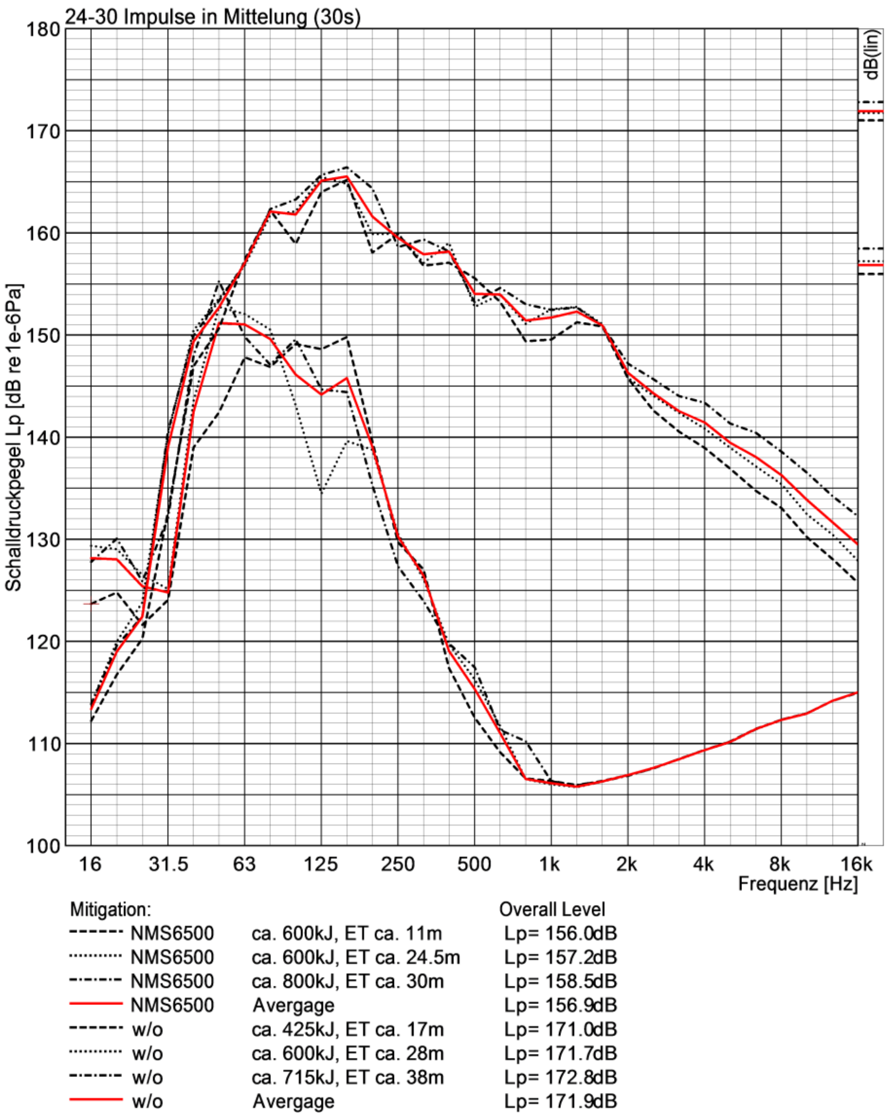


Figure 1: Pile-driving noise: comparison with / without mitigation.

Numerous member states of the European Union (e.g. Belgium, the Netherlands, Germany and Denmark) have initiated acoustic measurements to determine the actual noise impact during pile driving activities. Often, the measurements were (or are being) carried out in a distance of approx. 750 m. National [6] and international standards [3] have adopted this measuring distance and recommend it, which has helped to build up a large data base that is likely to further increase. OSPAR has already introduced this information as non-mandatory entries for the template of the noise register.

The concrete task is to integrate noise protection measures when it comes to formulate source levels for pile-driving noise.

For this purpose the document at hand should be used as a basis for discussion within the revision process of TSG Guidance.

2 General approach, principles

The following general principles serve as a basis for the formulation of the *Source* description*:*

a) The approach as described in TSG Guidance [1] is used. As this already is the basis of both national and international inventories, such as OSPAR the proxy (auxiliary variable) “hammer energy” shall be used.

b) It shall be as simple as possible to use.

c) As basis for measured levels the Sound Exposure Level in 750 m should be used.

d) Future modifications of the described approach must be possible.

Examples and the procedure will be given in the following chapters.

Remark on c):

Target of the noise registry is to classify impulsive noise sources. Ideally, one would – like in the „air world“ – prefer to describe the sources as sound power or sound energy. This would be advantageous, as all noise sources could be assessed consistently. However, for pile driving noise there is no simple equivalent to a source level. In addition, as far as we know, there are neither any standardized measurement procedures nor any theoretical approaches which could be cited that are available to do this. Instead, measurements at 750 m distance from the piling site are typically carried out. For this an international standard [3] does exist. Therefore, the working team decided to use the measurement distance of 750 m. This distance offers a good source description for the SEL.

Some countries like Belgium use the zero to peak sound pressure level as an acoustic metric. Figure 14 shows the relationship to the SEL without mitigation measures.

3 Documents

[1] Monitoring Guidance for European Seas, Parts I to III,
MSFD Technical Subgroup on Underwater Noise, 2014

[2] Ainslie M.A., de Jong C.A.F., Robinson S.P., Lepper P.A. (2012) What is the Source Level of Pile-Driving Noise in Water?. In: Popper A.N., Hawkins A. (eds) The Effects of Noise on Aquatic Life. Advances in Experimental Medicine and Biology, vol 730. Springer, New York, NY

[3] ISO 18406:2017-04: Underwater acoustics –
Measurement of radiated underwater sound from percussive pile driving

[4] ISO 18405:2017-04: Underwater acoustics – Terminology

[5] TG Noise Protocol –
Meeting of the EU Technical Group on Underwater Noise (EU TG-NOISE)
19th – 20th October, Ministry for the Sea, Lisbon, Portugal, November 2016

[6] DIN SPEC 45653:2017-04: Offshore wind farms –
In-situ determination of the insertion loss of control measures underwater

[7] A. Müller, C. Zerbs: “Measuring instruction for underwater sound monitoring – Current approach with annotations, Application instructions”

BSH (Bundesamt für Seenschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2011

[8] A. Müller, C. Zerbs: “Offshore Wind Farms Measuring Specification for the Quantitative Determination of the Effectiveness of Noise Control Systems”

BSH (Bundesamt für Seenschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2013

[9] Prognose des Unterwassergeräusches beim Bau und beim Betrieb des Offshore-Windparks Borkum-West („alpha ventus“) und Messung des Hintergrundgeräusches im Planungsgebiet (Forecast of underwater noise in the construction and operation of the Borkum-West offshore wind farm (“alpha ventus”) and measurement of the background noise in the planning area)

Itap (Institute of Technical and Applied Physics, Oldenburg, Germany), 2007

[10] ISO 3740:2000-11: Acoustics – Determination of sound power levels of noise sources – Guidelines for the use of basic standards

[11] NPL (National Physical Laboratory UK): Good Practice Guide No. 133, Underwater Noise Measurement, 2014

[12] OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise, 2014

[13] Zampolli, M., Nijhof, M. J. J., de Jong, C. A. F., Ainslie, M. A., Jansen, E. H. W. and Quesson, B. A. J.:
"Validation of finite element computations for the quantitative prediction of underwater noise from impact pile driving",
Journal of the Acoustical Society of America, Vol. 133, 2013, pp. 72 – 81

[14] Urick, Robert J.: "Principles of underwater sound", McGraw Hill Book Company, 3rd edition, 1983

[15] Adrian Farcas, Paul M. Thompson, Nathan D. Merchant: "Underwater noise modelling for environmental impact assessment", Environmental Impact Assessment Review 57 (2016) 114 – 122, 2016

[16] Reports on Predicting Underwater Noise due to Offshore Pile Driving, 2015, http://www.bora.mub.tuhh.de/pages/publications.html

[17] Documentation of the underlying data base and the numerical model of the BORA Expert System, 2015, https://bora.isd.uni-hannover.de/

[18] Weston DE (1976): "Propagation in water with uniform sound velocity but variable-depth lossy bottom", Journal of Sound Vibration 47(4) pp 473 – 483

[19] Thiele, R., Schellstede, G.: „Standardwerte zur Ausbreitungsdämpfung in der Nordsee (standard values for propagation loss in the North Sea)",
FWG-Report 1980-7,
Federal Armed Forces Research Institute for Underwater Acoustics and Marine Geophysics (Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik FWG), 1980

[20] M. Schulkin, J.A. Mercer, Colossus Revisited::"A Review and Extension of the Marsh-Schulkin Shallow Water Transmission Loss Model (1962)",
APL-UW 8508, Applied Physics Laboratory University of Washington, 1985

[21] Bellmann M: "Overview of existing Noise Mitigation Systems for reducing Pile-Driving Noise". Proceeding Internoise 2014, Melbourne, Australia, 2014

[22] Nehls G & Bellmann MA: „Further development and trial of the „Big Bubble Curtain" for the reduction of hydro sound emissions during Offshore pile-driving works". Promoted by PTJ (Project Management Jülich) and BMWi (German Federal Ministry for Economic Affairs and Energy), FKZ 0325645A/B/C/D, 2015 (www.hydroschall.de)

[23] Müller ,A, Revision of the "TG Noise monitoring guidance" Part 1: sound exposure levels of pile-driving noise with/without noise protection measures, Report No. M127311/9, Sep. 2017

[24] Andersson, M.H., Andersson, S., Ahlsén, J., Andersson, B.L.,Hammar, J., Persson, L.K.G., Pihl, J., Sigray, P., Wikström, A. 2016. A framework for regulating underwater noise during pile driving. A technical Vindval report, ISBN 978-91-620-6775-5, Swedish Environmental Protection Agency, Stockholm, Sweden.

[25] Lippert, T., Ainslie, M. A., & von Estorff, O. (2018). Pile driving acoustics made simple: Damped cylindrical spreading model. The Journal of the Acoustical Society of America, 143(1), 310-317

[26] Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2019. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation. Brussels: Royal Belgian Insti-

tute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 134 p.

[27] Müller A., Dual level statistics (SEL und L_{peak}), Müller-BBM, Document no. M146361/12, 2020

[28] Heaney KD, MA Ainslie, MB Halvorsen, KD Seger, RAJ Müller, MJJ Nijhof, T Lippert. 2020. A Parametric Analysis and Sensitivity Study of the Acoustic Propagation for Renewable Energy Sources. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. Prepared by CSA Ocean Sciences Inc. OCS Study BOEM 2020-011. 165 p

4 Proposal for an easy integration of noise protection measures into the existing concept for classifying the sound source „pile driving“

4.1 Introduction

In the current wording the source characterized by the hammer energy, see explanation in chapter 4.2. Thus, pile driving is exclusively classified by the hammer energy. Due to this situation it is not possible to classify those sound sources, where noise mitigation measures were applied. Implementing a noise mitigation measure, however, would have a significant effect both on the sound energy and on the spectral composition of the pile-driving noise event – an effect that could be relevant for future assessments.

There are three options to avoid this situation:

1. The source can be classified through a parameter that is equivalent to the sound energy, e.g. through the Energy Source Level.
2. The source can be described by an emission-relevant factor like the Sound Exposure Level at a defined measurement distance.
3. In the presence of a noise mitigation measure: a notional value for the hammer energy can be determined.

Choosing the second option is obvious as in this case the sound source is transparently presented.

In the following chapters the options two and three are described and the consequences for a notional hammer energy and its classification are discussed.

In this context the status quo according to [1] will be considered (chapter 4.2); it will be explained that there is the option of a computational description of level reductions due to a noise mitigation measure applying the insertion loss (chapter 4.3) and, furthermore, the determination of Sound Exposure Level and the notional hammer energy, respectively, will be formulated based on acoustic measurements in a defined distance and using a propagation model.

In Appendix A several available data on measurements and the development of noise reduction measures during pile driving works are summarized.

In Appendix B a typical pile driving process with applied noise protection measure is described. The issues on statistics of data from real measurements (keyword signal-to-noise ratio) are discussed there. This is important for being able to judge the appropriate frequency range, for which a source could be described in measurements.

In the Enclosure to this document the template of the OSPAR sound inventory is attached. It is divided into binding entries and further optional but necessary entries, e.g. to describe a sound source with noise mitigation measures.

4.2 Status quo

The TSG Noise Guidance [1] introduced the relation between the impact or hammer energy

$$E_{\text{hammer}} = \frac{1}{\mu} 10^{(SL_E - 170,7)/10} \ J \qquad (1)$$

and the equivalent energy source level SL_E in dB re (µPa m)^{2}s (defined as the energy source level of a point source that would radiate the same amount of energy as the driven pile), where μ is a constant of proportionality that quantifies the conversion of the mechanical hammer energy into sound energy. The hammer energy E_{hammer} is, as usual, given in joule (J). The usual hammer energy range is between 500 kJ and 4000 kJ.

Remark 1:

It is known that the sound radiation of a pile is not only dependent of the hammer energy but on various parameters such as the hammer's properties (piling mass, construction of the pile helmet and control of the pulse repetition frequency as well as impact speed), properties of the pile (pile design, e.g. pile diameter, anchoring depth), soil condition (soil resistance, soil profile), bathymetry etc. These interdependencies were already mentioned exemplarily in [9]. Modelling with numerical methods is quite complex, see e.g. the work of Zampolli and others [13] as well as the BORA project [16]. From the latter, a parametric model arose which can be used by the public within the framework of an expert system; with which essential parameters for sound radiation can be calculated, see [17]. However, for sound mitigation measures, it is inadequate. In 2016, the German Federal Maritime and Hydrographic Agency, BSH, initiated a project running through 2020 aiming at integrating all data on pile driving noise measured in Germany in a data base, also including a large number of the above-mentioned parameters. The so-collected data then shall be systematically analysed with regard to the impact of the various parameters on the sound contribution and evaluated (BMUB R&D ERa Report on Pile Driving Noise, BSH and itap). This professional information system will then provide features for specific search queries to find correlative parameters.

Remark 2:

In the Guidance [1] the sound contributions due to pile driving noise are classified as follows:

- Very low: less than 280 kJ,
- Low: 290 kJ – 2,80 MJ,
- Medium: 2,81 – 28 MJ,
- High: above 28 MJ,

4.3 Calculatory determination of pile driving noise while a noise mitigation measure is applied

4.3.1 Situation

In principle, there are two possible situations:

1. Measurements of pile driving noise with / or without sound reduction measures at approximately 750 m measurement distance are available.

   ⇒ If so, only recalculation to 750 m is needed.

2. No measurements of pile driving noise with / or without sound reduction measures at approximately 750 m distance are available.

   ⇒ An empirical model to approximate the SEL at 750 m with and without reduction measures is needed.

These topics are dealt with in this section. Thus, in chapter 4.3.2 the insertion loss is initially introduced to describe the noise reduction measures. In chapter 4.3.3 a very simple empirical model for the calculation of the Sound Exposure Level in 750 m distance with and without noise reduction measures is shown. Chapter 4.3.4 alludes to the possibility of classifying the noise sources in the noise registry and in chapter 4.3.5 the distance correction of measured SELs will be examined.

4.3.2 Insertion loss

In order to assess the pile driving noise with applied noise mitigation measure usually the insertion loss D of a noise barrier (e.g. bubble curtain, cofferdam etc.) is used. This is defined as the (frequency-dependent) decrease of the sound pressure level or the single-value level at the same position by inserting the obstacle with regard to a predefined point of interest.

$$D = L_{E2} - L_{E1} \tag{2}$$

In this equation L_{E1} and L_{E2} stand for the sound exposure level at the point of interest with and without sound obstacle, respectively. Usually, the insertion loss D is determined in measurements and given as a frequency-dependent quantity, see [6]. For a pre-defined measurement set-up often a single-number value is taken for the level reduction, see e.g. the compilation of noise mitigation measures in the OSPAR document [12] as well as in [21], [22] and [24]. This value can usually only be adopted for other set-up situations in case of a comparable spectral frequency distribution of the source, see below-mentioned example.

Two third spectres as well as a frequency-dependent insertion loss were taken as example. The insertion loss was oriented towards real measurement results, i.e. the used level values corresponded to rounded versions of measurement data, the assumed loss was also reproduced.

Figure 2 shows the two pile spectres without reduction measures (red and black curve) and with reduction measures (orange and grey curve). Piling QS1 has the spectral maximum in the range between 125 Hz and 200 Hz, piling QS2 between 100 Hz and 160 Hz.

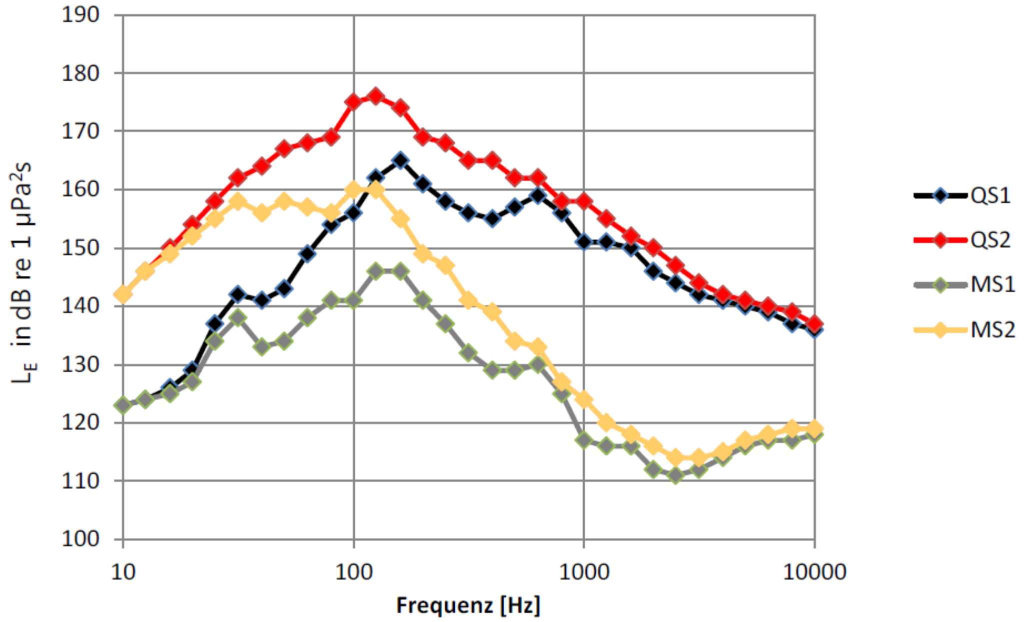


Figure 2: SEL(L_E) of two sources without mitigation measure (QS1 and QS2) and with identical mitigation measure (MS1 and MS2), see insertion loss in Figure 3.

The SEL(L_E) of each noise event results as level sum over all frequency stabilization points.

The level difference between the curves with and without loss is each the same and is shown in Figure 3 as insertion loss in dB.

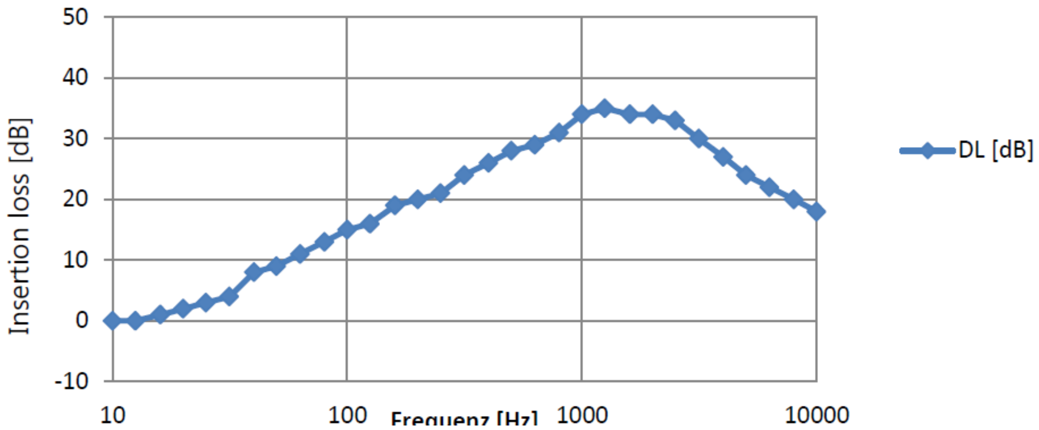


Figure 3: An insertion loss of noise reduction measures (example)

The insertion loss increases with increasing frequency, which means the reduction measure is more efficient within the range of the spectral maximum of spectrum 1 than in the range of the spectral maximum of spectrum 2.

The single values L_E and the differences are summarized in Table 1.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_06_BER_2E.DOCX: 23.08.2019

Thus, the same measure causes a reduction of (rounded) 18 dB for the exemplary spectrum 1 and of 14 dB for spectrum 2.

Table 1: SEL (L_E) of the two different noise events and the resulting level difference

	L_E [dB] without measure	**L_E [dB] with measure**	**ΔL [dB] Level difference**
Spectrum 1	170,1	151,7	18,4
Spectrum 2	181,7	167,5	14,1

Using single values for the characterization of noise reduction measures is a very crude approximation from an acoustical point of view. However, it offers the possibility to achieve rough estimates of level reductions when applying mitigation measures. Table 3 in Appendix A summarizes the publicly available information gained hitherto. The use of single values for broadband sound compared to values for each frequency band leads to a higher uncertainty in predictions. This has to be taken into account when considering the effectiveness of the mitigation measure for species which are sensitive to different frequencies.

4.3.3 Calculatory determination of the Sound Exposure Level (SEL) in a measurement distance of 750 m, with and without noise mitigation measures

The SEL at 750 m depends at least on:

- E = hammer energy
- d= diameter of pile at bottom
- h= waterdepth
- D= insertion loss
- Ham= Type of hammer (mass),
- Penetration depth, soil resistance to driving,
- …

An empirical model could look like

$$SEL(750m) = 175 + 10\log_{10}(E/E0) + 12.8\log_{10}(d/d0) + 10\log_{10}(h/h0) - D + (Z\log_{10}(ham/ham0)) \quad (3)$$

with

- E0=1000kJ,
- d0=4m,
- h0=30m

Remark:

This approximation was done by a student in contract of Müller-BBM GmbH (not published) using the Expert system from BORA [17]. (Publicly available program) and fits good with measured values, compare with Table 3 (from Appendix A). The influence of the hammer was not quantified but is outlined in the above model.

Collection of data see e.g. Figure 14: Citation from a framework for regulating underwater noise during pile driving Mathias H Anderson et al./ (A framework for regulating underwater noise during pile driving Mathias H Anderson et al. [24] and Itap [21])

Make it as simple as possible:

We decided to take as a reference a pile with a diameter of 6 m and a water depth of 30 m. If we take only into account the hammer the formula reduces to

$$SEL(750m) = 177 + 10\log_{10}(E/E0) - D \quad (4)$$

with

- E0=1000kJ,

Based on current information this model represents an upper limitation of the SEL.

In case the relation between the zero to peak level (L_{peak}) and SEL has to be calculated, the following formula can be chosen.

$$L_{peak}(750m) = SEL(750m) + 22 \quad (5)$$

Remark:

In order to justify the ratio Lpeak and SEL, numerous measurements were used, as shown e.g. in Appendix A. Further analyses can be found in the documents [26] on Belgium experiences, investigations in Germany [27] and research results from BOEM [28]. In the study [27], internal investigations on the dual level statistics of the BSH from 2014 on a total of 8 wind farms were examined. Figure 4 shows a summary result of the investigation. The mean value of the difference between the 5 % percentile of the L_{peak} and the 5 % percentile of the SEL from a sample size of 126 measurements was 22 dB. A standard deviation of 2.0 dB was calculated. The measurement distance in each case was approximately 750m.

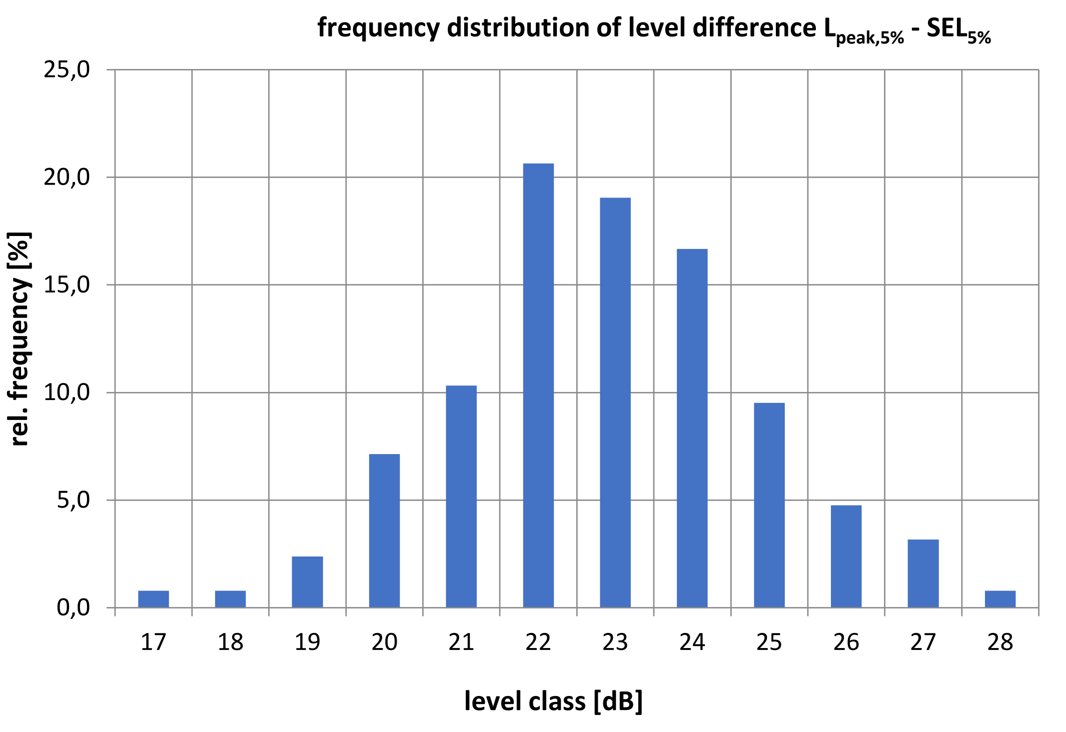


Figure 4: Relative frequency of the level classes of 126 (8 wind farms) evaluated difference values [27].

In the BOEM project [28], measurements of several pile driving of different wind farms at various distances were statistically investigated and a regression formula for the ratio Lpeak to SEL was found.

$$L_{\text{peak}} = 1.201 \cdot SEL - 12.8\text{dB}$$

Looking at measured values of current pile driving in 750 m, the ratios are also approx. 21-22 dB for this formula.

For the insertion loss D we propose to use the publicly available information, see Table 3 in Appendix A.

Now we come to the crucial point. In Table 3 in Appendix A only insertion losses for noise reduction measures complying with the state of the art, i.e. which guarantee to achieve a noise reducing efficiency are listed. Experience shows that new suppliers often fail to achieve these level reductions. It should be discussed how to deal with this state of affairs in practise.

Our proposals:

Take the lowest value of the insertion loss, e.g. 19 dB for IHC-Noise Mitigation System (NMS)+BBC (Table 2).

- Background, among others, is that strictly speaking the single value only has a real significance if the frequency spectrum of the source was known. Thus, different results can be reached by applying acoustically identical measures to different source spectra, see example in chapter 4.3.2.
- It is not sure that the measures regarding their acoustical efficiency are of equal quality.
- Furthermore, to provide an incentive for it to make measurements.

Table 2: Proposed values of broadband insertion loss, for use if measurements are not available.

noise mitigation technique	**recommended value of insertion loss D / dB**
big bubble curtain (BBC)	10
double big bubble curtain (DBBC)	14
small bubble curtain	5
hydrosound dampers (HSD)	8
noise mitigation screen	13
cofferdam	10
DBBC+BBC	15
IHC-Noise Mitigation System (NMS) +BBC	19
BBC+HSD	15
DBBC+HSD	14

4.3.4 Categories: SEL versus virtual hammer energy

Due to the fact that the SEL in 750 m has now been defined, it was mutually agreed that the introduction of a virtual hammer energy would not be useful and necessary and to stick to the SEL.

In the following the virtual hammer energy is introduced nevertheless, in order to ensure a comparison with the current noise registry.

From equations (1) and (4) it is easy to derive the ratio between the hammer energy E_{hammer} and a virtual hammer energy E'_{hammer} that describes the mitigated Sound Exposure Level:

$$E_{\text{hammer}} = E'_{\text{hammer}} \cdot 10^{D/10} \qquad (6)$$

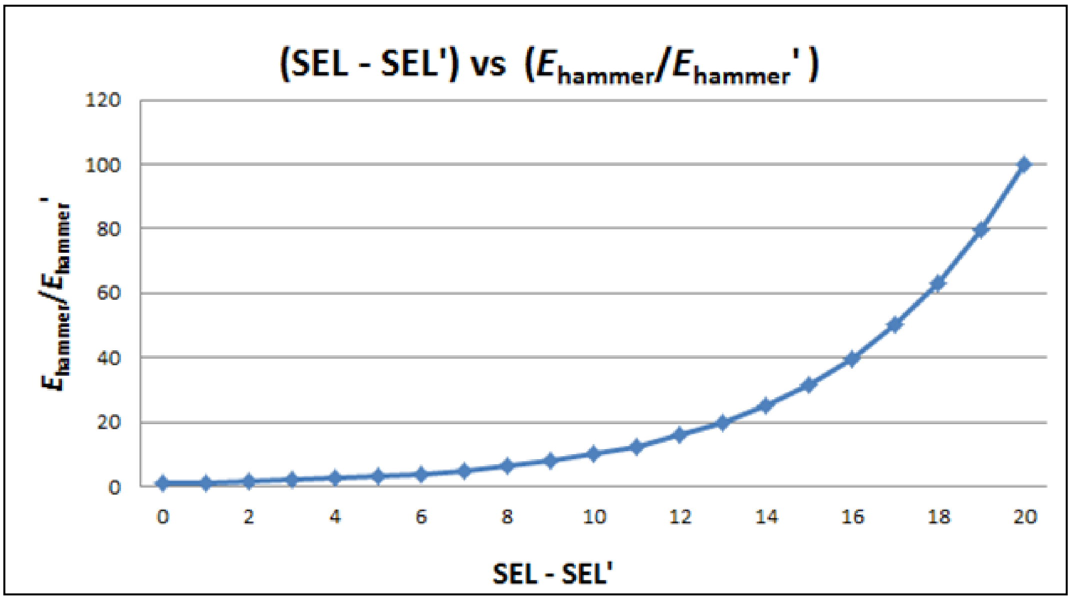


Figure 5: Ratio of the hammer energy to the virtual hammer energy with known insertion loss D.

Remark 3:

If a level reduction of at least 10 dB is achieved with a sound mitigation measure all pile driving activities are classified as *Very low* according to the current Guidance [1].

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_06_BER_2E.DOCX: 23.08.2019

Thus, it becomes furthermore possible to calculate the virtual hammer energy also for measurements with noise mitigation measures, in that case, we take as a basis equation (4) with D=0, see Figure 5.

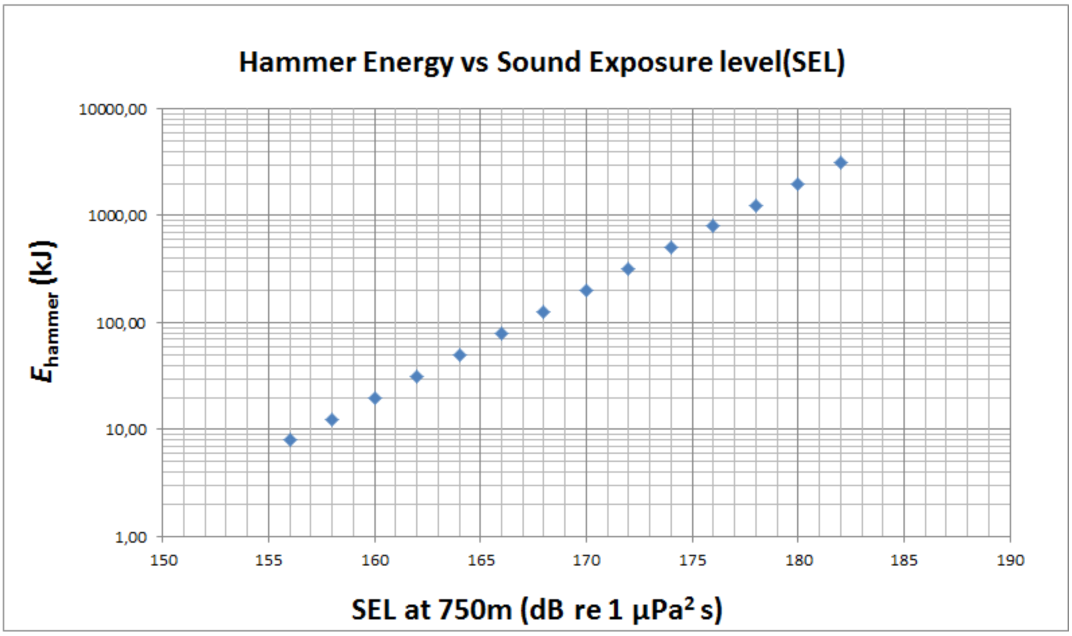


Figure 6: Sound exposure level *SEL* at 750 m, depending on the hammer energy, according to equation (4).

Remark 4:

In Germany the individual sound exposure levels SEL have to be below the precautionary level of 160 dB re 1 $(\mu Pa)^2 s$ at a distance of 750 m from the pile. Such values can be achieved with one or more noise mitigation measures applied. For mono-pile installations with large pile diameters it is often necessary to achieve a noise reduction of 20 dB to comply with the precautionary level [21] [22]). The virtual hammer energy E'_{hammer} of the precautionary level is lower than 25 kJ.

4.3.5 Calculatory determination of the Sound exposure Level from measurements, with and without noise mitigation measure, Distance correction

The sound exposure level at distance R_0 (= 750 m) from the centre of the pile can be estimated from a measurement at distance R using

$$L_E(R_0) = L_E(R) - 10\log_{10}\frac{R_0}{R}\ \text{dB} - \alpha(R_0 - R)$$

The value of α depends on sediment type and is inversely proportional to water depth H. For simplicity we assume a value for sand associated with the Borkum Riffgrund I site (see Figure 6), leading to

$$\alpha = \alpha_{\text{BR1}}\frac{H_{\text{BR1}}}{H}$$

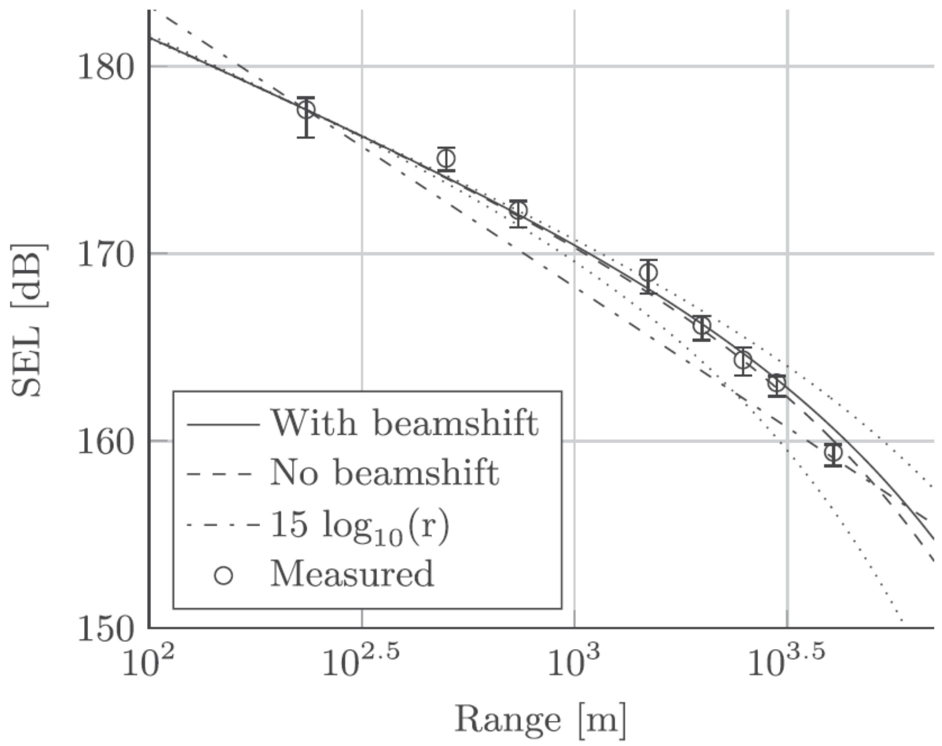


Figure 7: Sound exposure level *SEL* vs range for Borkum Riffgrund I; the decay rate α is 1.38 dB/km and the water depth is 27 m. From Lippert et al., 2018.

Using $\alpha_{\mathrm{BR1}} = 1.38\ \mathrm{dB/km}$ and $H_{\mathrm{BR1}} = 27\ \mathrm{m}$ (Lippert et al., 2018) gives

$$\alpha \approx \frac{0.037\ \mathrm{dB}}{H}$$

resulting in the following equation for L_E at 750 m

$$L_E(750\ \mathrm{m}) = L_E(R) - 10\log_{10}\frac{750\ \mathrm{m}}{R}\ \mathrm{dB} - (0.037\ \mathrm{dB})\left(\frac{750\ \mathrm{m} - R}{H}\right) \qquad (7)$$

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_06_BER_2E.DOCX: 23.08.2019

Appendix A

Experience with sound mitigation measures

Collection of data

Development of Noise Mitigation Systems in 2013 and 2014

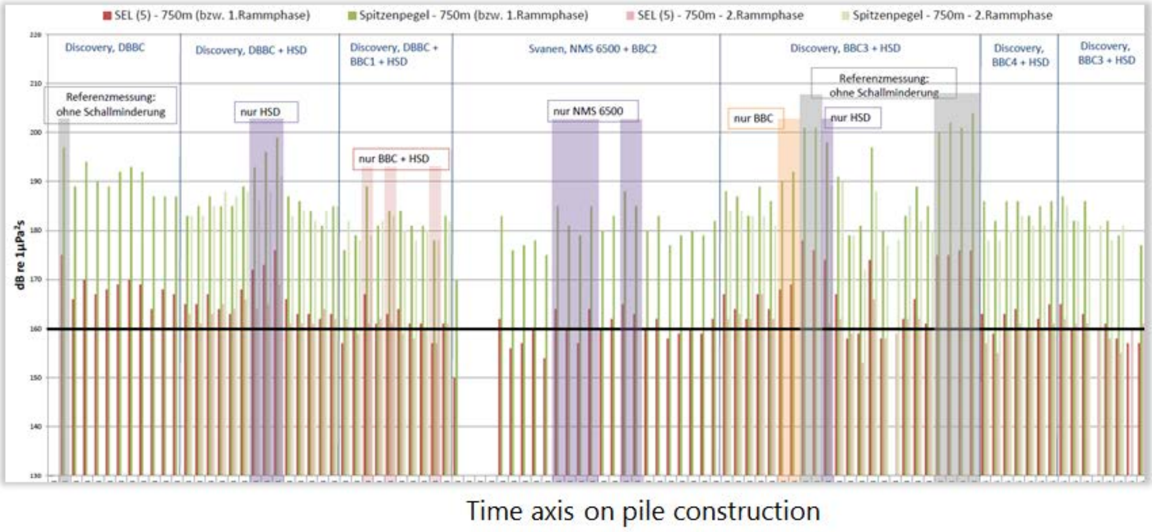


Figure 8: Bubble curtain, Cofferdam, Hydro-Sound Damper, IHC-NMS. Source: BSH
Project 2013 /2014 – multiple tests on noise mitigation.
(Diameter of 6 m, 20 -22 m water depth, Hammer 2500 S, medium sandy soil, max. energy deployed 2400 kJ.)

Noise Mitigation - Developments

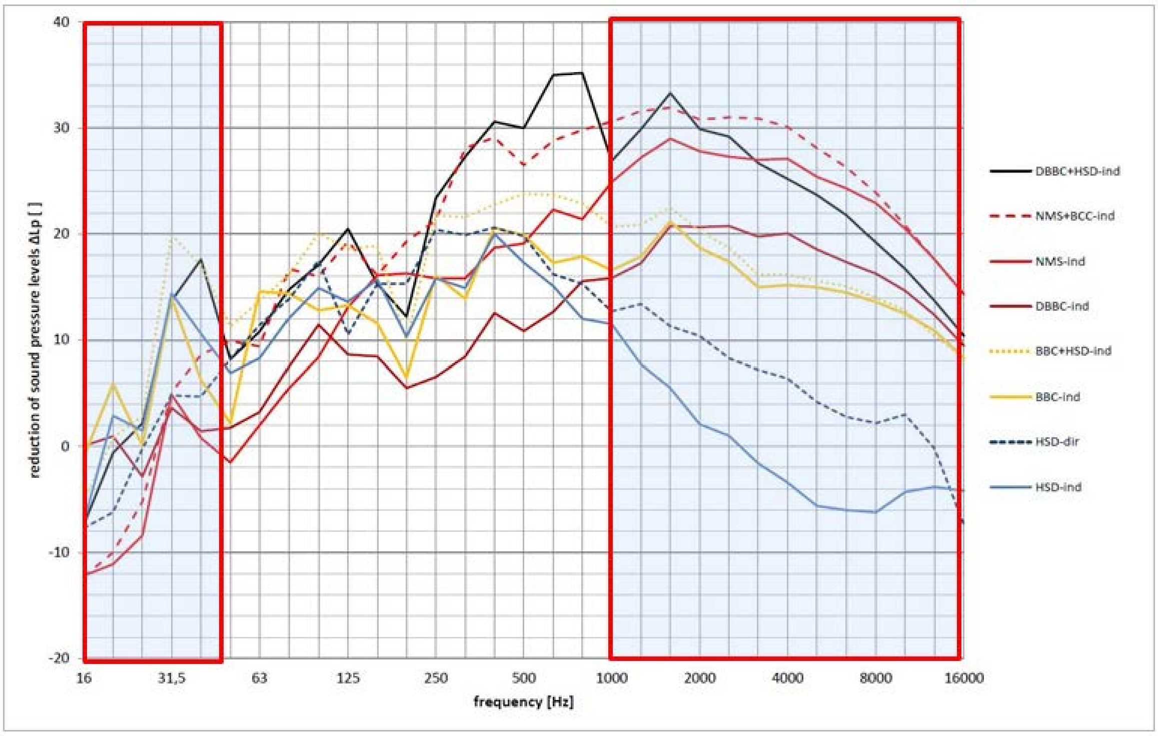
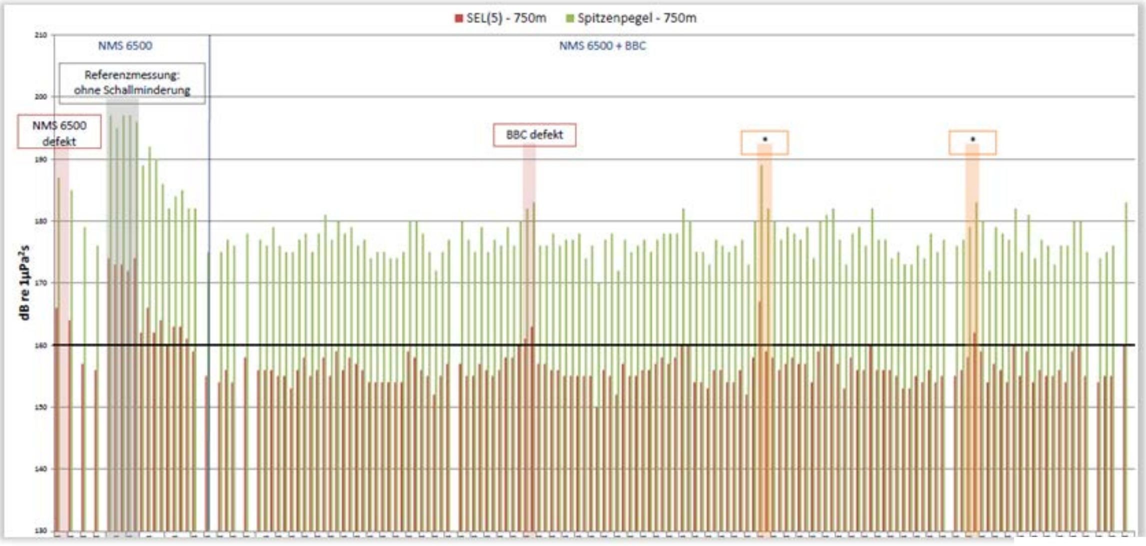


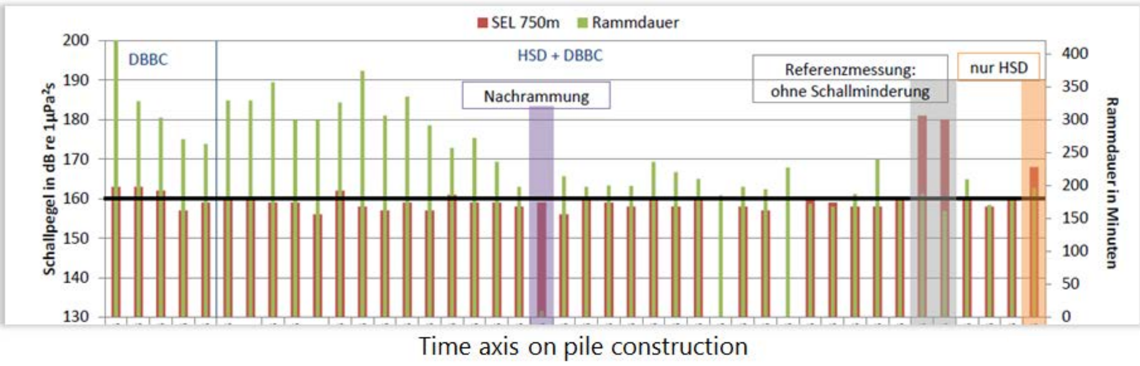
Figure 9: (D)BBC… (Double) Big Bubble Curtain, HSD… Hydro Sound Damper, NMS… IHC-NMS, dir/ind… direct/indirect method.

Noise Mitigation – Achievements since 2014



Source: BSH

Figure 10: The sound exposure level remains below the threshold Combined measures: Single Bubble Curtain + IHC-NMS
Diameter 6,5 m, 17-22 m water depth, Hammer S-2000, max. energy deployed 1300 kJ, penetration depth 22 m, medium sandy soil.



Source: BSH

Figure 11: Project in 2015: diameter 6,8 m, water depth 30 34 m, Hammer 3500S, max. energy deployed 2000 kJ, penetration depth 30 – 35 m, medium and partially dense sandy soil.

Project 1/ 2016

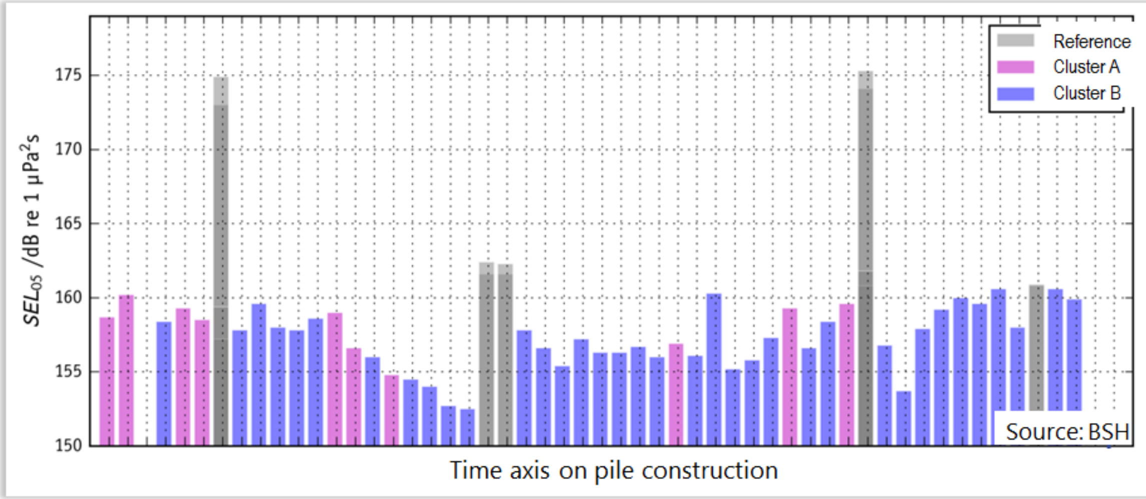


Figure 12: Project in 2016: diameter 6,7 m, water depth 27 -29 m, cluster A = dense sandy soil, cluster B = medium sandy soil, Hammer S-3000, S-4000 (one reference location for each hammer, penetration depth 27 to 30 m, max. energy deployed, 1900 kJ).

Project 2/ 2016

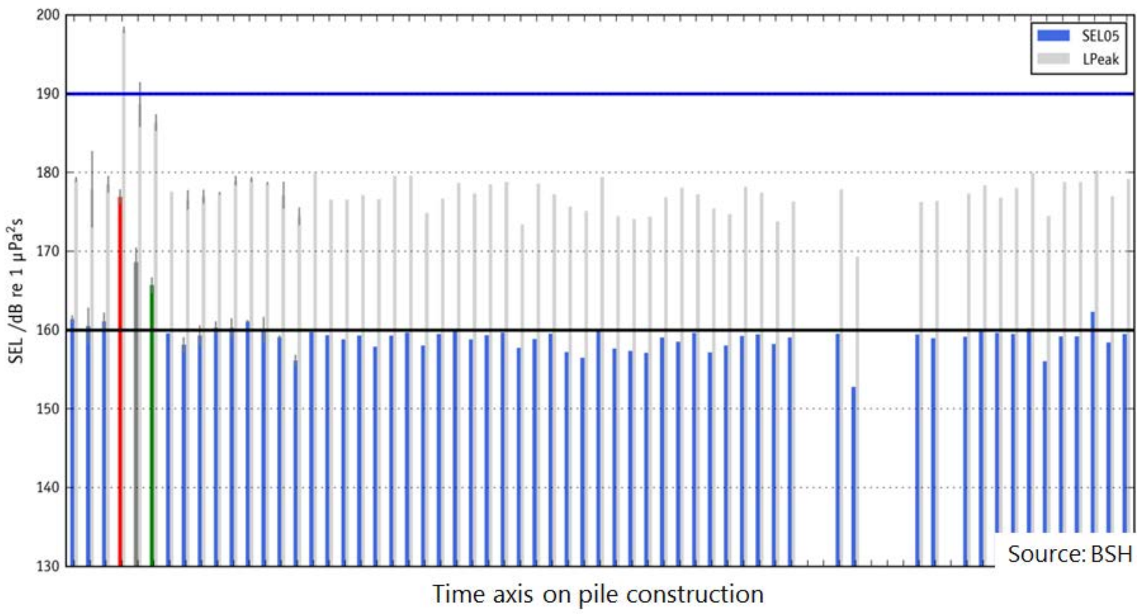


Figure 13: Project in 2016: diameter 7,8 m, water depth 39 -41 m, medium and dense sandy soil, penetration depth up to 41 m, Hammer S-4000, max. energy deployed 2000 kJ, noise mitigation systems in combination HSD and double bubble curtain.

Project 2017

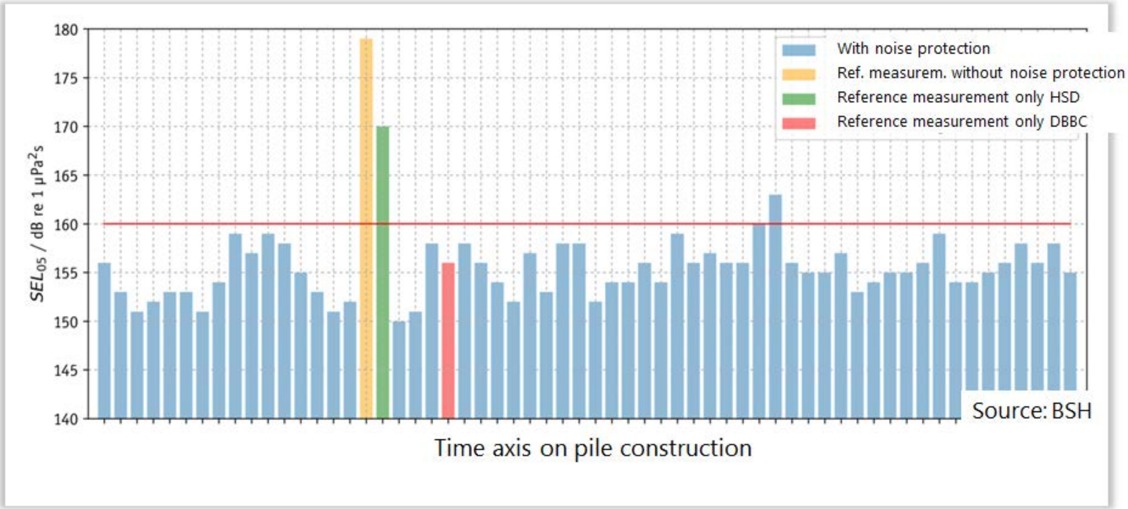


Figure 14: Project in 2017 diameter 7,8 m, water depth 23 -37 m, extreme soil conditions, penetration depth 27 m up to 43 m, Hammer S-4000, max. energy deployed 1900 kJ (three locations up to 2500 kJ), noise mitigation systems in combination HSD and double bubble curtain.

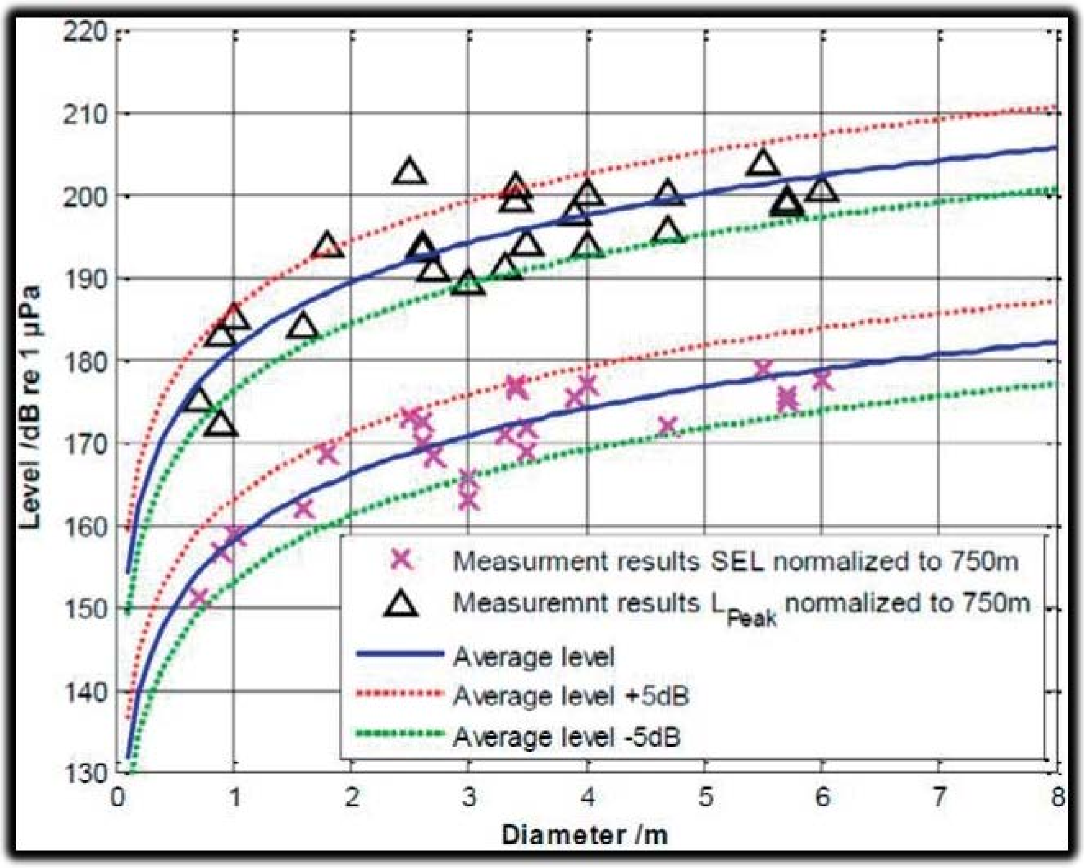


Figure 15: Citation from a framework for regulating underwater noise during pile driving Mathias H Anderson et al./ [24] and Itap [21]

Table 3: Overview of noise mitigation techniques and measured mitigation (in dB), and the number of piles that these techniques have been used for. Table modified after Bellmann et al.[21] from Anderson et al. [24]. Completed through experience of the BSH (state of the art).

noise mitigation technique	**∆SEL [dB]**	**Number of test (piles)**
Big bubble curtain (BBC) (>0.3 m³/(min*m), ballast chain inside, water depth <30 m)	10 < 13 < 15	> 150 (>300)
Double big bubble curtain (DBBC) (>0.3 m³/(min*m), ballast chain inside, water depth <30 m, distance between hoses >water depth	14 < 17 < 18	> 150 (>300)
Small bubble curtain (SBC) (Use air volume, hole configuration)	(5<) 10 < 14	2
Hydro Sound Dampers (HSD) (number and size of HSD elements)	8 < 10 < 13	>50
Noise mitigation screen (IHC-NMS)	13 < 15 < 18	>140
Cofferdam (Function of sealing gasket)	problem < 10 no problem ≥ 20	>10 (>10)
Combination of two BBC systems (DBBC + BBC)	15 < 16 < 19	>30(>70)*
Combination of IHC-NMS + BBC	19 < 22 < 25	>90
BBC (HTL) + HSD	15 < 16 < 20	>10
DBBC (Weyres) + HSD	14 < 16 < 22	2
DBBC + HSD	18 < 20 < 24	

Appendix B

Realistic pile driving scenario: measurement data and statistics

B1 Realistic pile driving scenario: measurement data and statistics

B1.1 Measurement data for the sound inventory

A large chunk of data is gathered within pile driving measurements. For the sound inventory OSPAR, for example, only aggregated data are forwarded, see enclosure. Statistical concepts are used to aggregate the data, see discussion in section B1.2.

For evaluating the sound propagation and the source level, it is important to be able to make a reliable statement on the data quality. One parameter is the signal-to-noise ratio or the interference distance of the desired signal to the background noise. For this, pile driving measurements are usually carried out with insensitive hydrophones in a measuring distance of 750 m. Often, if noise mitigation measures are taken, the desired signal is only recordable for the low frequencies in those measurements with insensitive hydrophones, see chapter B1.3. On the one hand, this is due to the hydrophone's sensitivity properties and, on the other hand, it has to do with the environmental situation, e.g. noise caused by ship traffic, construction site traffic and nature noise.

B1.2 A typical pile driving operation

For pile foundations the pile is driven into the soil by hammer strokes. In this process, some thousand strokes are needed, depending on the soil quality.

In Germany, underwater sound measurements are performed in distances of 750 m and 5000 m to the construction site during the noise construction work, such as the pile foundation (pile driving), see [8].

The measured data are analysed and the sound pressure behaviour is presented as the sound pressure level L_p, with the single-event sound pressure level L_E (SEL) and the peak sound pressure level L_{peak}. The following Figure B 1 shows the evaluation of a typical pile driving operation on a foundation. In this case, the time span *T,* for which the assessment parameters are calculated, is 30 s. For the single-event level the individual strokes are analysed.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_06_BER_2E.DOCX:27. 05. 2020

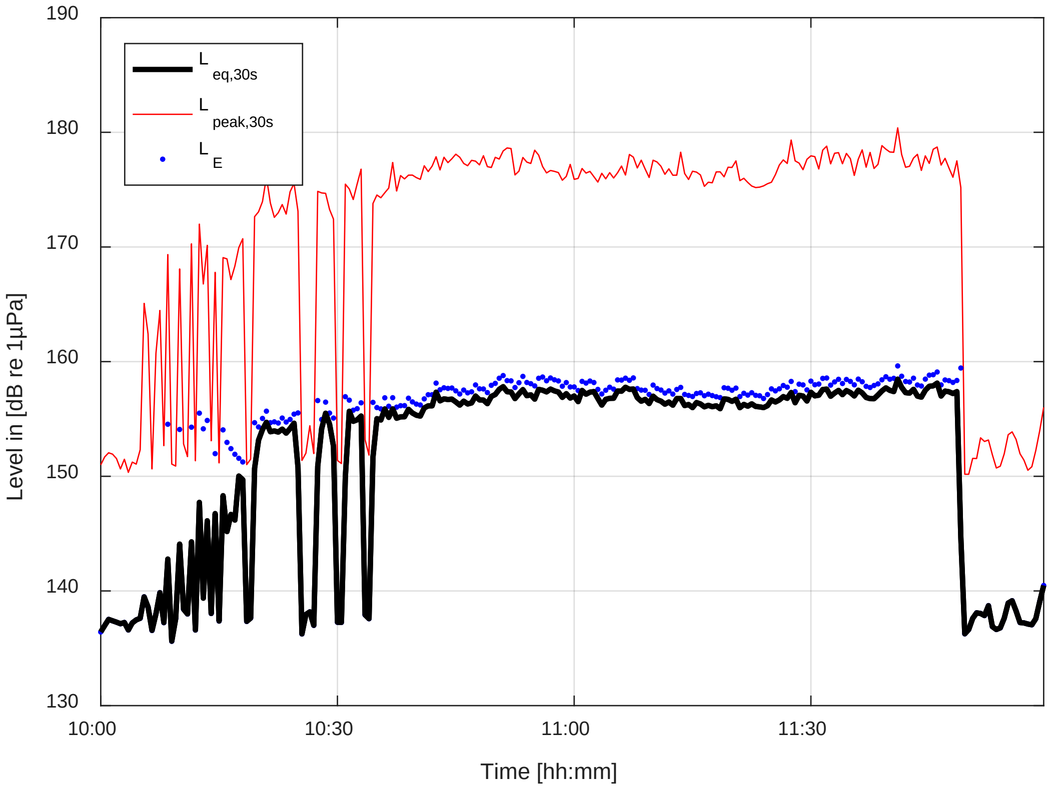


Figure B 1. Presentation of the sound pressure level L_p, of the single-event sound pressure level L_E and of the peak sound pressure level L_{peak}.

In addition, the broad-band levels (L_p, L_E, L_{peak}) have to be determined according to [8] related to the following statistics:

- $L_{90,30\ s}$
  30 s percentile level, exceeded in 90 % of the measurements for the entire duration
- $L_{50,30\ s}$
  30 s percentile level, exceeded in 50 % of the measurements for the entire duration
- $L_{05,30\ s}$
  30 s percentile level, exceeded in 5 % of the measurements for the entire duration

Assessment is made based on the percentile level $L_{05,30\ s}$ of the single-event sound exposure level L_E, measured in a distance of 750 m to the foundation. As described in [8] this value must not exceed the single-event level (SEL) of 160 dB (re 1 µPa^{2}s).

For the question „how well does the 5 % percentile level represent the maximum sound pressure level of the sound event?“ the percentile levels $L_{E01,30\ s}$ to $L_{E10,30\ s}$ were calculated using five examples (pile foundations of offshore wind farms). To better clarify the level difference ΔL_E between the 1 % percentile level $L_{E01,30\ s}$ and the 10 % percentile level $L_{E10,30\ s}$ the levels were adapted using the following equation:

$$\Delta L_E = L_{Ex,30\ s} - L_{E1,30\ s}\ , \qquad (8)$$

This means that the 1 % level was scaled to 0 dB. In Figure B 2 the X-axis shows the percentile levels $L_{E01,30\,s}$ to $L_{E10,30\,s}$, while the Y-axis shows the level difference ΔL_E. After analysing the five exemplary data sets the level difference between the 5 % percentile level $L_{E05,30}$ and the maximum level (at the 1 % percentile level $L_{E01,30\,s}$) is not more than $\Delta L_E \approx 0{,}5$ dB, and at most $\Delta L_E \approx 0{,}7$ dB for the 10 % percentile level.

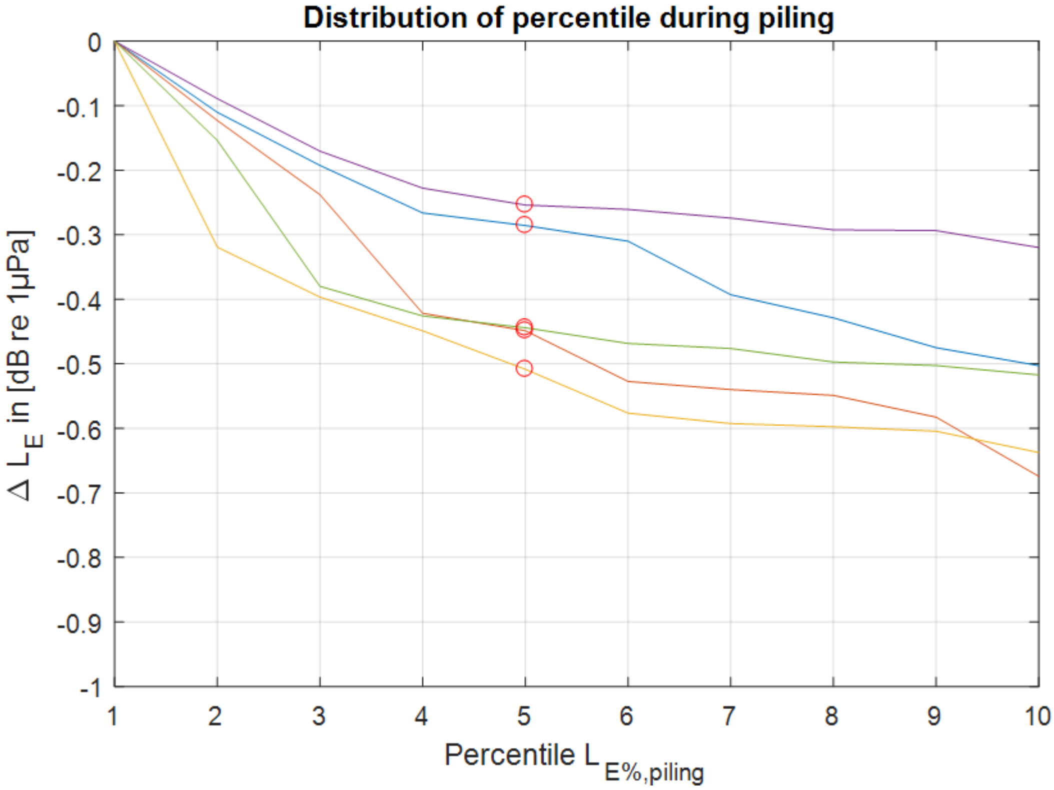


Figure B 2. Level difference ΔL_E between the 1 % percentile $L_{E01,30\,s}$ and the 10 % percentile $L_{E10,30\,s}$.

The determined level differences show that the 5 % percentile $L_{E05,30\,s}$ is suited for assessing the sound event. Further percentiles up to 10 % usually show only a minor level change, probably below the measurement accuracy.

B1.3 Signal-to-noise ratio

The signal-to-noise ratio (SNR) is a measure for the technical quality of the desired signal which is superimposed by a noise signal. In acoustic measurements the interfering signal is declared as background noise (BGN). The background noise is composed of the noise sources in the vicinity of the measuring site and of the inherent noise of the sensor (e.g. the hydrophone in water-borne sound).

For analysing pile driving noise acoustic measurements are carried out in a distance of 750 m according to [8]. Before and after the actual pile driving operations the hydrophone will also record the background noise. In Figure B 3 sound pressure levels in third-octave bands are given for the background noise and for the pile driving process using a pile driving situation with applied noise mitigation measure as an example. A short time span of ca. 10 s was analysed.

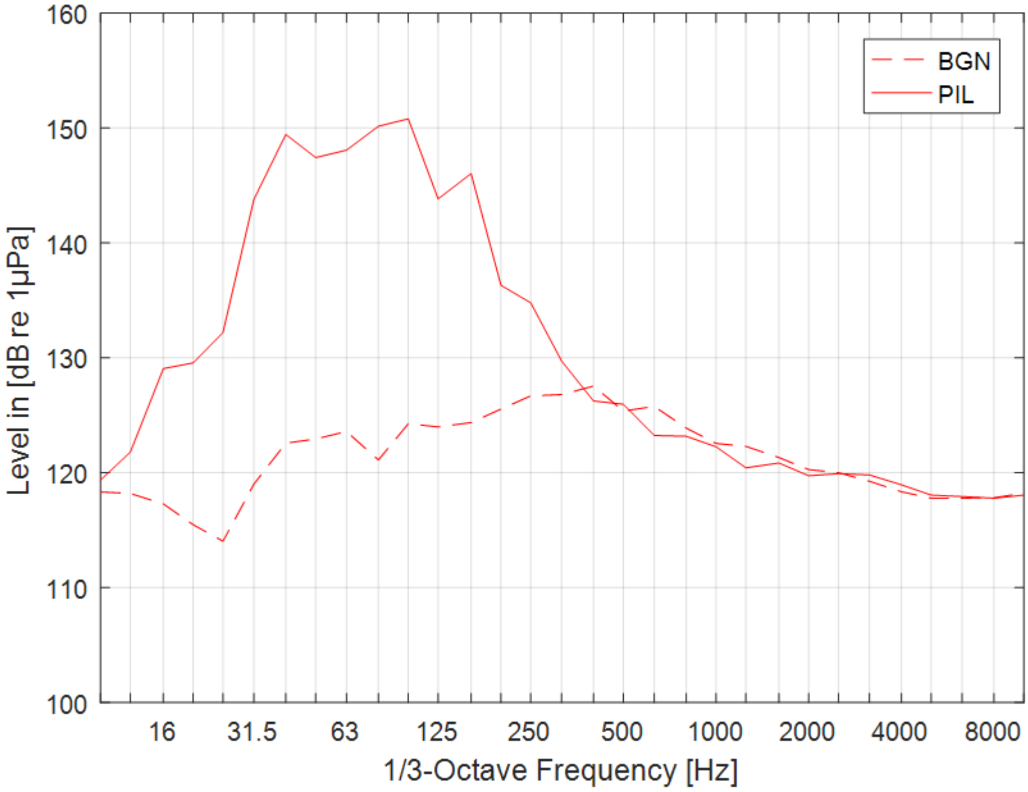


Figure B 3. Example sound pressure levels in third-octave bands for the background noise (BGN) and the pile driving operations (PIL) –pile driving situation with applied noise mitigation measure.

The energy induced to the water by the piling impulses increases waterborne sound spectrally in a frequency range below 400 Hz; in this frequency range the analysed sound pressure levels stand out from the background noise by up to 25 dB. Above 400 Hz the levels of pile driving noise and background noise are nearly identical. This might be due to the selected hydrophones or due to ship traffic, environmental noise etc. For propagation calculations, however, this means that there is no valid statement on the source characteristics of the pile driving sound event for frequencies above the maximum desired frequency (in the present example higher than 400 Hz).

Remark 8:

For pile driving situations without noise mitigation measure there usually is a sufficient „signal-to-noise“ ratio.

The SNR is large enough to identify and analyse the pile driving noise, still, however, the significance of the measurements for high-frequency sound contributions is not always ensured.

MÜLLER-BBM

Müller-BBM GmbH
Niederlassung Hamburg
Bramfelder Str. 110 B / 3. Stock
22305 Hamburg

Telephone +49(40)692145 0
Telefax +49(40)692145 11

www.MuellerBBM.de

Dr. rer. nat. Andreas Müller
Telephone +49(40)692145 19
Andreas.Mueller@mbbm.com

2020-03-19
M146361/12 MLR/APK

Verteiler

Bundesamt für Seeschifffahrt und Hydrographie
Frau Maria Boethling
Frau Carina Juretzek
Bernhard-Nocht-Straße 78
20359 Hamburg

Dual level statistics (SEL und L_{peak})

Note No. M146361/12

1 Situation

Approvals for offshore wind farms given by the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH) include mandatory deployment of noise abatement systems in incidental provisions to minimise the noise immission values from pile-driving activities. The monitoring of the construction phase also includes measurements of underwater noise according to the measuring instructions by BSH (BSH, 2011, 2013) [2], [3] and since 2017 according to the ISO 18406:2017 [4] and the DIN SPEC 45653:2017 [5].

To evaluate the effectiveness of the noise reduction measures, measurements under deployment of the noise abatement systems and so-called reference measurements without deployment of noise abatement systems are carried out and evaluated. The sound exposure level (SEL = L_E) and the peak sound pressure level (L_{peak}) are considered as the relevant metrics. Based on the statistical analysis of measurements at a distance of 750 m with different pile-driving conditions and configurations of abatement systems, it was examined in 2014 how these two level-quantities are related to each other [1].

This document summarizes selected points from the above analysis to make the results available for the revision of the TG Noise guidance.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_12_NOT_1E.DOC : 19. 03. 2020

2 References

[1] Müller-BBM, Notiz M100004/49 (1D), Prüfung der dualen Pegelstatistik (SEL und L_{peak}), 17.13.2014, (BSH internal note, not publicly available)

[2] A. Müller, C. Zerbs: “Measuring instruction for underwater sound monitoring – Current approach with annotations, Application instructions” BSH (Bundesamt für Seenschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2011

[3] A. Müller, C. Zerbs: “Offshore Wind Farms Measuring Specification for the Quantitative Determination of the Effectiveness of Noise Control Systems” BSH (Bundesamt für Seenschifffahrt und Hydrographie, German Federal Maritime and Hydrographic Agency), 2013

[4] ISO 18406:2017-04: Underwater acoustics – Measurement of radiated underwater sound from percussive pile driving

[5] DIN SPEC 45653:2017-04: Offshore wind farms – In-situ determination of the insertion loss of control measures underwater

3 Level statistics

The following offshore wind farm projects were considered for the statistical evaluation.

- Borkum West II
- DolWin alpha
- DanTysk
- Nordsee Ost
- HelWin
- DolWin
- Baltic II
- Amrumbank West

The evaluation includes analyses of the measurements for the projects mentioned above and carried out by ITAP and Müller-BBM. The evaluation shows that the pile driving process and the measured sound pressure at a distance of 750 m from the ramming location depend on various variables. The results also reveal variations regarding the implementation of single noise abatement systems. Variations found depending on the pile driving process as well as noise abatement systems are considered in the following when applying the dual evaluation criterium.

From the level statistics of the individual analyses, the 5% percentiles were taken for the sound exposure level SEL and the peak level Lpeak and entered in Table 1 together with the configurations.

4 Results

The following diagrams show the relative frequency of the difference between the sound exposure level SEL and the peak level Lpeak. The noise abatement system, foundation, pile energy and in case of bubble curtain systems airflow per minute per meter of air hose were examined as potentially critical variables. The latter was analyzed only when using a simple Large Bubble Curtain (BBC).

4.1 Total sample sizes until 2014

A statistical analysis of each 126 SEL- and L_{peak}-level values (from 126 different series of measurements) considered is shown in Table 1.

Table 1: Statistics of the level classes of the full sample size (using the 5 % percentile of the SEL and the L_{peak}).

	SEL 5 % [dB]	L_{peak} 5 % [dB]	ΔL [dB]
Average value [dB]:	166.9	189.2	22.4
Sample size [1]:	126	126	126
Standard deviation [dB]:	5.0	5.4	2.0
Min [dB]:	156.5	177.7	16.4
Max [dB]:	179.1	202	27.1

The mean value of the difference between the 5 % percentile of the SEL and the 5 % percentile of the L_{peak} from a sample size of 126 measurements is 22.4 dB. A standard deviation of 2.0 dB was calculated.

The following graph (Figure 1) shows the relative frequency of the level differences (calculated from all level differences between the 5% percentile of the SEL and the 5% percentile of the L_{peak}).

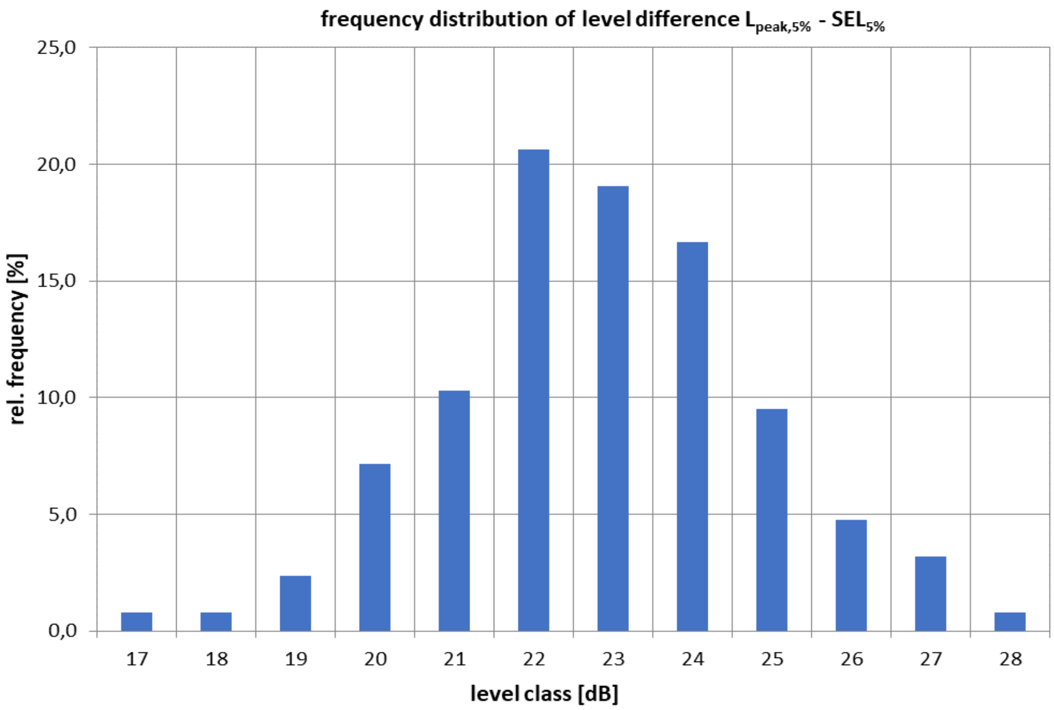


Figure 1: Relative frequency of the level classes of all evaluated difference values.

The relative frequency of the level differences results in a maximum at around 21% for the 22 dB level class.

4.2 Influence of the type of foundation

As a further variable, the influence of the type of foundation is analysed. A distinction is made between the installation of a monopile, a tripod, and a jacket foundation for wind mill or platform.

A statistic of the level differences from 5%-percentile of the SEL and 5%-percentile of the L_{peak} is shown in Table 2.

Table 2: Statistics of level differences for the installation of different foundations.

Foundation	Jacket	Monopile	Tripod
Average value [dB]:	23.2	20.3	22.7
Sample size [1]:	26	23	77
Standard deviation [dB]:	1.5	1.5	1.9
Min [dB]:	20.8	16.4	17.7
Max [dB]:	27	22.8	27.1

For the installation of different foundations, the relative frequency of the level differences between 5%-percentile of the SEL and 5%-percentile of the L_{peak} is shown (Figure 2).

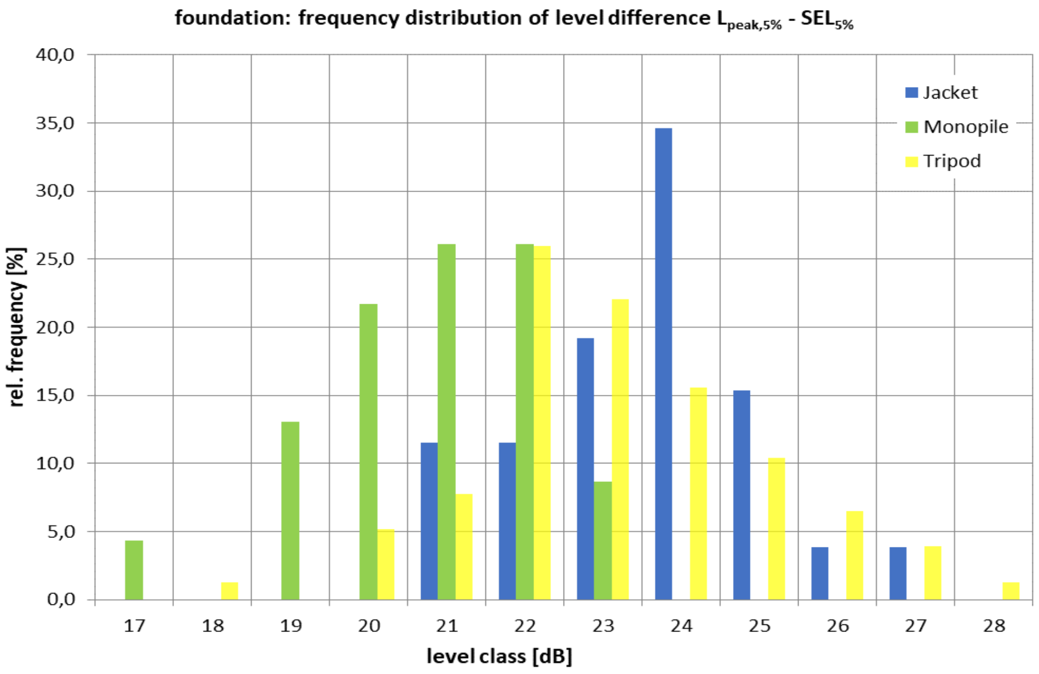


Figure 2: Relative frequency of level classes when installing different foundations.

When looking at Figure 2, the lowest level of the level class distribution can be found for the installation of a monopile. The difference between the level class distribution for "jacket" and "tripod" is small and can only be determined by the maxima.

4.3 Influence of the pile energy

The influence of the pile driving energy on the level difference between 5%-SEL and 5%-L_{peak} was investigated using classes of maximum pile driving energy. For this purpose, maximum ram energies of 300-700 kJ, 701-1000 kJ, 1001-1500 kJ and 1501-2200 kJ were considered.

Statistics on the level differences between 5%-SEL and 5%-L_{peak} are shown in Table 3.

Table 3: Statistics on level differences during pile driving with different maximum pile driving energy.

Max. pile driving engergy [kJ]	**300-700**	**701-1000**	**1001-1500**	**1501-2200**
Average value [dB]:	20.7	21.7	22.7	21.3
Sample size [1]:	6	29	57	11
Standard deviation [dB]:	2.0	2.0	1.8	2.0
Min [dB]:	17.7	16.4	19.3	19
Max [dB]:	23.4	25.9	27.1	24.7

With increasing energy class, the mean value of the level differences between 5%-SEL and 5%-L_{peak} increases. In the highest energy class, the mean value decreases again. An increase in the average value from 300-700 kJ to 1001-1500 kJ of 2 dB can be observed.

For piling with different maximum pile energy, the relative frequency of the level cassettes of the difference between 5%-SEL and 5%-L_{peak} is shown (Table 3). The maximum pile energy was divided into level classes.

The trend in the data is in the magnitude of the standard deviation for each level class.

However, it is important to mention here, that by 2014 the different types of impact hammers were not evaluated as a separate variable. This is part of ongoing analyses.

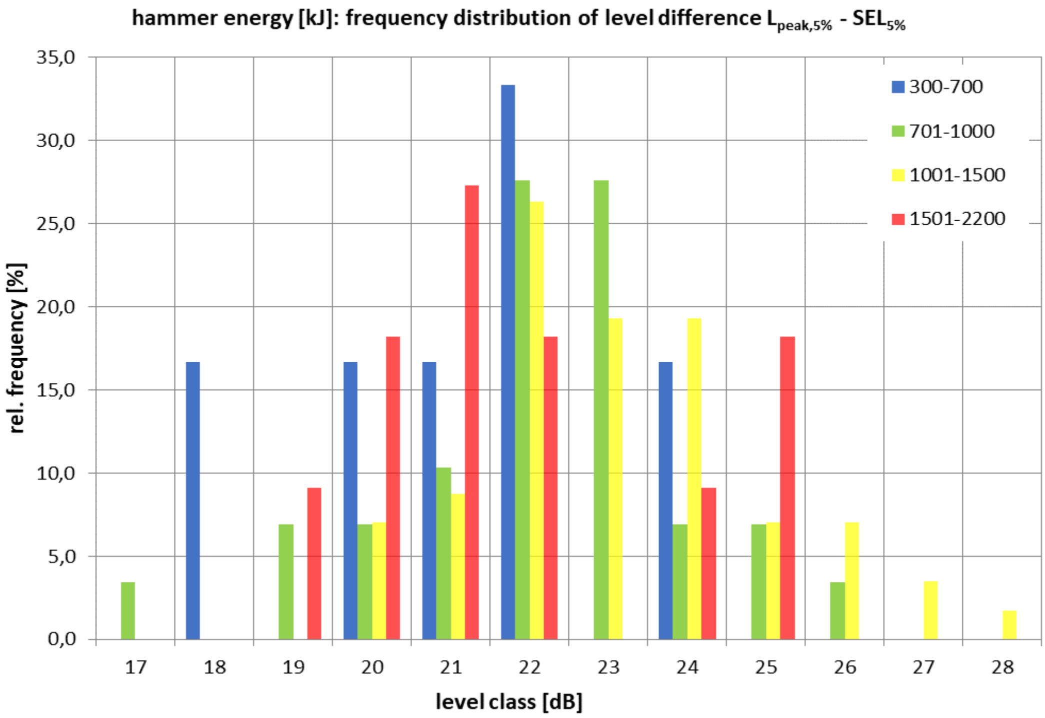


Figure 3: Relative frequency of level classes during pile driving with different maximum pile driving energy.

When looking at Figure 3, it becomes clear that the maxima of relative frequency can be assigned to similar level classes (21 dB and 22 dB). A comparison of the relative frequencies between the energy classes reveals a higher level of level classes for energy class 1001-1500 kJ than for energy class 300-700 kJ.

5 Discussion

Due to the high diversity of variables, the sample size for individual descriptors is sometimes quite small. Results with a sample size < 5 were not presented. A cross-project analysis of key figures also bears the risk of misinterpretations.

In addition, the analysis was carried out according to selected variables while neglecting some more variables. A correlation of all variables was thus not considered.

An influence of noise abatement systems on the difference between the SEL and the L_{peak} is presumed.

An influence of the foundation type on the level difference between SEL and L_{peak} is also possible. Driving a pile to install a tripod or a jacket foundation for platform has a greater level difference than when driving a monopile. A correlation between type of foundation and diameter of the pile is documented and can be one of the possible reasons for diverging level differences.

The total sample size has a spread of 10.7 dB and a standard deviation of 2.0 dB for the difference between SEL and L_{peak}. These measurement and prediction uncertainties must be accepted in individual cases.

Dr. Andreas Müller

MÜLLER-BBM

Müller-BBM GmbH
Niederlassung Hamburg
Bramfelder Str. 110 B / 3. Stock
22305 Hamburg

Telephone +49(40)692145 0
Telefax +49(40)692145 11

www.MuellerBBM.de

Dr. rer. nat. Andreas Müller
Telephone +49(40)692145 19
Andreas.Mueller@mbbm.com

2020-04-27
M146361/13 Version 3 MLR/WNR

Pile-driving

Classification and assessment of impulsive noise with and without noise mitigation measures

Exposure Index

Report No. M146361/13

Client:	Bundesamt für Seeschifffahrt und Hydrographie Dr. Maria Boethling Carina Juretzek Bernhard-Nocht-Straße 78 20359 Hamburg
Consultant:	Dr. rer. nat. Andreas Müller Thierry Maquil Ramona Eigenmann Carina Juretzek
Total number of pages:	27 pages in total, thereof 27 pages of text.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_13_BER_3E.DOCX 30.03.2020

Müller-BBM GmbH
Niederlassung Hamburg
HRB Munich 86143
VAT Reg. No. DE812167190

Managing directors:
Joachim Bittner, Walter Grotz,
Dr. Carl-Christian Hantschk,
Dr. Alexander Ropertz,
Stefan Schierer, Elmar Schröder

Table of Contents

1 Abstract

Noise pollution of the world's oceans has been of substantial public interest in recent years. Marine scientists continue to build our knowledge base by steadily/regularly recording underwater noise, attempting to assess the effects of anthropogenic noise input (such as ship noise and construction noise) in the marine environment. National legislators and international organisations are endeavouring to limit noise emission or immission by regulatory means where necessary. The EU Marine Strategy Directive classifies sound as impulsive and continuous sound events. A noise registry has been developed for impulsive noise sources at ICES, providing a basis for assessments in the OSPAR and HELCOM regions. Member states report their sound events annually. An active reduction of impulsive noise emissions can be mainly achieved by means of noise abatement systems. Current improvements in the noise quantification will consider the up to now non-mandatory information of the noise registry on noise mitigation measures. In the present work, actual data of the noise registry is used to perform an analysis on the effect of sound mitigation measures. It depicts the consequences for the classification and the current assessment with and without application of noise abatement systems.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_13_BER_3E.DOCX:30.03.2020

2 Relevant Documents

[1] Thiele, R & Schellenstede, G (1982): Standardwerte zur Ausbreitungsdämpfung in der Nordsee. FWG-Bericht 1980-7, Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik

[2] Dekeling, R; Tasker, M; Van der Graaf, S; Ainslie, M; Andersson, M; André, M; Borsani, J; Brensing, K; Castellote, M; Cronin, D; Dalen, J; Ferreira, M; Folegot, T; Leaper, R; Pajala, J; Redman, P; Robinson, S; Sigray, P; Sutton, G; Thomsen, F; Werner, S; Wittekind, D; Young, J; Zampoukas, N; (2014): Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications http://dx.doi.org/10.2788/27158

[3] Merchant, N; Faulkner, R & Martinez, R. (2017) Marine Noise Budgets in Practice. Conservation Letters., Volume 11, Issue 3 https://doi.org/10.1111/conl.12420

[4] de Jong, C; Heinis, F; von Benda-Beckmann, S & Binnerts, B. (2019-12) CEAF in SEANSE case studies, Impact of piling for wind farms on North Sea harbour porpoise population. TNO report, TNO 2019 R11563

[5] Tougaard, D & Dähne, J. (2017) Why is auditory frequency weighting so important in regulation of underwater noise? The Journal of the Acoustical Society of America 142, EL415 https://doi.org/10.1121/1.5008901

[6] DIN SPEC 45653:2017-04: Offshore wind farms –
In-situ determination of the insertion loss of control measures underwater

[7] ISO 18406:2017-04: Underwater acoustics –
Measurement of radiated underwater sound from percussive pile driving

[8] Bundesamt für Seeschiffahrt und Hydrographie (BSH) 20191002_DEsubmission_NoiseRegisterTemplate_NavalNoise_Explosion_Pile Driving, Events 2018

[9] Müller-BBM 2015: Report M100004/54 unpublished

[10] Alain Norro, Andreas Müller, Michael A. Ainslie, Nathan Merchant, Russell Leaper Müller-BBM Report No. M146361/06, Revision of the “TG Noise monitoring guidance“ Sound exposure levels of pile-driving noise with/without noise protection measures, Background paper, Sep. 2019

[11] BMU Schallschutzkonzept, Konzept für den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee, 2013

3 Sound propagation under different scenarios in the German EEZ of the North Sea

In this study different scenarios were examined. Figure 1 and Figure 2 show the comparison of measurements at three wind farms constructed in 2018, where the average sound levels regarding the metric SEL were below a value of 160 dB (Fig. 1) with the virtual non-mitigated case (Fig. 2).

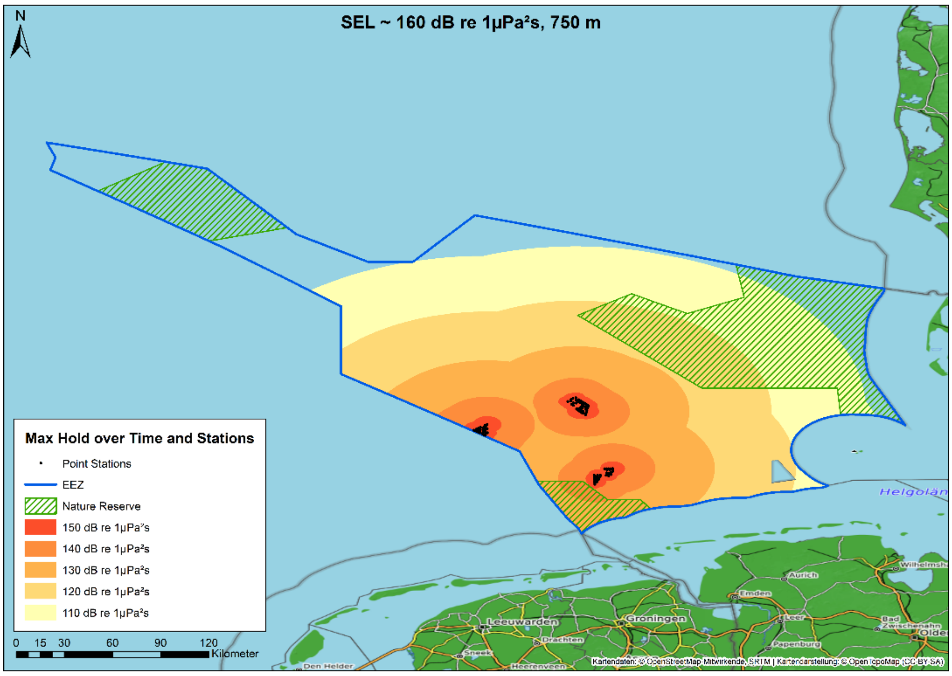


Figure 1: Max hold over time and stations (average Sound Exposure Level of 160 dB re 1 µPa²s) at 750 m distance to piling location for different sound radii from an empirical propagation model.

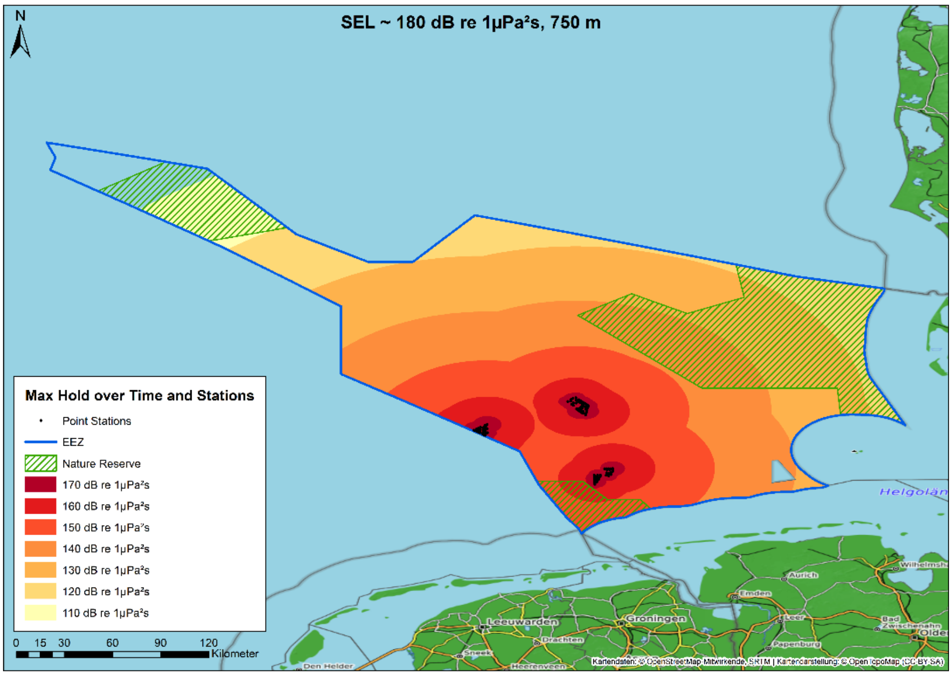


Figure 2: Max hold over time and stations (virtual non-mitigated: average Sound Exposure Level of 180 dB re 1 µPa²s) at 750 m distance to piling location for different sound radii from an empirical propagation model.

The sound insulation effect was estimated at approx. 20 dB. Figure 1 and Figure 2 show the areas of the German EEZ (North Sea) affected by impact sound in the period considered. Obviously, the noise abatement systems lead to a significantly reduced sound impact. These calculations were performed with a simple established empirical propagation model according to Thiele [1]. The propagation is conservative for long distances and will be able to give slightly reduced effective radii due to higher losses. For this study, these calculations are sufficiently accurate, as especially the relative comparisons and methodologies will be considered.

4 OSPAR: Impact Indicator Assessment

4.1 Introduction and procedure

The focus of the indicator is on the large scale, cumulative exposure to noise disturbance. The acoustic metrics are different for different sound events like explosion, seismic and pile-driving, see TSG Guidance [2], and cannot be easily compared. Following a proposal by Merchant et al. [3], an exposure index was introduced. This procedure was discussed at EIHA 2019 and was defined for the assessment. Roughly it comprises the steps described below.

A. Define management area (MA) for indicator species.

B. Use the population density as % of population within MA.

C. Determine the noise pressure map of assessment period.

D. Calculate a risk map using B and C.

E. Calculate the exposure curve using the risk map.

F. Define an Exposure Index (EI).

In the present study the area of the German EEZ (North Sea) was chosen as MA. As discussed in the methodology under development by TG-Noise and at the ongoing assessment of the indicator for OSPAR in the framework of the ICG-Noise population or habitat may be used alternatively under B. Herewith an example based on the habitat approach is conduted. In the first step, the entire EEZ is to be habitat of harbour porpoise, which is comparable to the population approach with an equal distribution of harbour porpoise density, which was e.g. considered in the TNO study. [4]. This approach automatically results in a direct comparability of the risk map and the noise pressure map. In the present study, exclusively pile-driving events of the year 2018 have been considered. Figure 3 schematically depicts the procedure used in the present work.

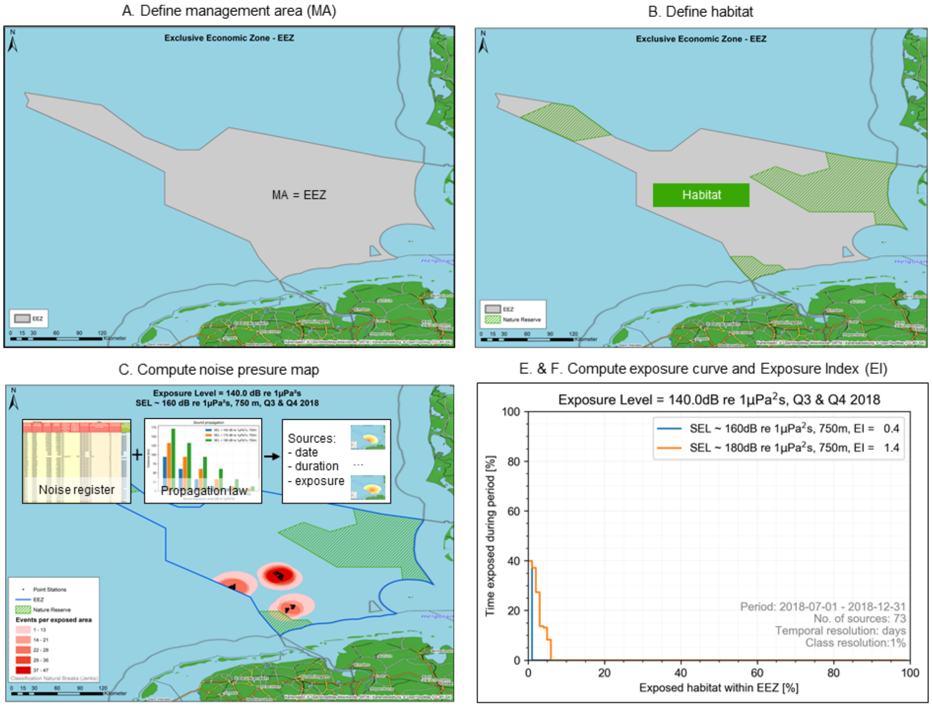


Figure 3: Schematic description of the procedure used in the present work.

Figure 4 and Figure 5 show the events per area exposed to 140 dB re 1 µPa²s for Sound Exposure Levels of 160 dB re 1 µPa²s, at 750 m distance to the piling location, respectively 180 dB re 1 µPa²s, at 750 m distance (virtual non-mitigated case). The images are comparable to the risk maps proposed by Merchant et al. [3], since the habitat approach relies on a uniform distribution.

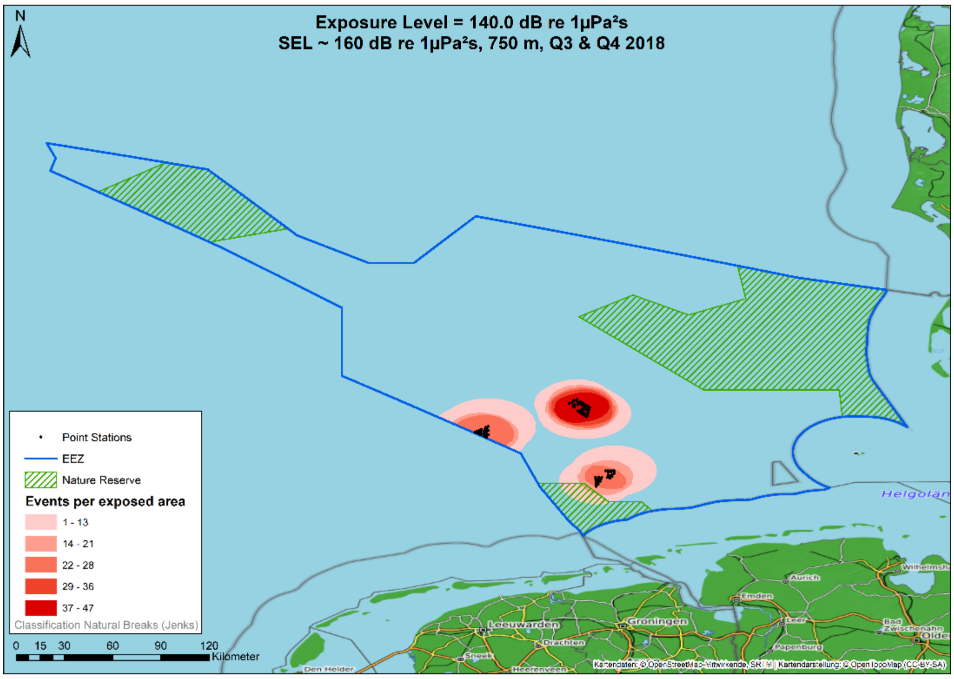


Figure 4: Events per exposed area (exposure level = 140 dB re 1 µPa²s) for a period of half a year at an average SEL of 160 dB re 1 µPa²s at 750 m distance.

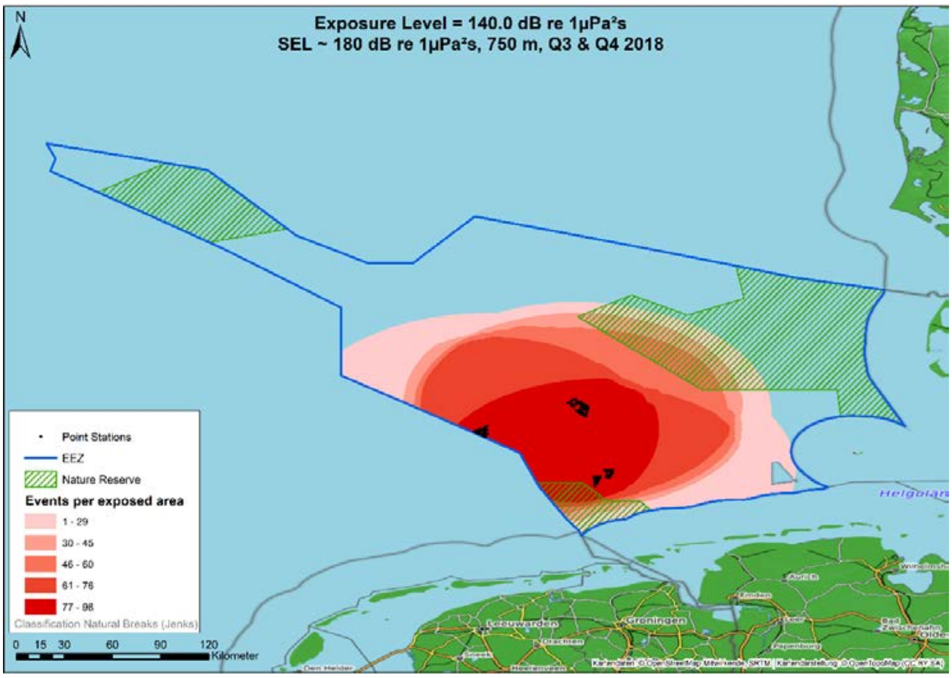


Figure 5: Events per area exposed to 140 dB re 1 µPa²sfor a period of half a year at an average SEL of 180 dB re 1 µPa²s at 750 m distance to piling location.

The exposure curve and the exposure index are exemplary as shown in Figure 6 for the second half of the year 2018.

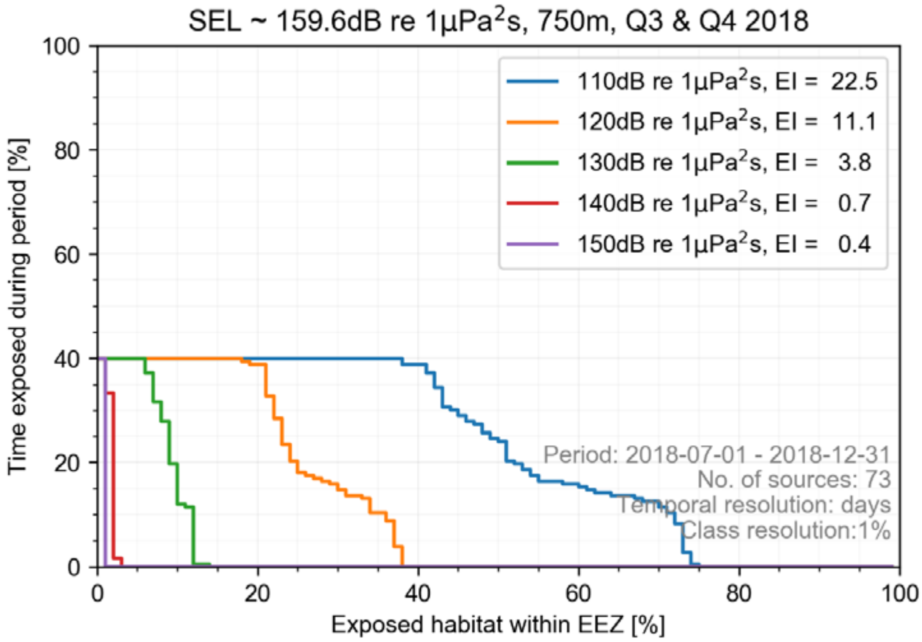


Figure 6: Exposure curve and Exposure Index for a period of half a year at an average SEL of 159.6 dB re 1 µPa²s at 750 m distance to piling location, at 73 pile-driving events per day for sound radii >110 dB to >150 dB. The class resolution of 1 % means that one hundredth of an area step is considered.

Notes on Figure 6:
The following information can be inferred from the exposure curves. 40 percent of the total days (here pulse block (1% class) days are shown) are exposed to a part of the habitat and if an equal distribution of the population were assumed, this part of the population is also influenced. Exemplary acoustic threshold values were included in the analysis. By decreasing the threshold, the Exposure Index (since the exposed area is increasing) increases.

The following chapters discuss the influence of individual parameters such as time, space, but also sound mitigation measures (insertion loss) on the Exposure Index. An arc is drawn to the impulsive noise register.

4.2 Influence of the temporal resolution and investigation time on the Exposure Index

4.2.1 Temporal resolution

With the previous representations, the effect of one event per day was examined. The temporal sound exposure may significantly differ for the type of impulsive noise event, while explosions are very short-time, pile-driving may last for up to three hours a day, seismic surveys possibly for the whole day. Figure 7 illustrates the influence of the temporal resolution on the time exposed during the period using a limited time period.

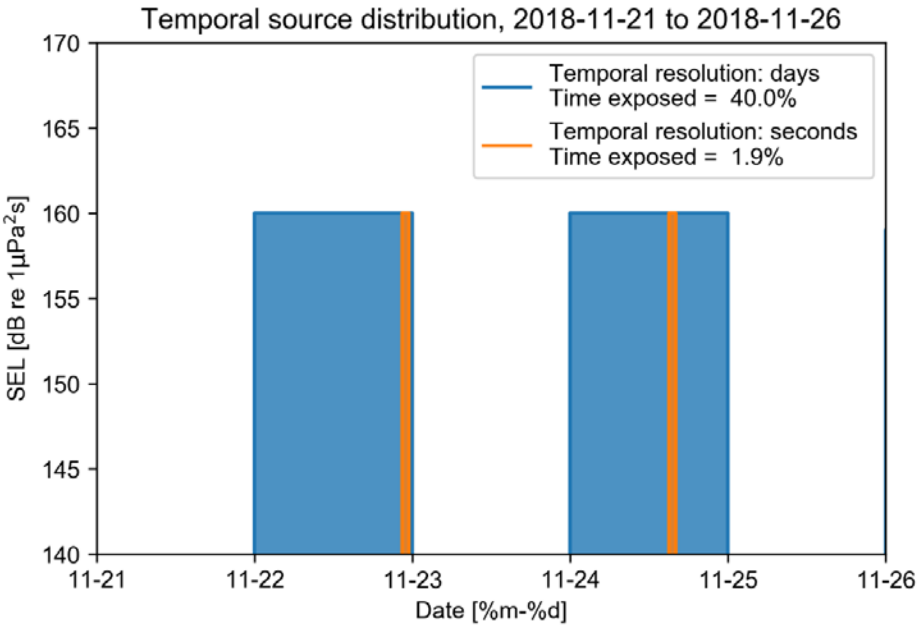


Figure 7: Demonstration of temporal resolution influence on time exposed during period, period is limited to 5 days with two pile-driving.

Figure 8 shows an example of the Exposure Index for a classification per day compared to a classification per second. In the present case the overall time period is half year (third and fourth quarter of 2018).

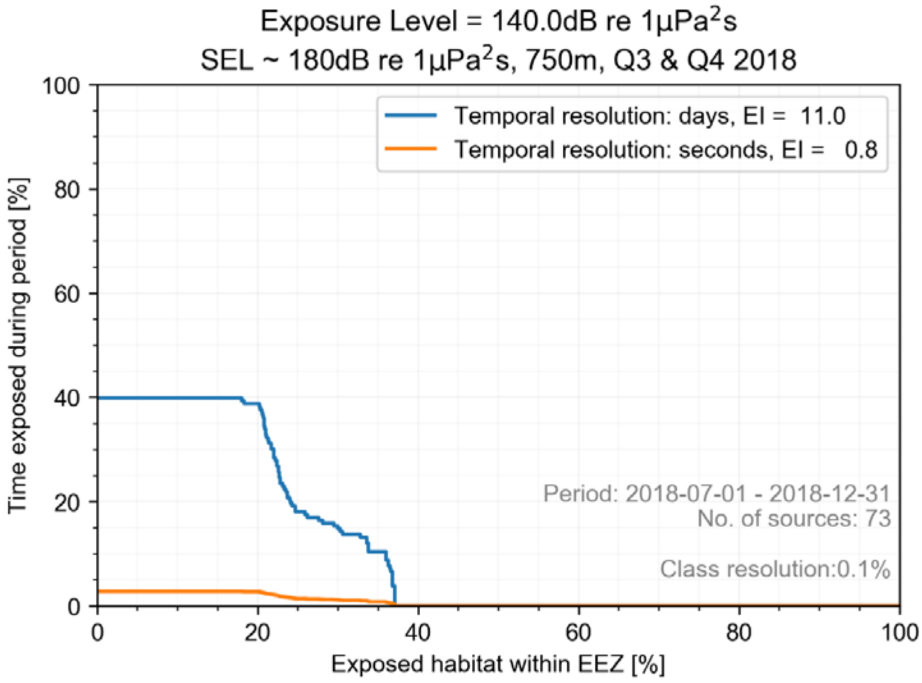


Figure 8: An example of the Exposure Index for a classification per day compared to one per second.

The analysis shows that the Exposure Index is highly dependent on its temporal resolution.

4.2.2 Investigation time

Usually annual and seasonal temporal analyses are performed. Figure 9 and Figure 10 show the entire second half of 2018 and the third and fourth quarters separately. As there were more events in the third quarter than in the fourth quarter, the Exposure Index of the third quarter shows the highest value.

Remark:
In order to enable an absolute evaluation for effects yet to be defined, a reference period (e.g. monthly, quartally or annually) for the Exposure Index is required; for comparative studies, this Exposure index should already be used now. Suitable threshold values must be specified in future.

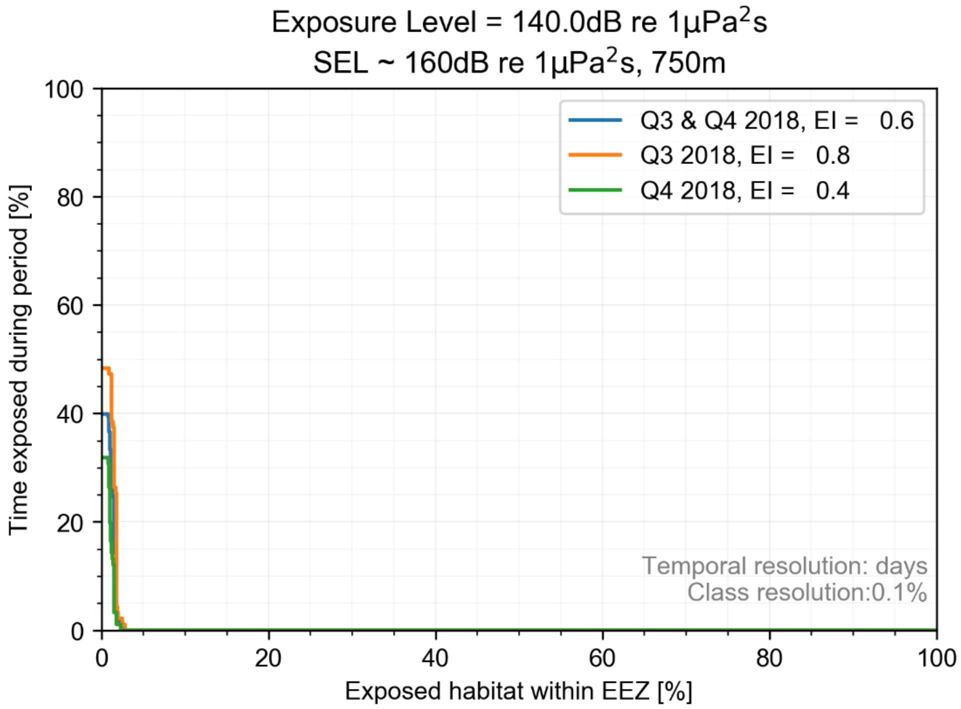


Figure 9: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

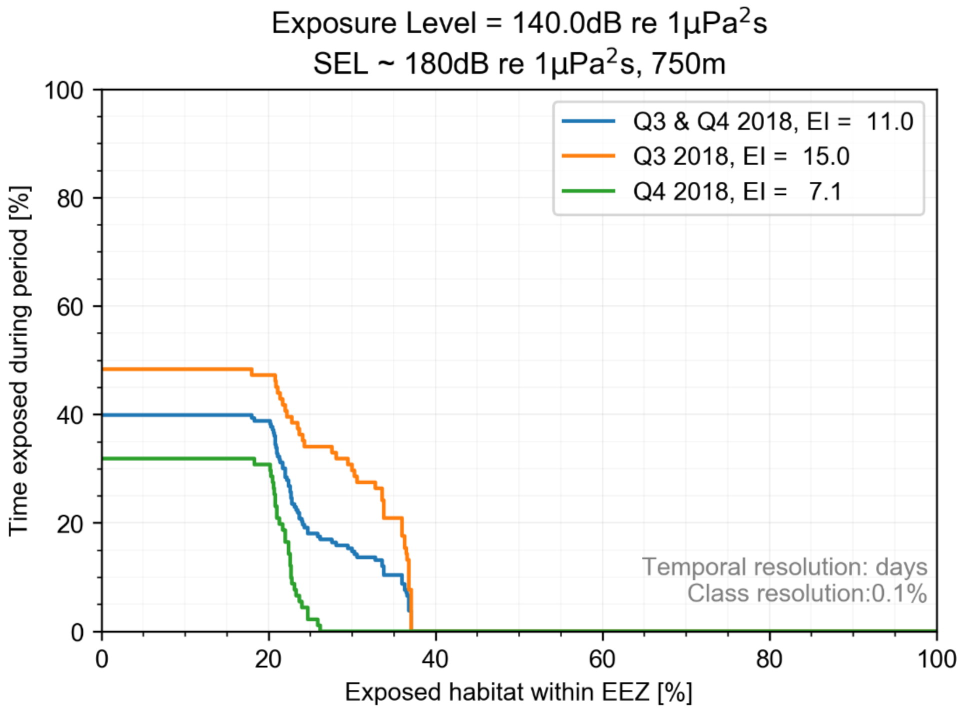


Figure 10: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 180 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

The analysis shows that the Exposure Index is dependent on the analysed period. However, with reservations smaller periods can be joined to a larger one.

Another effect, not shown in the present work, is that analysing the same sources with periods having different percentage of exposed time leads to a difference in Exposure Indexes. E.g. 15 pile-driving events which occurred during the first 15 days of a month will lead to a peak value of the exposure curve of up to 50 % time exposed when considering a period of a total month. However, if instead only the first half of the month is considered in an assessment, the exposure curve would show a peak value of up to 100 % and thus result in another, higher, Exposure Index.

4.3 Influence of the grid size on the Exposure Index

For a long time, the spatial resolution of the investigations has been controversially discussed. To illustrate this, the ICES rectangles of the German EEZ and the sound prediction for the pile-driving events in 2018 are presented jointly, see Figure 11.

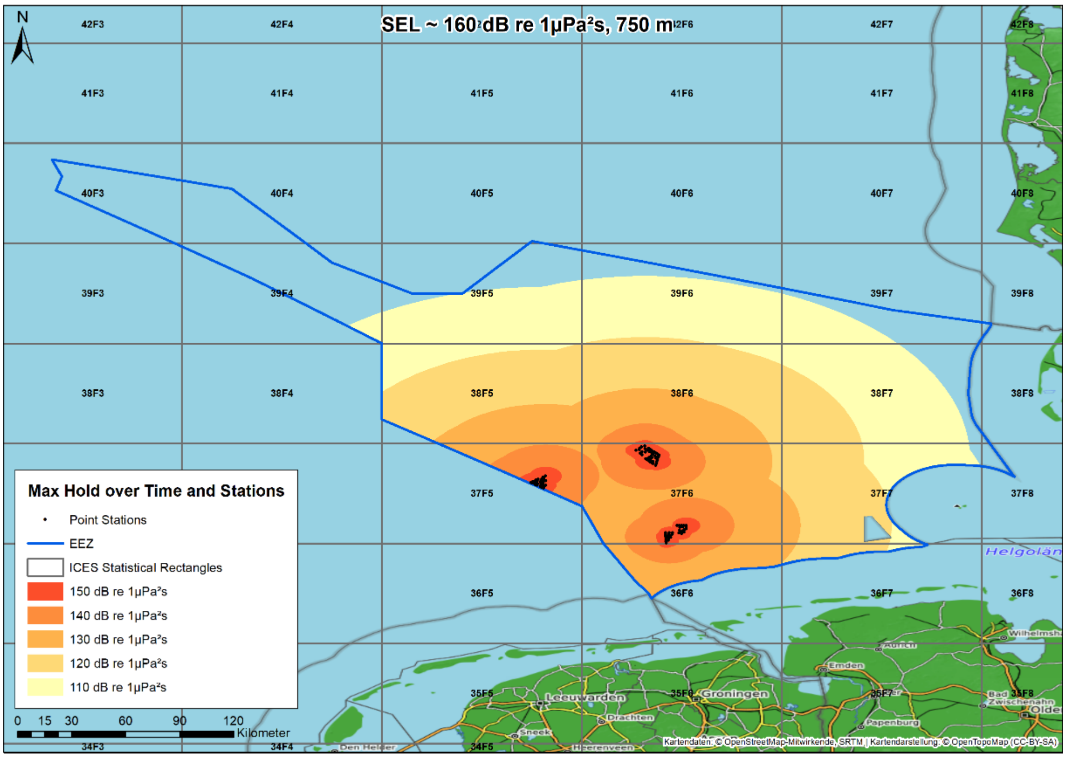


Figure 11: Sound prediction over the year 2018 displayed in German EEZ (North sea) together with ICES rectangles.

Figure 11 clearly shows that such a coarse resolution is not suitable for an accurate assessment of the situation regarding the pressure or risk from impulsive noise events. The German EEZ (North Sea) covers an area of 28,539 km². Figure 12 and Figure 13 show the influence of the grid size on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA. It can be seen that the resolution for the question presented here is in principle accurate at a resolution of one percent. With coarser grids, the area is incorrectly weighted, i.e. an overestimated weight is assumed. This point will be further discussed in Section 4.6.

Remark:
Please note that the computation of the exposed area in this study follows the scheme of Thiele [8] and thus does not depend on a grid size. The degrading into classes with a specific grid size is only apply while calculating the exposure curve and the Exposure Index (step E. and F. of the computation procedure).

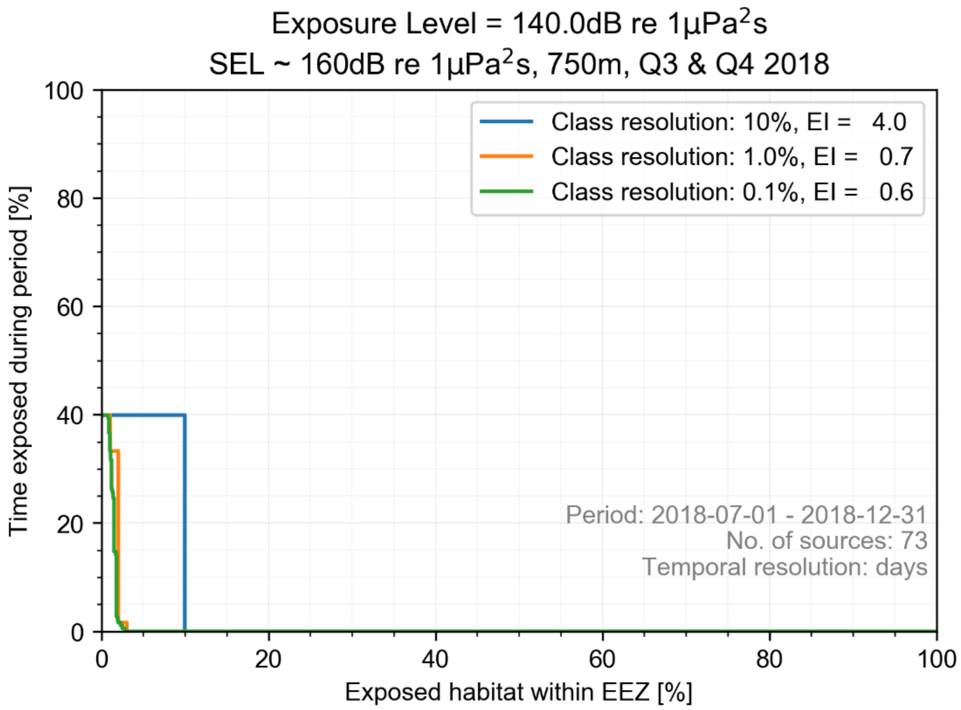


Figure 12: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1% of the MA, 1% of the MA and 10% of the MA, SEL of 160 dB re 1 µPa²s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa²s.

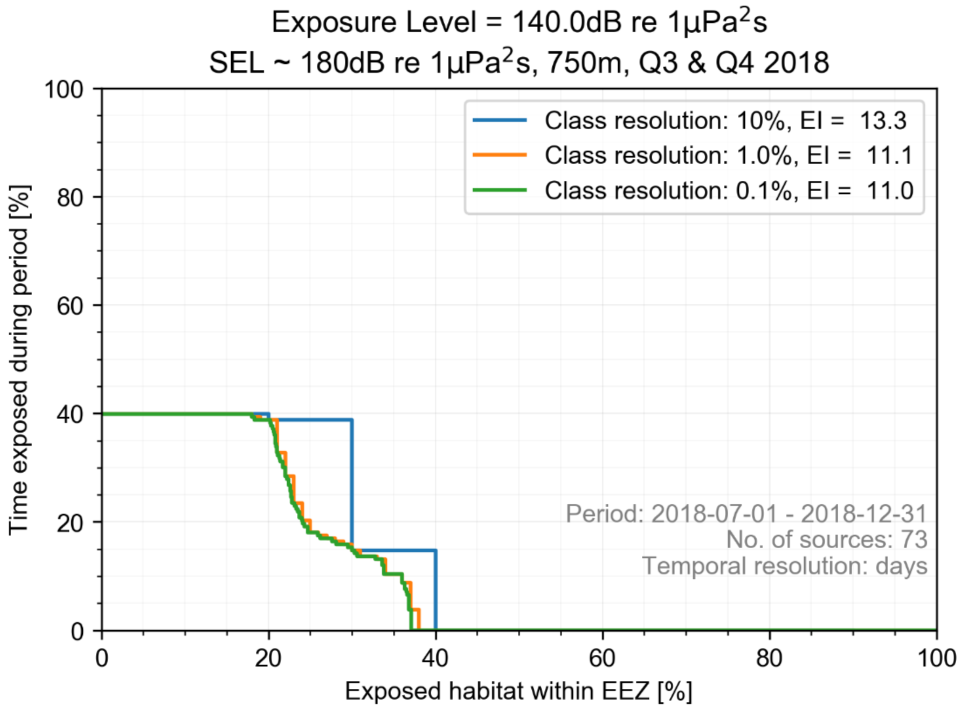
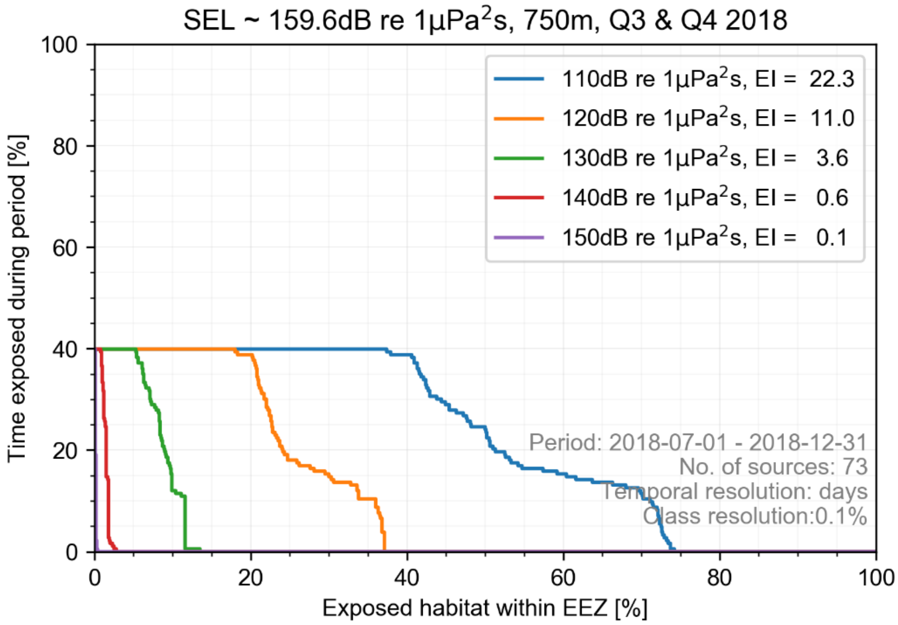


Figure 13: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA, SEL of 180 dB re 1 µPa²s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa²s.

4.4 Influence of sound mitigation measures on the exposure Index

In order to perform an exemplary test regarding the influence of sound mitigation measures on the Exposure Index, it was assumed that the pile-driving was carried out in the second half of the year 2018 without sound mitigation measures, see Figure 14. It can be seen that this situation leads to a significant change in the Exposure Index, and thus the source strength in itself can be a first indicator for the assessment. We will discuss this again in Section 4.7.



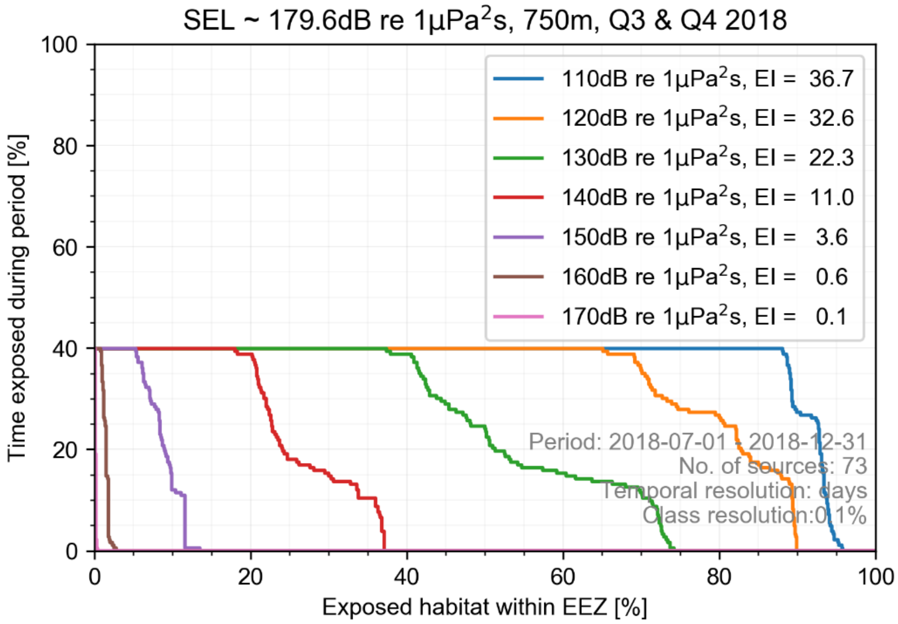


Figure 14: Exposed habitat depending on received level. The upper graph illustrates a source strength of SEL 159.6 dB re 1 µPa²s, 750m, the lower graph the non-mitigated case with a source strength of SEL 179.6 dB re 1 µPa²s, 750m.

4.5 Consideration of nature conservation areas

There are different possibilities to include nature conservation areas, esp. Natura2000-areas in the approach. In the previous sections we have considered the entire EEZ as MA and habitat. If nature conservation areas are included in the overall analysis, they should be evaluated separately or given special weight in the overall assessment.

The concept for the protection of harbour porpoises in the German EEZ of the North Sea was established 2013 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and follows the habitat approach in regard with disturbance as a cumulative impact of sound emissions due to percussive pile driving [11].

The concept addresses the reduction of sound emissions during installation of piles for wind farms by means of technical noise abatement and cumulative effects on habitats due to simultaneous activities at several construction sites.

The main rules of the concept regarding avoidance and reduction of disturbance on habitats for harbour porpoise are as follows:

a) The proportion of area affected by impulsive noise shall not exceed 10% of the entire area of the German EEZ in the North Sea in the case of parallel pile-driving operations,

b) The proportion of the area affected by impulsive noise shall not exceed 10% of the area of one of the nature conservation areas (Natura 2000 sites),

c) In the time from 01.05. to 31.08. the proportion of the area affected by impulsive noise shall not exceed 1% of the area of the nature conservation site "Sylter Außenriff - Östliche Deutsche Bucht", which is identified as calving ground for harbour porpoises.

The rules presume compliance with thresholds at activity level (SEL < 160 dB re 1 µPa^{2}s, Lpeak < 190 dB re 1µPa) and onset of significant disturbance at 140 dB re 1 µPa^{2}s.

Figure 15 shows that criterion a) was safely met for a SEL of 160 dB re 1µPa^{2}s at 750 m. The rate was well below 5% for the entire half year. A temporally parallel pile driving activity would have been possible. However, Figure 15 also shows that for a SEL of 180 dB re 1µPa^{2}s at 750 m (non-mitigated case), criterion a) was not met. It should however be noted that according to [11] a propagation model was used, which rather overestimates occurring sound pressure values at long distances.

\\S-HAM-FS01\ALLEFIRMEN\M\PROJ\146\M146361\M146361_13_BER_3E.DOCX:30.03.2020

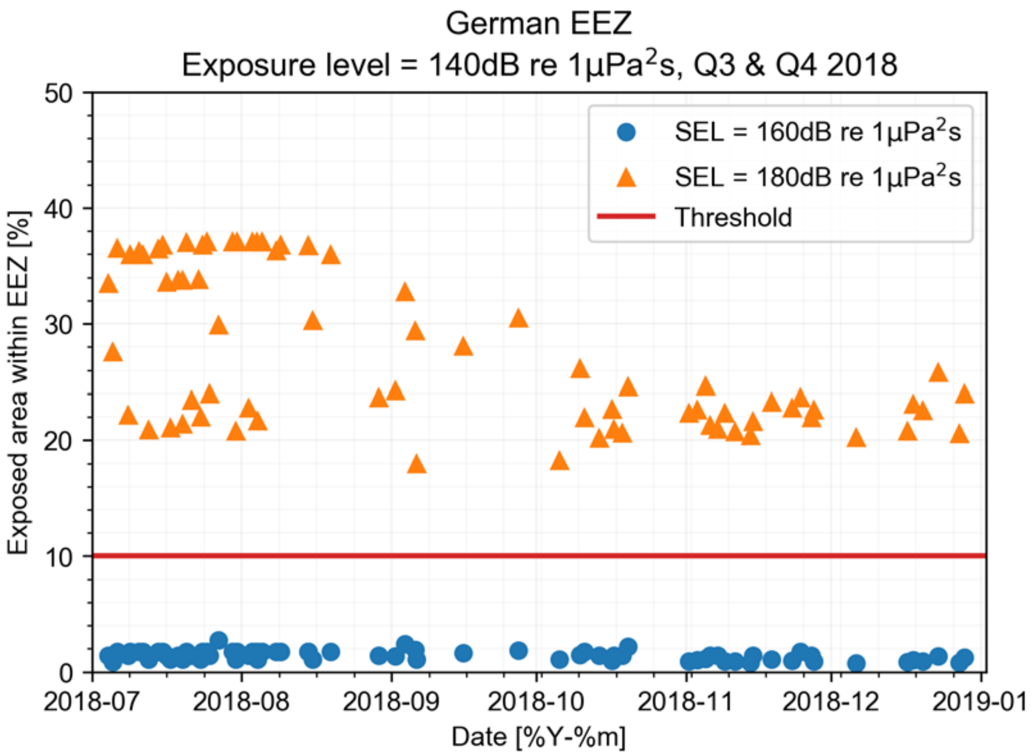


Figure 15: Exposed area over time (daily resolved) within EEZ for a source strength of SEL 160 dB re 1 µPa²s, 750m, and SEL 180 dB re 1 µPa²s, 750m with 10% criteria.

If criterion b) is considered for the example of the nature conservation area “Borkum Riffgrund”, the resulting situation is shown in Figure 16. Again, the criterion is fulfilled in most cases for a compliance with a SEL of 160 dB re 1µPa²s at 750 m. Without noise abatement measures, the threshold would always be exceeded.

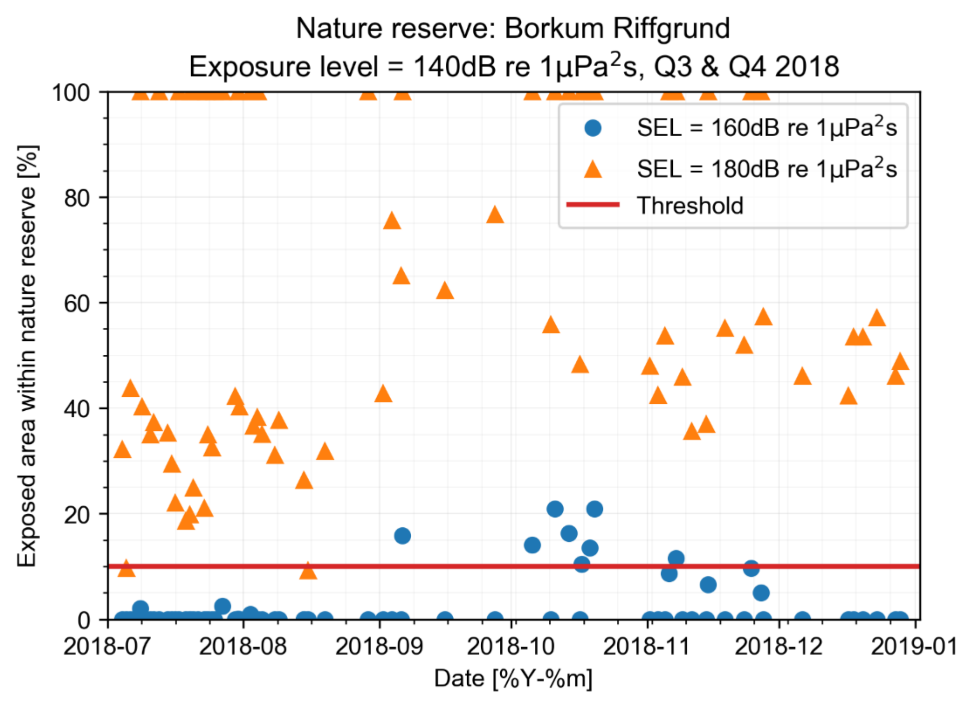


Figure 16: Exposed area over time (daily resolved) within nature conservation areaconservation area (Borkum Riffgrund) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 10% criteria.

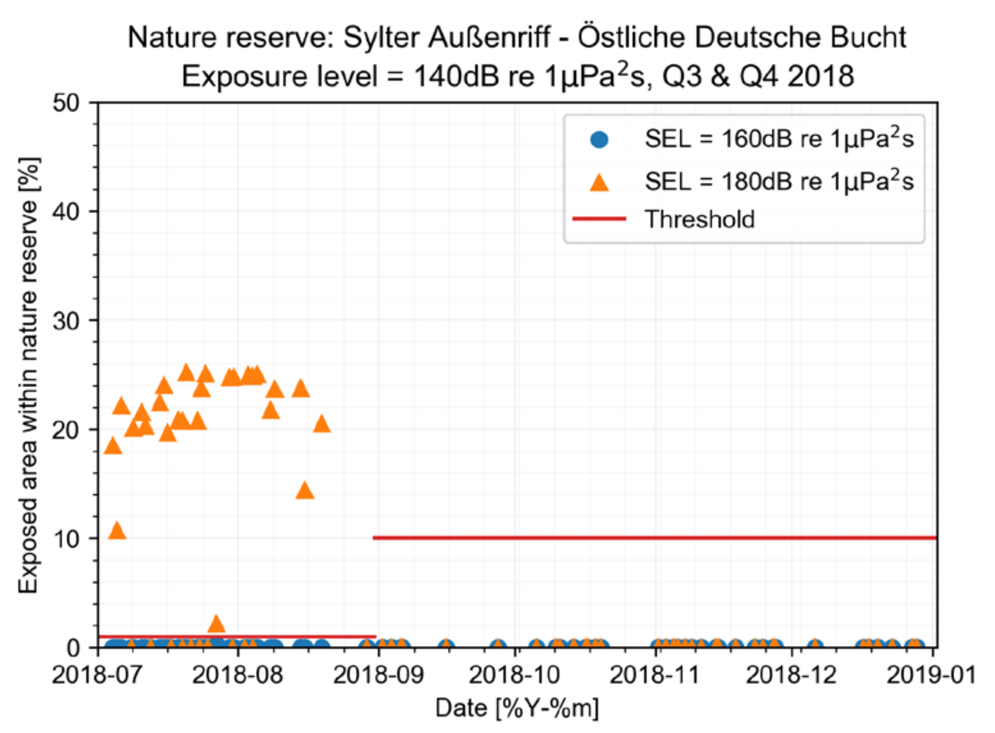
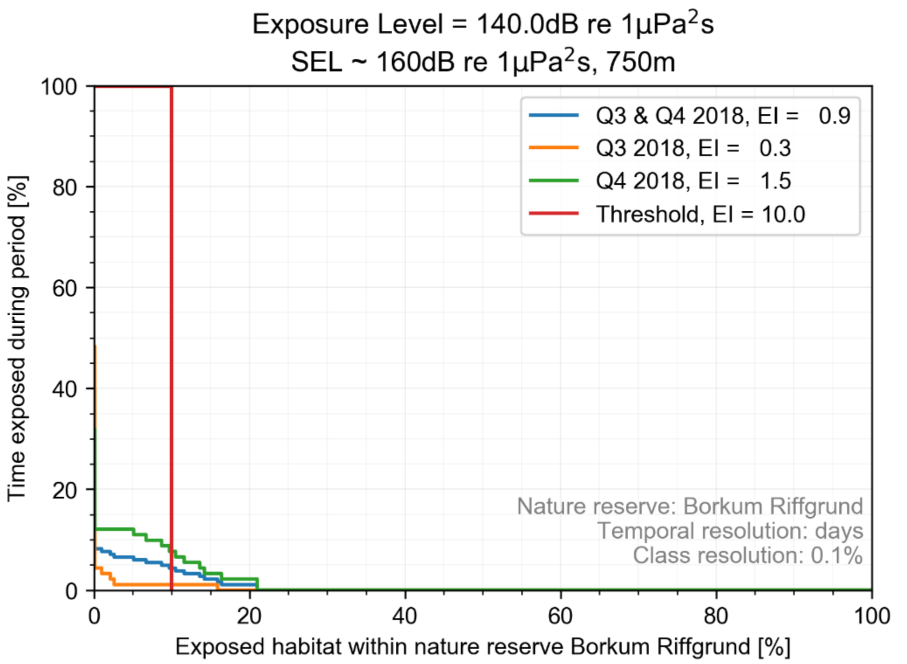


Figure 17: Exposed area over time (daily resolved) within nature conservation area (Sylter Außenriff) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 1% and 10% criteria.

The last case c) is displayed in Figure 17 for the Nature conservation area “Sylter-Aussenriff”. For the period considered, the target was met during the construction phase in 2018. If no noise abatement measures had been used, it would not have been possible to meet the target.

Finally, let us briefly consider the exposure curve and Exposure Index (EI) proposed by OSPAR. Figure 18 shows the test case for the nature conservation area “Borkum Riffgrund”. In addition, the 10% area criterion is considered. This criterion leads to a permitted single value EI of 10. The EI remained below this value during the period under consideration in the construction phase, however at individual times the 10% rule was exceeded. Hence, the consideration of the EI alone is therefore not suitable for assessing the specific situation. Additionally. spatial and temporal limits should be specified, ideally with tolerances of the allowed exceedances.



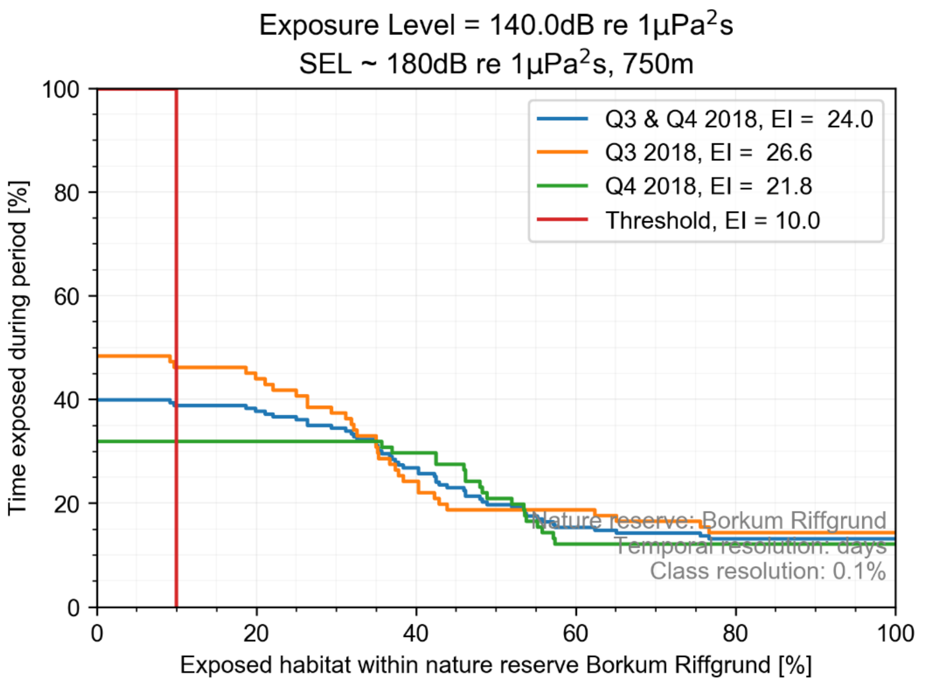


Figure 18: Exposure curves and Exposure Index: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB and 180 dB re 1 µPa²s at 750m and a maximum permissible received exposure level of 140 dB re 1 µPa²s.

4.6 Discussion of the different assessment methods in relation to the Exposure Index

In principle, there are two different evaluation options, one based on habitats (e.g. Natura 2000 sites) and one based on population. For the population option, one can assume mean distributions and "exact" distributions (snap shots) determined for a particular time span. Both will result in an additional uncertainty in the prediction. However, independently of the approach taken, a comparability of the indicator and assessment result should be garantueed.

In the OSPAR-approach, observed radii of action are assumed for mitigated (12 km) and non-mitigated sound events (20 km). However, these radii do not correlate with the radii that would be determined according to the application of sound mitigation measures based on sound propagation. An example on this is given in Figure 19.

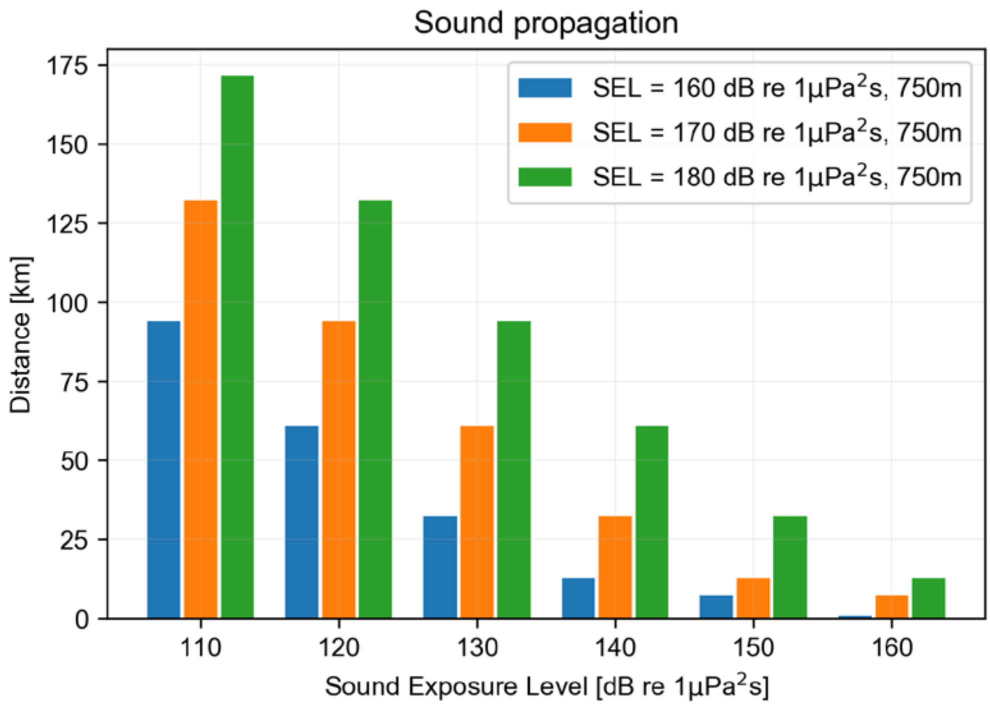


Figure 19: Distance to Received Sound Exposure Level for different source strength (computed according to [1]).

If the assessment were to be based on the hearing threshold (curve), in this case for harbour porpoise, an even more profound analysis would be required, as most sound abatement systems provide better insulation in the medium and high frequency spectrum, see Figure 20.

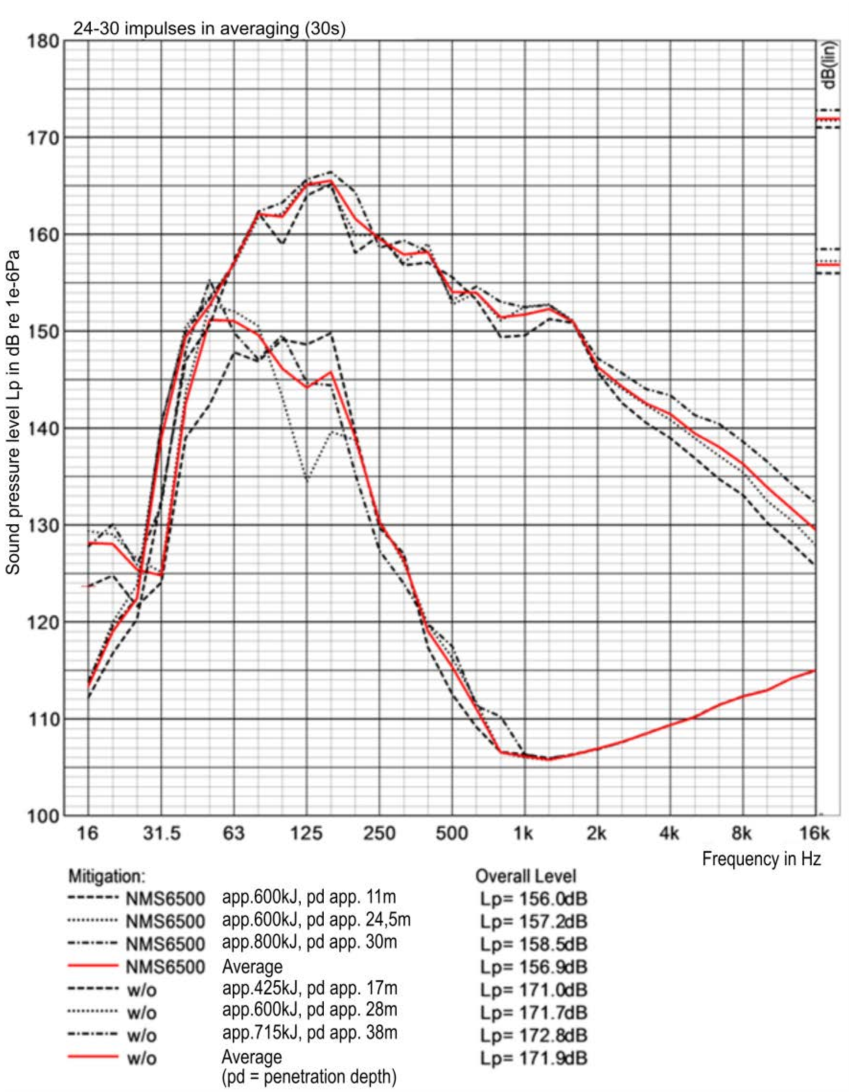


Figure 20: Sound Pressure Level with and without mitigation measures [9].

Auditory frequency weighting is regularly discussed, see [5]. A frequency weighting would emphasize the positive influence of noise abatement measures even more clearly. However, suitable threshold values should be further evaluated and proposed by bioacoustic experts.

4.7 Significance of the classification in the noise registry

Some member states of the European Union (e.g. Belgium, the Netherlands, Germany and Denmark) have initiated acoustic measurements to determine the actual noise impact during pile driving activities. Often, the measurements were (or are being) carried out in a distance of approx. 750 m to the piling location. National [6] and international standards [6] have adopted this measuring distance and recommend it, which has helped to build up a large data base that is likely to further increase. OSPAR has already introduced this information as non-mandatory entries for the template of the noise register.

The following task will be to integrate noise abatement systems and results of the measurements when it comes to formulate source levels for pile-driving noise (status Sep. 2019) [10]. A categorisation of sound events (pile-driving) is now under discussion in TG Noise as shown in Table 1.

Table 1: Current state of discussion of the categorisation of sources.

Categories	SEL (750 m) dB re 1µPa²s	L_{peak} (750 m) dB re 1µPa
A	152 – 161,5	172 – 181,5
B	162 – 171,5	182 – 191,5
C	172 – 181,5	192 – 201,5
D	182 – 191,5	202 – 211,5
E	192 – 201,5	212 – 221,5
F	202 -	222 -

The sound events considered in the present study were in the categories A to C.

It is very well possible to classify the source strength objectively. If this is to be achieved for the sound impact, i.e. the Exposure Index, clear procedures must be defined in order to ensure objective statements. Uncertainties enter the approach, for example, due to the selection of habitats and the weighting of habitats. This also applies for the case when population models are used, as each approach is based on assumptions that are certainly only a limited representation of the ground truth, e.g. since not all individuals were actually monitored during the observation period.

On the basis of the investigations, it can be established that there must be a direct correlation between the source category and the sound exposure. The EI naturally varies with the change in source strength. However, the sound concept that has been put into practice in Germany, see Section 4.5, adds a further component, namely the permissible spatial acoustic radiation at a threshold value of the EEZ and nature conservation area. In Table 2 an example is given which considers the approach to habitat protection in Germany. The entries of EI and permissible exceedances (PE) are to be seen as a proposal of the concept which motivate further analysis and discussion. Details would have to be examined in a deeper consideration.

Table 2: Example for a possible combination of source categories with the Exposure Index (EI) and percentage exceeding of exposed area per day (PE) during the observation period based on received level SEL140 dB re 1µPa²s for nature conservation areas.

Categories	SEL (750 m) dB re 1µPa²s Categorie	Allowed EI and PE for EEZ *		Allowed EI and PE for nature conservation area *	
		EI	PE	EI	PE
1	A	<5	<1%	<5	<1%
2	A	<5	<5%	<5	<5%
3	A	<5	<10%	<5	<10%
4	B	…	…	…	…
5	…	…	…	…	…

*during the observation period based on received level SEL140 dB re 1µPa²s

The assessment criteria should be be clarified. Under this premis, a categorisation can be successful. From the German point of view, the undercutting of the SEL 160 dB in 750 m is a suitable measure that should also be reflected and depicted in a module for the evaluation of the behavioural disturbance.

5 Conclusion

In this study, some aspects of the assessment of an Exposure Index have been addressed. Further comparative studies are necessary to enable an objective assessment. For the consideration of sound, for example, the frequency weighting must certainly be pursued further.

The study shows that the Exposure Index can in principle describe the profit of using sound abatement systems. The methodology also allows to compare different time periods (e.g. compare different quarter of a year) and to analysis different exposure thresholds.

However, the study displays the dependency of the Exposure Index on several parameters. With the adoption that the noise pressure map and the habitat follow the state-of-the-art, the most important parameters to consider are the spatial and temporal resolution. The consequences are that specifications for the spatial and temporal resolution must be made when using the Exposure Index. Otherwise, a global classification will not be possible and the comparability and interpretability of assessment results remains a challenge.

A follow up to the present study will be the analysis of the Exposure Index when different types of sound source activities occur during a given period.

MÜLLER-BBM

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

„Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive – BeMo"

Technical Report

Classification and assessment of impulsive noise with and without noise mitigation measures

Exposure Index based on a Habitat Approach

Andreas Müller, Thierry Maquil
Ramona Eigenmann and Carina Juretzek

With contributions by Thomas Merck (BfN),
Alexander Liebschner (BfN), Stefanie Werner (UBA) and
Maria Boethling (BSH)

Bundesamt für Seeschifffahrt und Hydrographie
Federal Maritime and Hydrographic Agency (BSH)
Hamburg and Rostock, 2020

Research and Development Project, Order Nr. 10036955

Bundesamt für Seeschifffahrt und Hydrographie (BSH)
Federal Maritime and Hydrographic Agency
Bernhard-Nocht-Straße 78
20359 Hamburg

May 2020

The main objective of the R&D „ Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive " is to give insights in issues of mitigation applied to reduce impact from percussive pile driving on the marine environment. Information and data in the technical report have been available by the German National Noise Registry and the Informationsystem marinEARS of BSH.

Authors are responsible for the contributions in the technical report.

Authors

Dr. Andreas Müller, Müller-BBM

Thierry Maquil, Müller-BBM

Ramona Eigenmann, Müller-BBM

Carina Juretzek, BSH

To be cited as: Müller, A., T. Maquil, R. Eigenmann & C. Juretzek, 2020: Classification and assessment of impulsive noise with and without noise mitigation measures - Exposure Index based on a Habitat Approach. Technical Report , R&D „Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive – BeMo", Order Nr. 10036955, Bundesamt für Seeschiffahrt und Hydrographie (BSH).

Further contributed: Thomas Merck (BfN), Alexander Liebschner (BfN), Stefanie Werner (UBA) and Maria Boethling (BSH).

Table of contents

1 Introduction

Noise pollution of the world's oceans has been of substantial public interest in recent years. Marine scientists continue to build our knowledge base by steadily/regularly recording underwater noise, attempting to assess the effects of anthropogenic noise input (such as ship noise and construction noise) in the marine environment. National legislators and international organisations are endeavouring to limit noise emission or immission by regulatory means where necessary. The EU Marine Strategy Directive classifies sound as impulsive and continuous sound events. A noise registry has been developed for impulsive noise sources at ICES, providing a basis for assessments in the OSPAR and HELCOM regions. Member states report their sound events annually. An active reduction of impulsive noise emissions can be mainly achieved by means of noise abatement systems. Current improvements in the noise quantification will consider the up to now non-mandatory information of the noise registry on noise mitigation measures. In the present work, actual data of the noise registry is used to perform an analysis on the effect of sound mitigation measures applying the proposed OSPAR 'Indicator for the risk of impact from impulsive noise'. It depicts the consequences for the classification and the current assessment with and without application of noise abatement systems.

2 Relevant Documents

[1] Thiele, R & Schellenstede, G (1982): Standardwerte zur Ausbreitungsdämpfung in der Nordsee. FWG-Bericht 1980-7, Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik

[2] Dekeling, R; Tasker, M; Van der Graaf, S; Ainslie, M; Andersson, M; André, M; Borsani, J; Brensing, K; Castellote, M; Cronin, D; Dalen, J; Ferreira, M; Folegot, T; Leaper, R; Pajala, J; Redman, P; Robinson, S; Sigray, P; Sutton, G; Thomsen, F; Werner, S; Wittekind, D; Young, J; Zampoukas, N; (2014): Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications http://dx.doi.org/10.2788/27158

[3] Merchant, N; Faulkner, R & Martinez, R. (2018) Marine Noise Budgets in Practice. Conservation Letters., Volume 11, Issue 3 https://doi.org/10.1111/conl.12420

[4] de Jong, C; Heinis, F; von Benda-Beckmann, S & Binnerts, B. (2019-12) CEAF in SEANSE case studies, Impact of piling for wind farms on North Sea harbour porpoise population. TNO report, TNO 2019 R11563

[5] Tougaard, D & Dähne, J. (2017) Why is auditory frequency weighting so important in regulation of underwater noise? The Journal of the Acoustical Society of America 142, EL415 https://doi.org/10.1121/1.5008901

[6] DIN SPEC 45653:2017-04: Offshore wind farms –
In-situ determination of the insertion loss of control measures underwater

[7] ISO 18406:2017-04: Underwater acoustics –
Measurement of radiated underwater sound from percussive pile driving

[8] Bundesamt für Seeschiffahrt und Hydrographie (BSH) 20191002_DEsubmission_NoiseRegisterTemplate_NavalNoise_Explosion_Pile Driving, Events 2018

[9] Müller-BBM 2015: Report M100004/54 unpublished

[10] Alain Norro, Andreas Müller, Michael A. Ainslie, Nathan Merchant, Russell Leaper Müller-BBM Report No. M146361/06, Revision of the “TG Noise monitoring guidance“ Sound exposure levels of pile-driving noise with/without noise protection measures, Background paper, Sep. 2019

[11] BMU Schallschutzkonzept, Konzept für den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee, 2013

3 Sound propagation under various scenarios in the German EEZ of the North Sea

In this study different scenarios were examined. Figure 1 and Figure 2 show the calculation of the different sound fields at three wind farms constructed in 2018, where the measured average sound levels regarding the metric SEL were below a value of 160 dB (Fig. 1) at 750 m distance and the virtual non-mitigated case with a SEL of 180 dB at 750 m distance (Fig. 2).

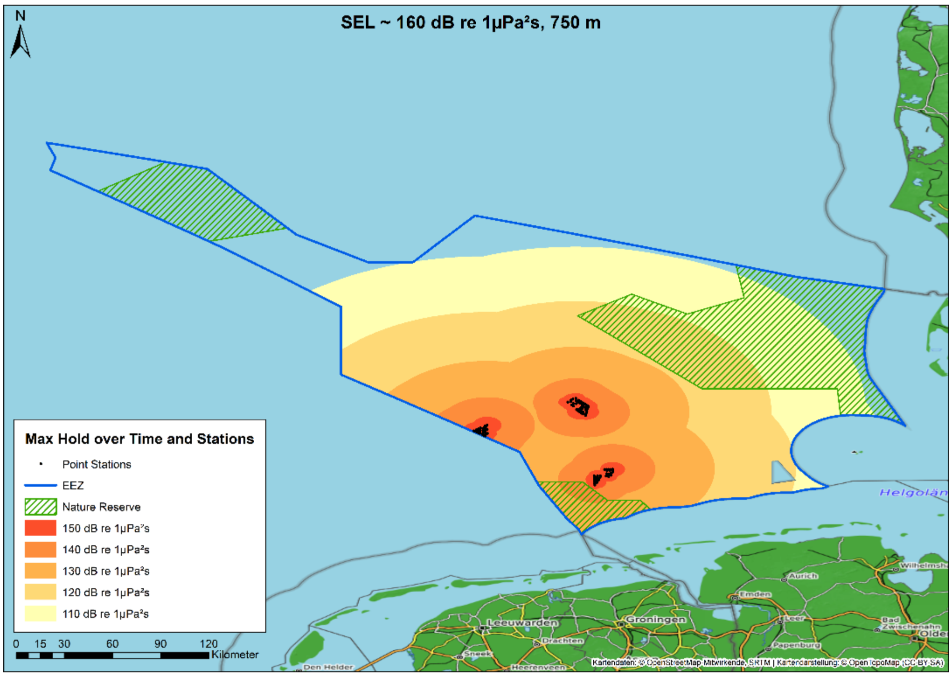


Figure 1: Maximum sound exposure level (Max Hold, 10 dB steps) of all pile driving activities in 2018 at an sound exposure level during pile driving of 160 dB re 1 µPa²s at 750 m

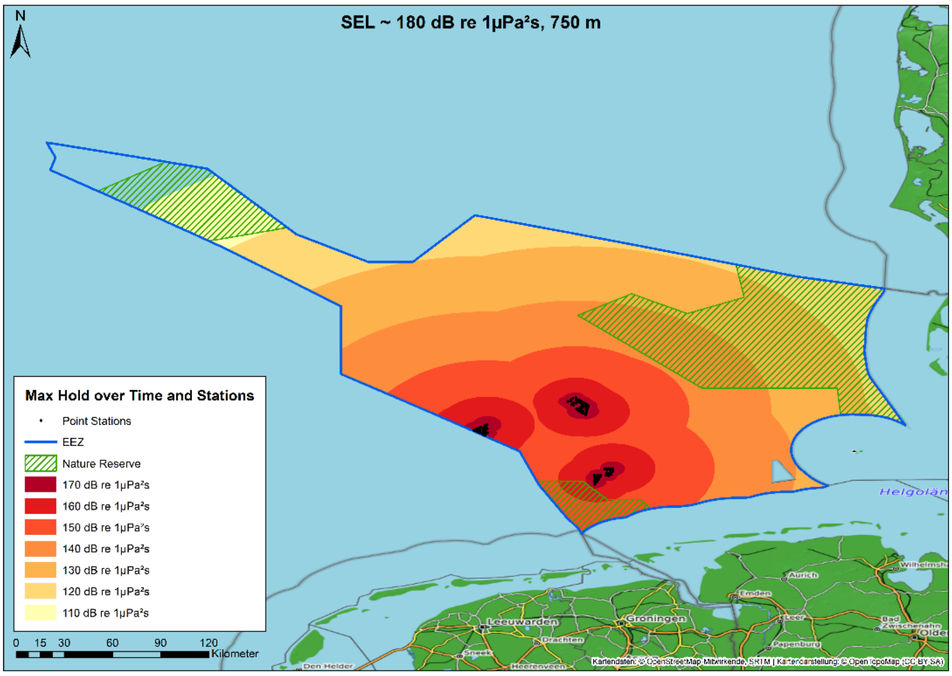


Figure 2: Maximum sound exposure level (Max Hold, 10 dB steps) of all pile driving activities in 2018 at a sound exposure level during pile driving of 180 dB re 1 µPa²s at 750 m

The sound insulation effect was assumed to be approx. 20 dB. Figure 1 and Figure 2 show how the area of the German EEZ (North Sea) is affected by impulsive noise in the period considered. Obviously, the noise abatement systems lead to a significantly reduction of the area impacted. These calculations were performed with a simple established empirical propagation model according to Thiele [1]. The propagation is conservative for long distances and may lead slightly reduced effective radii due to higher losses. For this study, these calculations are sufficiently accurate, as especially the relative comparisons and methodologies will be considered.

\\S-ham-fs01\allefirmen\M\Proj\146\M146361\M146361_16_Ber_1E.DOCX:18. 05. 2020

4 OSPAR: Indicator for the risk of impact from impulsive noise

4.1 Introduction and procedure

The OSPAR Committee EIHA is developing an indicator describing the impact of anthropogenic impulsive noise on the marine biota. The focus of the indicator is on the large scale, cumulative impact of impulsive noise exposure. The latest version of the indicator supplemented by an example of its application was presented to EIHA (Apri 2020). Applying the indicator roughly follows the steps described below.

A. Define assessment area (MA) and select indicator species.

B. Use the animal density or habitat area of the selected species within MA.

C. Determine the noise pressure map of assessment period.

D. Calculate a risk map using B and C.

E. Calculate the exposure curve using the risk map.

F. Compute the Exposure Index (EI).

Merchant et al. [3] published examples of the application of this indicator regarding disturbing effects both based on density data and on habitats.

However, the acoustic metrics are different for different sound events like explosion, seismic and pile-driving, see TSG Guidance [2], and cannot be easily compared. In the present study the area of the German EEZ (North Sea) was chosen as MA. As discussed in the methodology under development by TG-Noise and at the ongoing assessment of the indicator for OSPAR in the framework of the ICG-Noise population or habitat may be used alternatively under B.

Herewith an example based on the habitat approach is conducted. In the first step, the entire EEZ is taken as habitat of harbour porpoise, which is comparable to the population approach with an equal distribution of harbour porpoise density, which was e.g. considered in the TNO study. [4]. This approach automatically results in a direct comparability of the risk map and the noise pressure map. In the present study, exclusively pile-driving events of the year 2018 have been considered. Figure 3 schematically depicts the procedure used in the present work.

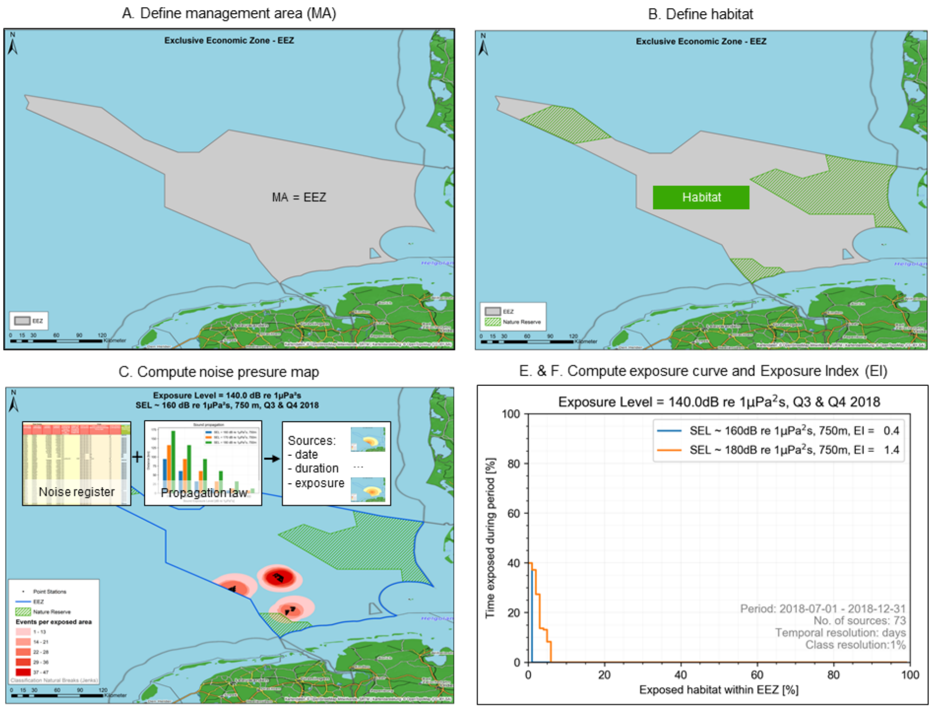


Figure 3: Schematic description of the procedure used in the present work.

Figure 4 and Figure 5 show the number of events (days with pile-driving) per area exposed to impulsive noise levels exceeding 140 dB re 1 µPa²s SEL in case of 160 dB re 1 µPa²s, at 750 m distance to the piling location, respectively 180 dB re 1 µPa²s, at 750 m distance (virtual non-mitigated case).

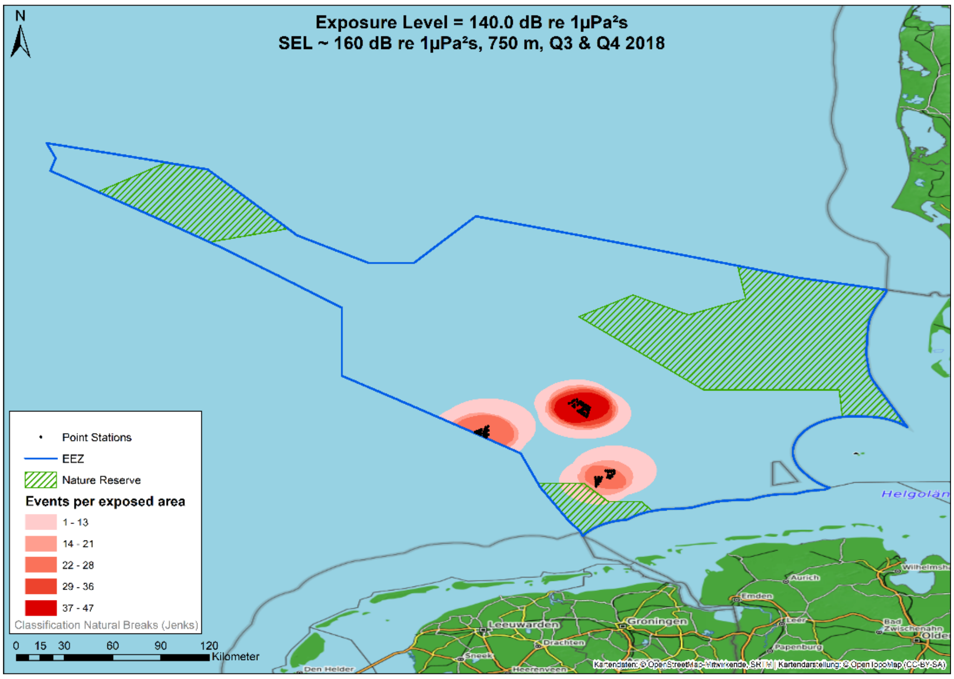


Figure 4: Number of events (days with pile-driving) per area (exposure level ≥ 140 dB re 1 µPa²s) for a period of half a year with a SEL of 160 dB re 1 µPa²s at 750 m distance to piling location.

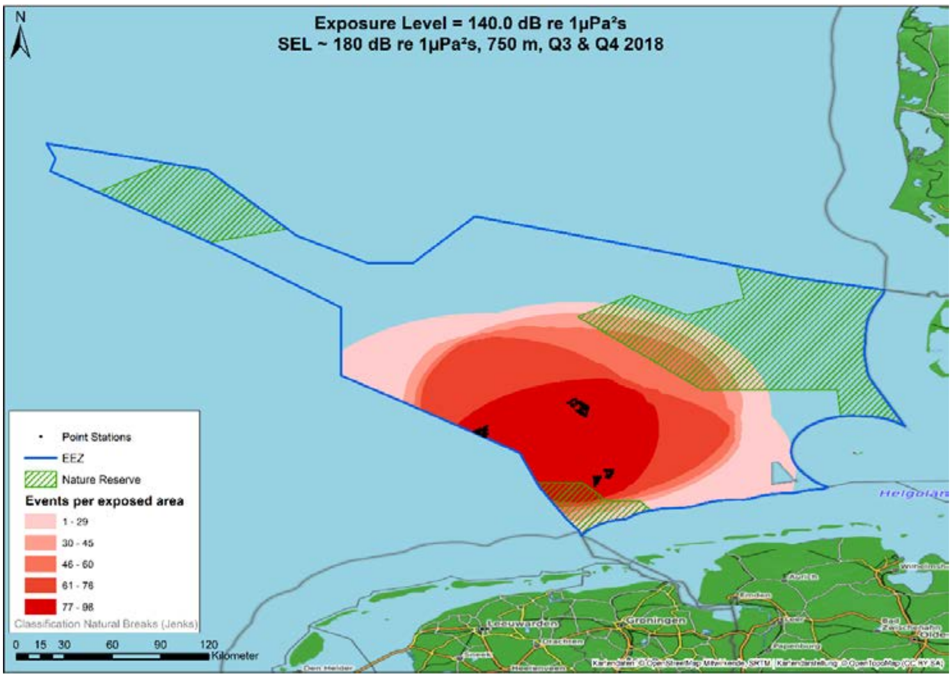


Figure 5: Number of events (pile driving) per area exposed ≥ 140 dB re 1 µPa2s for a period of half a year with a of 180 dB re 1 µPa2s at 750 m distance to piling location.

The images are comparable to the risk maps proposed by Merchant et al. [3], since the habitat approach relies on a uniform distribution, and can directly be converted to exposure curves. The exposure curve and the exposure index are exemplary as shown in Figure 6 for the second half of the year 2018.

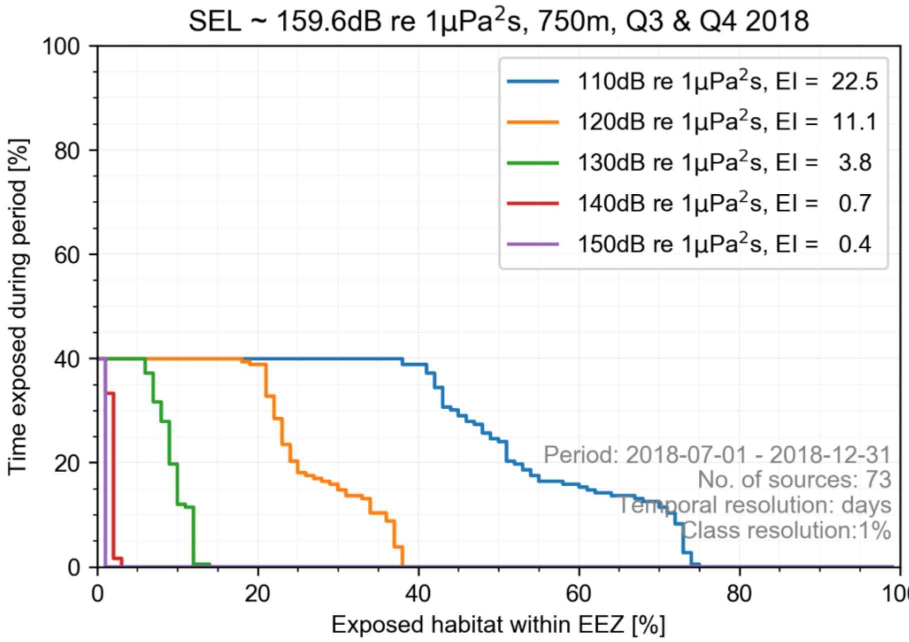


Figure 6: Exposure curve and Exposure Index for the second half of the year 2018 at an average SEL of 160 dB re 1 µPa²s at 750 m distance to piling location, at 73 pile-driving events per day for sound radii >110 dB to >150 dB. The class resolution of 1 % means that one hundredth of an area step is considered, see section 4.3.

Notes on Figure 6:
Short note on the interpretation of the Figure 6:

The following information can be inferred from the exposure curves. At 40 percent of the total days (73 days out of 183 days) piling events took place. Up to 40 % of the habitat has been exposed to a noise level above 110 dB SEL during the whole piling period (73 days) and the sound never reached this level in 25 % of the area.

Assuming an equal spatial distribution of the population in the area considered, in the same way up to 40 % of the population has been exposed to a noise level above 110 dB SEL for the whole piling period and 25 % of the population has never been exposed to impulsive noise above this level.

Exemplary acoustic threshold values were included in the analysis. By decreasing the threshold, the Exposure Index (since the exposed area is increasing) increases.

The following chapters analyse the influence of individual parameters such as time, space, but also sound mitigation measures (insertion loss) on the Exposure Index. We further examine how the noise registry content may be exploited in a best possible way. This applies in particular for categories of sources.

4.2 Influence of the temporal resolution and investigation time on the Exposure Index

4.2.1 Temporal resolution

With the previous representations, the effect of one event per day was examined. The temporal sound exposure may significantly differ for the type of impulsive noise event: while explosions are very short-time, pile-driving may last for up to three hours a day[1], seismic surveys possibly for the whole day. Figure 7 illustrates the influence of the temporal resolution on the time exposed for a 5 days period.

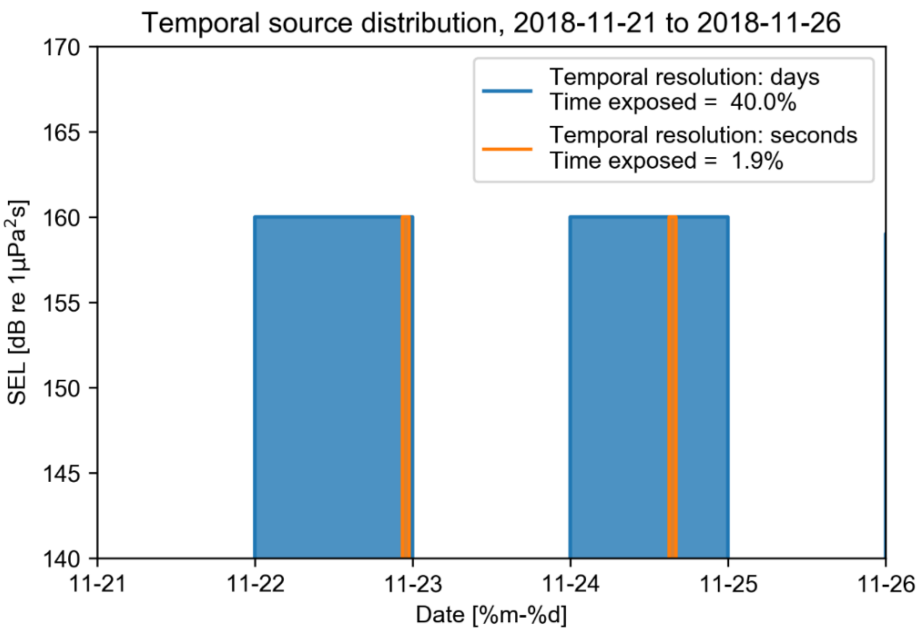


Figure 7: Demonstration of temporal resolution influence on time exposed during period, period is limited to 5 days with two pile-driving.

Figure 8 shows an example of the Exposure Index for a classification per day compared to a classification per second. In the present case the overall time period is half year (third and fourth quarter of 2018).

\\S-ham-fs01\allefirmen\M\Proj\146\M146361\M146361_16_Ber_1E.DOCX:18. 05. 2020

[1] Following the clauses in the German approvals the duration of driving a single pile may not last for more than three hours.

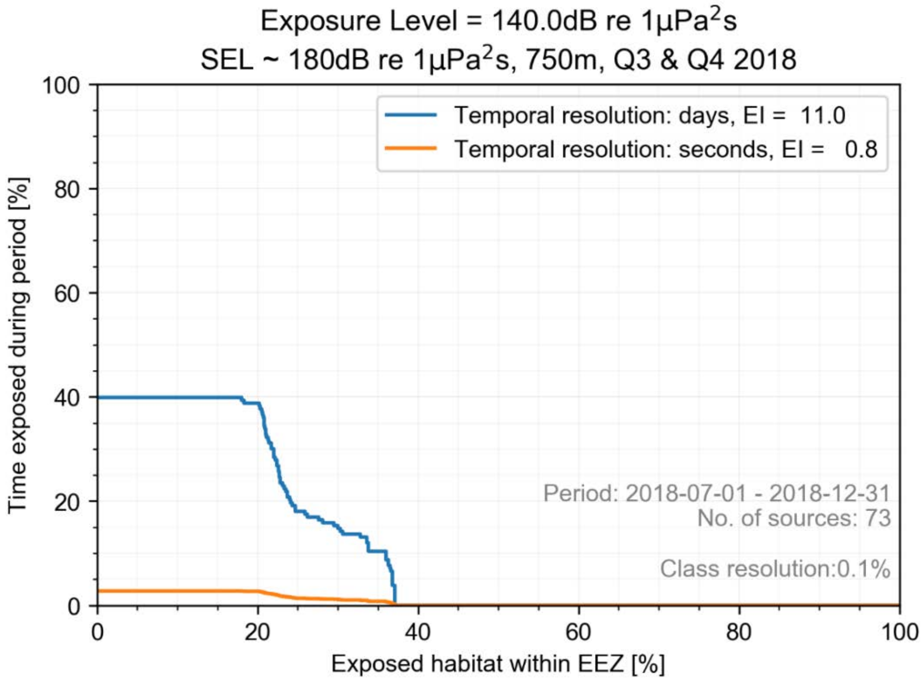


Figure 8: An example of the Exposure Index for a classification per day compared to one per second.

The analysis shows that the Exposure Index is highly dependent on the temporal resolution chosen.

Remark:

A further question arises if several events occur on one day. In this case, cumulative considerations must be made.

4.2.2 Investigation time

Usually annual and seasonal temporal analyses are performed. Figure 9 and Figure 10 show the entire second half of 2018 and the third and fourth quarters separately. As there were more events in the third quarter than in the fourth quarter, the Exposure Index of the third quarter shows the highest value.

Remark:
In order to enable an absolute evaluation for effects yet to be defined, a reference period (e.q. monthly, quarterly or annually) for the Exposure Index is required; for comparative studies, this Exposure index should already be used now. Suitable threshold values must be specified in future.

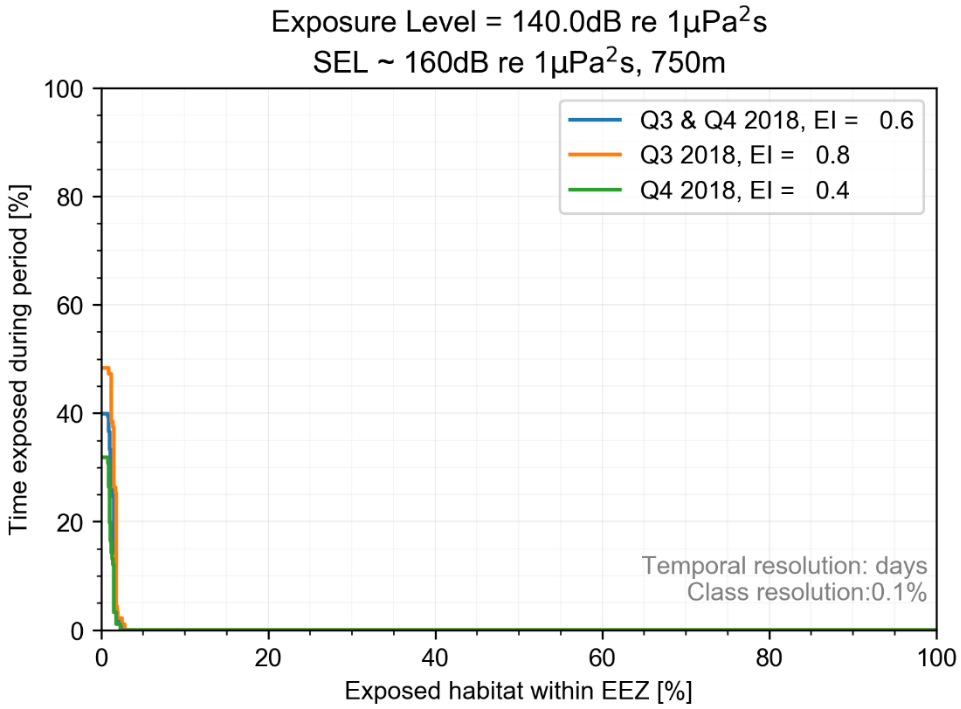


Figure 9: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

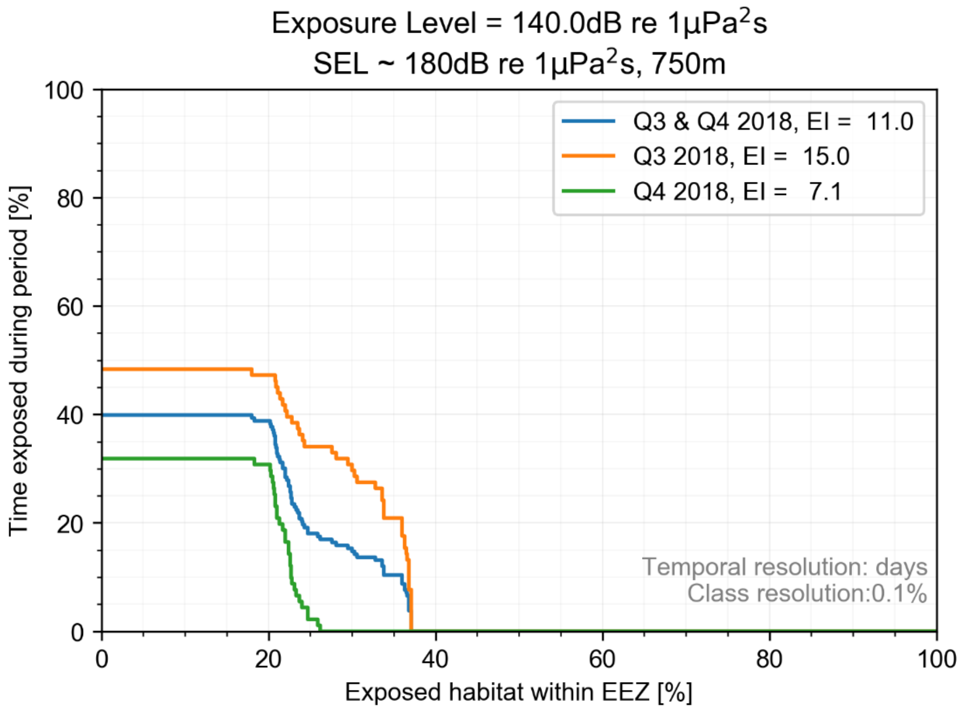


Figure 10: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 180 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

The analysis shows that the Exposure Index is dependent on the analysed period. However, with reservations shorter periods can be joined to a longer one.

Another effect, not shown in the present work, is that analysing the same sources with periods having different percentage of exposed time leads to a difference in Exposure Indexes. E.g. 15 pile-driving events which occurred during the first 15 days of a month will lead to a peak value of the exposure curve of up to 50 % time exposed when considering a period of a total month. However, if instead only the first half of the month is considered in an assessment, the exposure curve would show a peak value of up to 100 % and thus result in another, higher, Exposure Index.

4.3 Influence of the grid size on the Exposure Index

For a long time, the spatial resolution of the investigations has been controversially discussed. To illustrate this, the ICES rectangles of the German EEZ and the sound prediction for the pile-driving events in 2018 are presented jointly, see Figure 11.

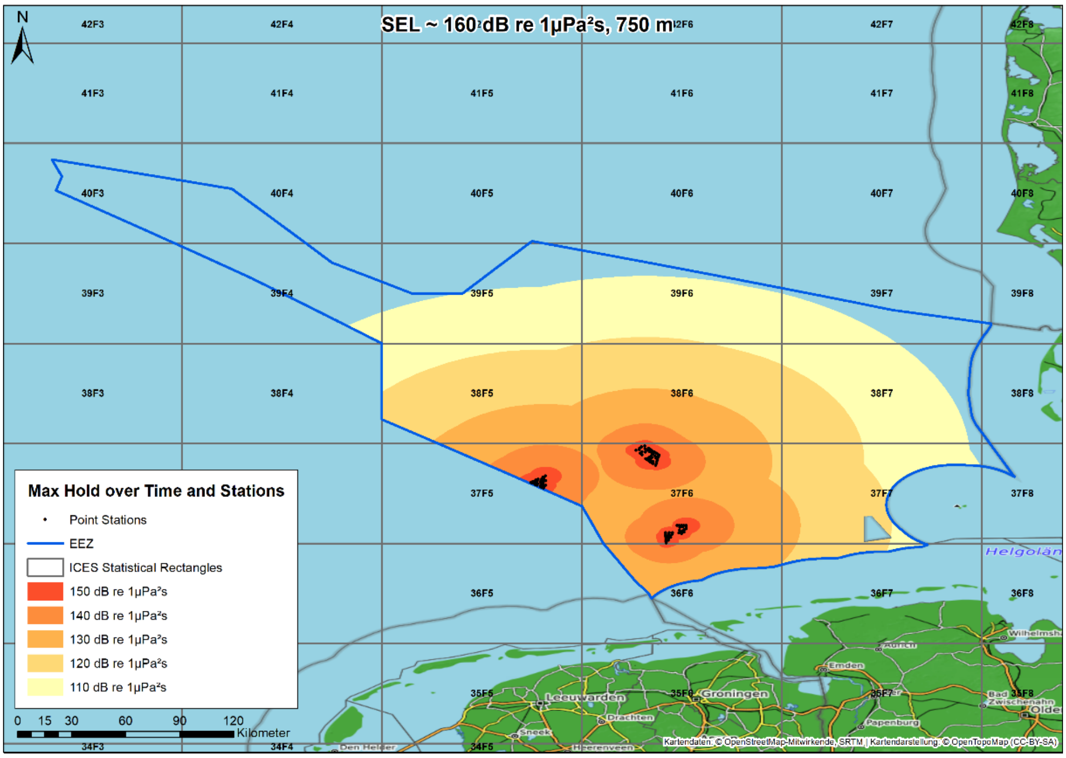


Figure 11: Sound prediction over the year 2018 displayed in German EEZ (North sea) together with ICES rectangles.

Figure 11 clearly shows that such a coarse resolution is not suitable for an accurate assessment of the situation regarding the pressure or risk from impulsive noise events. The German EEZ (North Sea) covers an area of 28,539 km^2. Figure 12 and Figure 13 show the influence of the grid size on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA. It can be seen that the resolution for the question presented here is in principle accurate at a resolution of one percent. With coarser grids, the area is incorrectly weighted, i.e. an overestimated weight is assumed. This point will be further discussed in Section 4.6.

Remark:
Please note that the computation of the exposed area in this study follows the scheme of Thiele [8] and thus does not depend on a grid size. The degrading into classes with a specific grid size only applies while calculating the exposure curve and the Exposure Index (step E. and F. of the computation procedure).

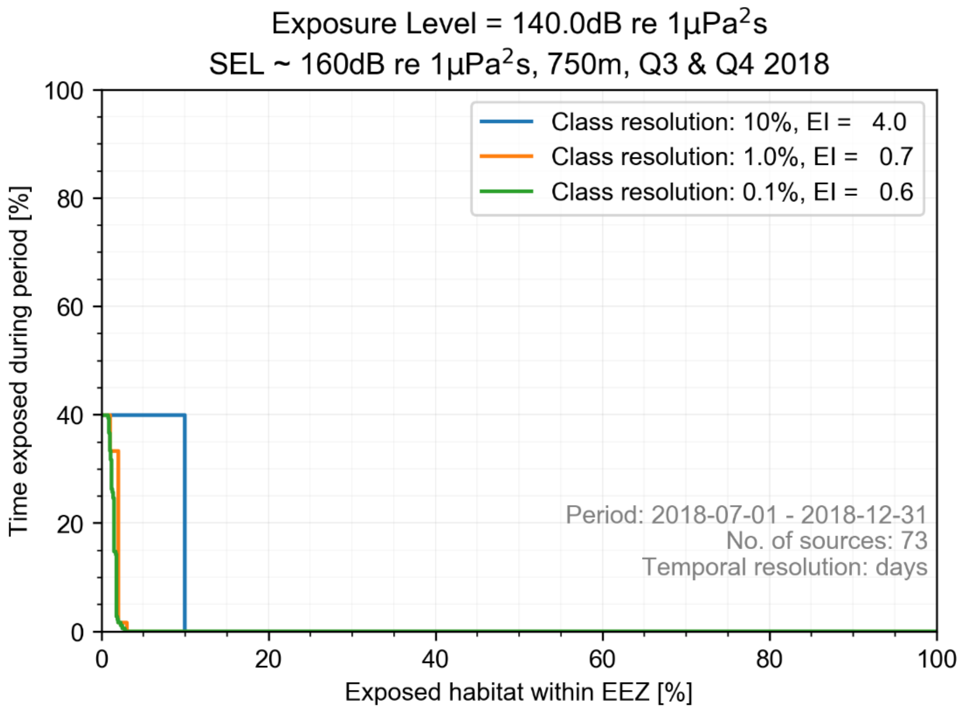


Figure 12: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1% of the MA, 1% of the MA and 10% of the MA, SEL of 160 dB re 1 µPa^{2}s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa^{2}s.

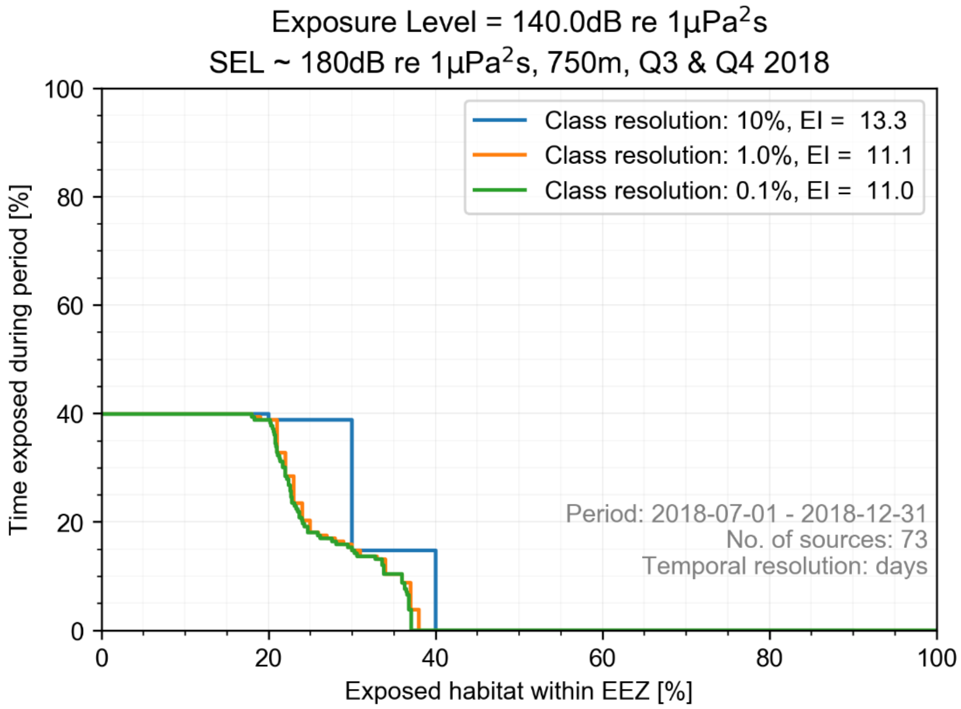


Figure 13: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA, SEL of 180 dB re 1 µPa²s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa²s.

4.4 Influence of sound mitigation measures on the exposure Index

In order to perform an exemplary test regarding the influence of sound mitigation measures on the Exposure Index, it was assumed that the pile-driving was carried out in the second half of the year 2018 without sound mitigation measures, see Figure 14. It can be seen that this situation leads to a significant change in the Exposure Index, and thus the source strength in itself can be a first indicator for the assessment. We will discuss this again in Section 4.7.

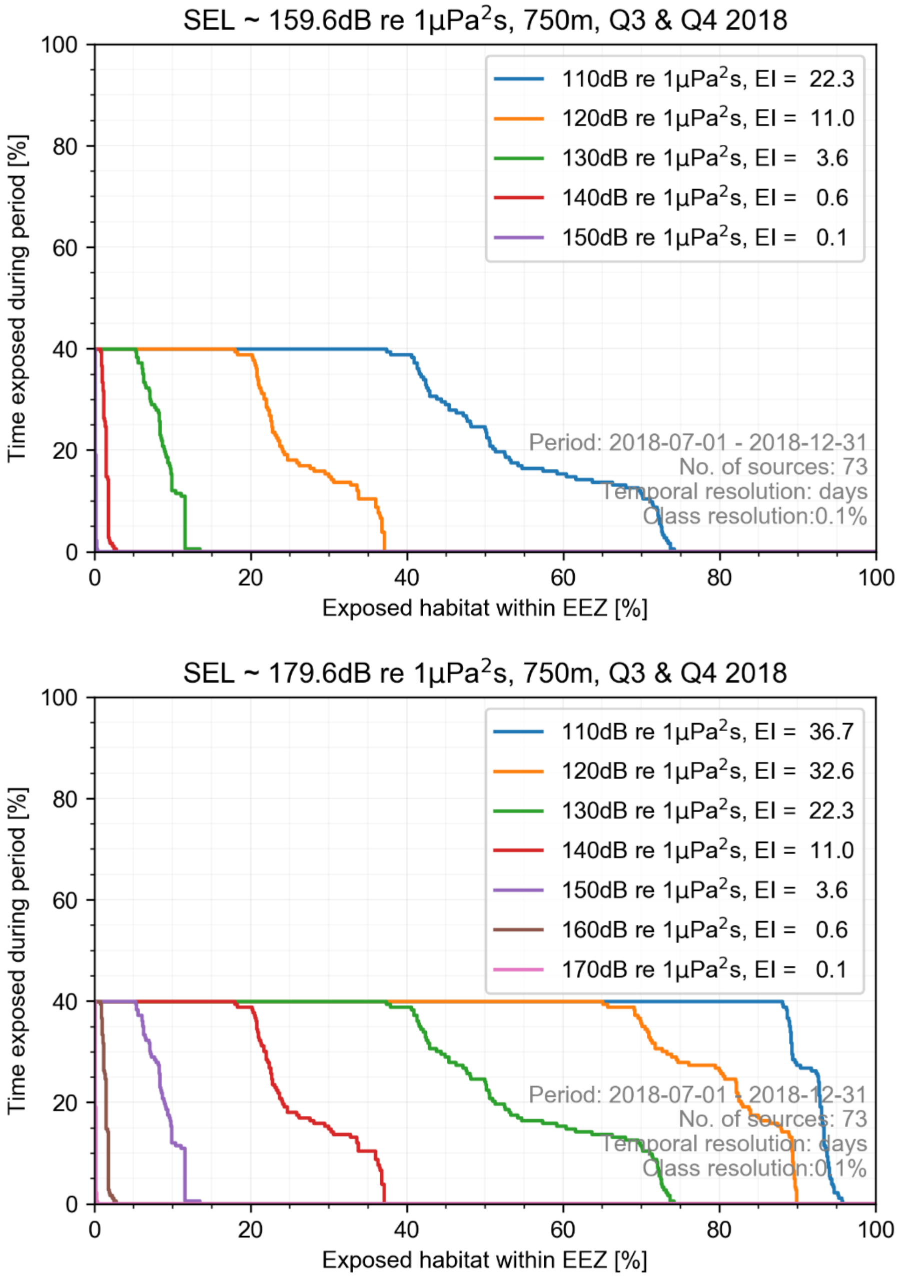


Figure 14: Exposed habitat depending on received level. The upper graph illustrates a source strength of SEL 159.6 dB re 1 µPa²s, 750m, the lower graph the non-mitigated case with a source strength of SEL 179.6 dB re 1 µPa²s, 750m.

4.5 Consideration of nature conservation areas

There are different possibilities to include nature conservation areas, esp. Natura2000-areas in the approach. In the previous sections we have considered the entire EEZ as MA and habitat. If nature conservation areas are included in the overall analysis, they should be evaluated separately or given special weight in the overall assessment.

The concept for the protection of harbour porpoises in the German EEZ of the North Sea was established 2013 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and follows a habitat approach in regard with disturbance as a cumulative impact of sound emissions due to percussive pile driving [11].

The concept addresses the reduction of sound emissions during installation of piles for wind farms by means of technical noise abatement and cumulative effects on habitats due to simultaneous activities at several construction sites.

The main rules of the concept regarding avoidance and reduction of disturbance on habitats for harbour porpoise are as follows:

a) The proportion of area affected by disturbing impulsive noise shall not exceed 10% of the entire area of the German EEZ in the North Sea in the case of parallel pile-driving operations,

b) The proportion of the area affected by disturbing impulsive noise shall not exceed 10% of the area of one of the nature conservation areas (Natura 2000 sites),

c) In the time from 01.05. to 31.08. the proportion of the area affected by disturbing impulsive noise shall not exceed 1% of the area of the nature conservation site "Sylter Außenriff - Östliche Deutsche Bucht", which is identified as calving ground for harbour porpoises.

The rules presume compliance with thresholds at activity level (SEL < 160 dB re 1 $\mu Pa^2 s$, Lpeak < 190 dB re 1µPa) and onset of significant disturbance at 140 dB re 1 $\mu Pa^2 s$.

Figure 15 shows that criterion a) was safely met for a SEL of 160 dB re 1$\mu Pa^2 s$ at 750 m. The rate was well below 5% for the entire half year. A temporally parallel pile driving activity would have been possible. However, Figure 15 also shows that for a SEL of 180 dB re 1$\mu Pa^2 s$ at 750 m (non-mitigated case), criterion a) was not met. It should however be noted that according to [11] a propagation model was used, which rather overestimates occurring sound pressure values at long distances.

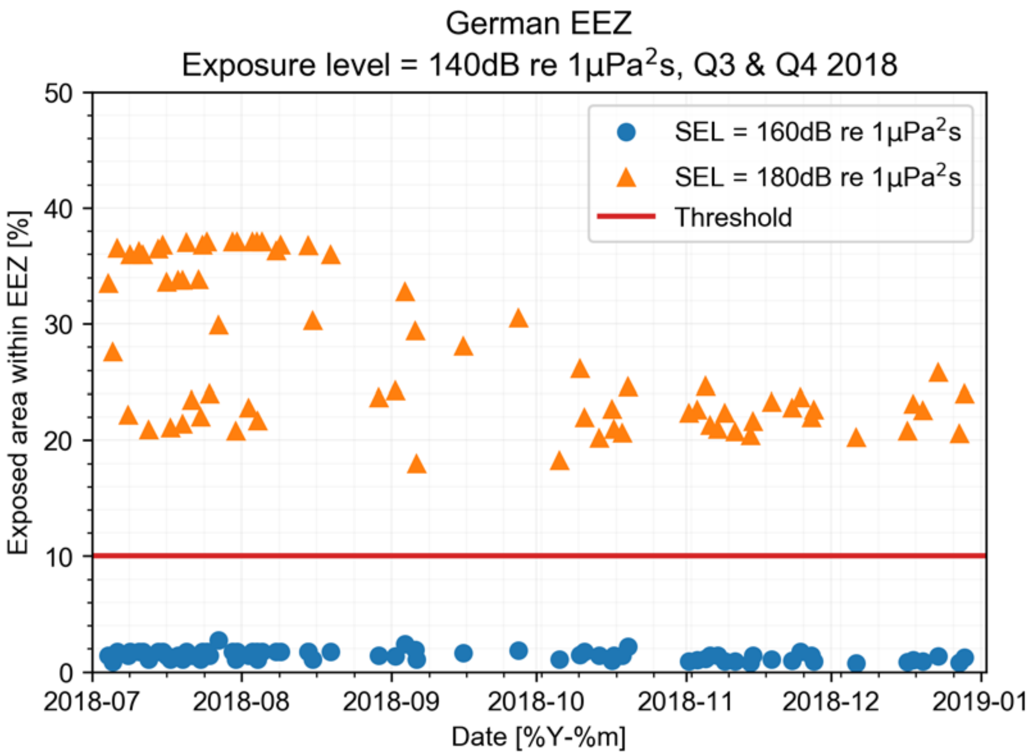


Figure 15: Percentage of area exposed per day within the German EEZ for a source strength of SEL 160 dB re 1 µPa²s, 750m, and SEL 180 dB re 1 µPa²s, 750m with 10% criteria.

If criterion b) is considered for the example of the nature conservation area "Borkum Riffgrund", the resulting situation is shown in Figure 16. Again, the criterion is fulfilled in most cases for a compliance with a SEL of 160 dB re 1µPa²s at 750 m. Without noise abatement measures, the threshold would always be exceeded.

\\S-ham-fs01\allefirmen\M\Proj\146\M146361\M146361_16_Ber_1E.DOCX:18. 05. 2020

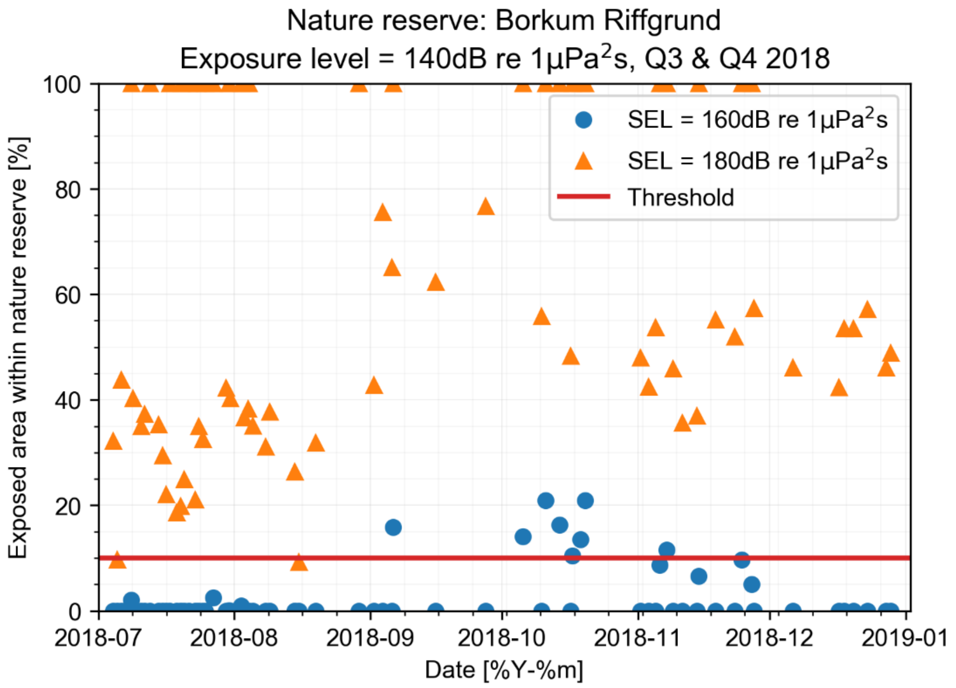


Figure 16: Exposed area over time (daily resolved) within nature conservation area (Borkum Riffgrund) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 10% criteria.

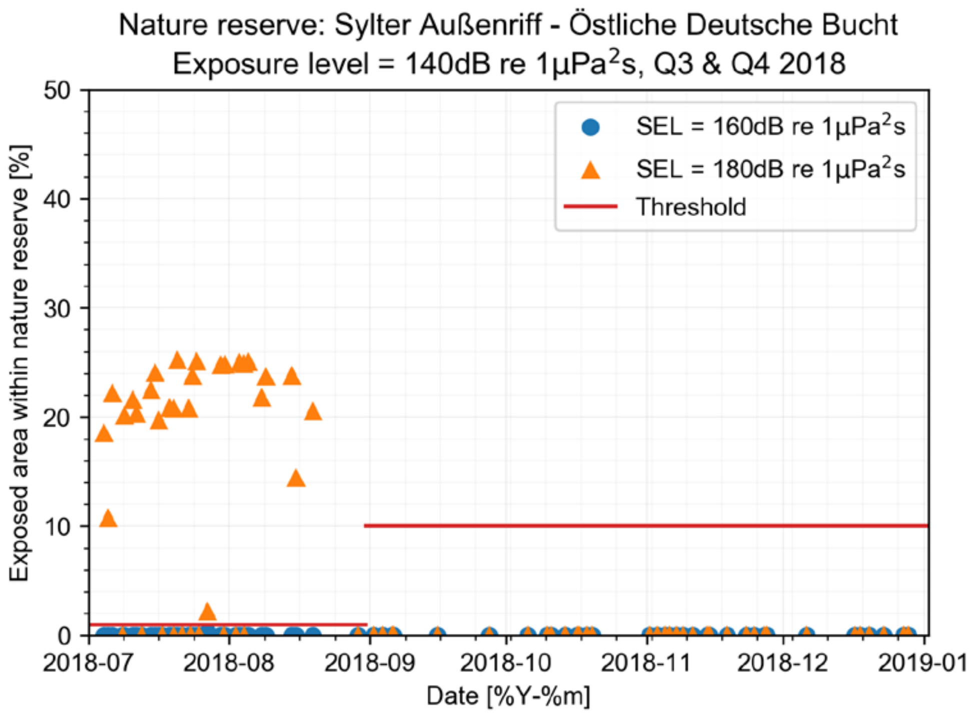
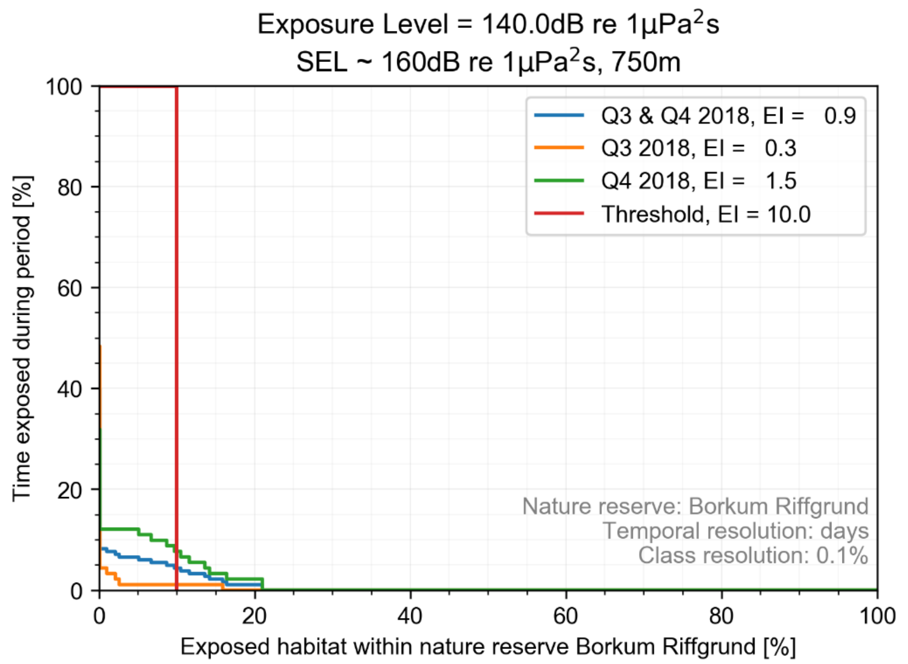


Figure 17: Exposed area over time (daily resolved) within nature conservation area (Sylter Außenriff) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 1% and 10% criteria.

The last case c) is displayed in Figure 17 for the Nature conservation area “Sylter-Aussenriff”. For the period considered, the target was met during the construction phase in 2018. If no noise abatement measures had been used, it would not have been possible to meet the target.

Finally, let us briefly consider the exposure curve and Exposure Index (EI) proposed by OSPAR. Figure 18 shows the test case for the nature conservation area “Borkum Riffgrund”. In addition, the 10% area criterion is considered. This criterion leads to a corresponding single value EI of 10. The EI remained below this value during the period under consideration in the construction phase, however at individual times the 10% rule was exceeded. Hence, the consideration of the EI alone is therefore not suitable for assessing the specific situation and might be complemented by additional spatial and temporal criteria.



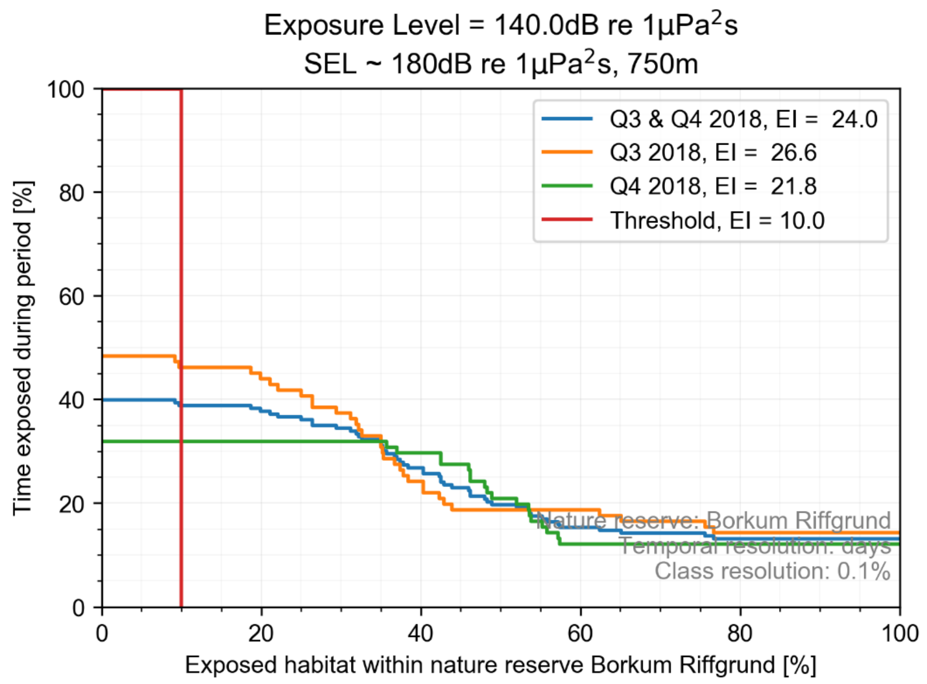


Figure 18: Exposure curves and Exposure Index: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB and 180 dB re 1 µPa²s at 750m and a maximum permissible received exposure level of 140 dB re 1 µPa²s.

4.6 Discussion of the different assessment methods in relation to the Exposure Index

In principle, there are two different evaluation options, one based on habitats (e.g. Natura 2000 sites) and one based on population. For the population option, one can assume mean distributions and "exact" distributions (snap shots) determined for a particular time span. Both will result in an additional uncertainty in the prediction. However, independently of the approach taken, a comparability of the indicator and assessment result should be guaranteed.

In the OSPAR-approach, observed radii of action are assumed for mitigated (12 km) and non-mitigated sound events (20 km). However, these radii do not correlate with the radii that would be determined according to the application of sound mitigation measures based on sound propagation. An example on this is given in Figure 19.

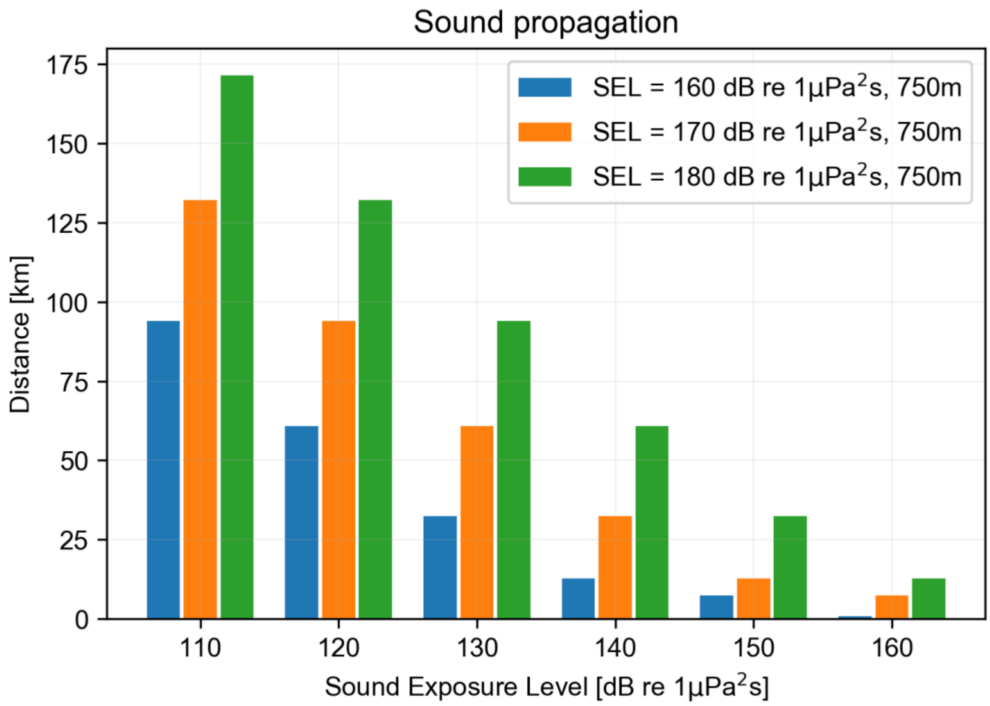


Figure 19: Distance to Received Sound Exposure Level for different source strength (computed according to [1]).

If the assessment were to be based on the hearing threshold (curve), in this case for harbour porpoise, an even more profound analysis would be required, as most sound abatement systems provide better insulation in the medium and high frequency spectrum, see Figure 20.

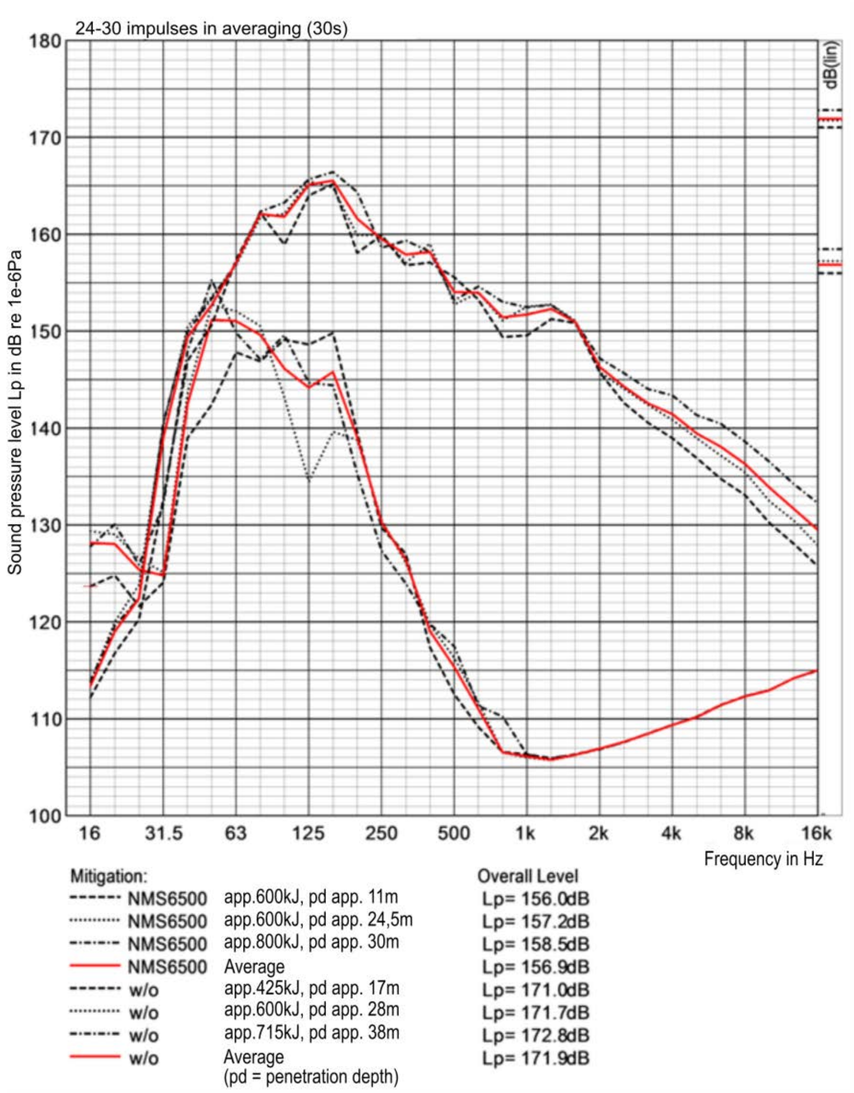


Figure 20: Sound Pressure Level with and without mitigation measures [9].

Auditory frequency weighting is regularly discussed, see [5]. A frequency weighting would emphasize the positive influence of noise abatement measures even more clearly. However, suitable threshold values should be further evaluated and proposed by bioacoustic experts.

4.7 Significance of the classification in the noise registry

Some member states of the European Union (e.g. Belgium, the Netherlands, Germany and Denmark) have initiated acoustic measurements to determine the actual noise impact during pile driving activities. Often, the measurements were (or are being) carried out in a distance of approx. 750 m to the piling location. National [6] and international standards [6] have adopted this measuring distance and recommend it, which has helped to build up a large data base that is likely to further increase. OSPAR has already introduced this information as non-mandatory entries for the template of the noise register.

The following task will be to integrate noise abatement systems and results of the measurements when it comes to formulate source levels for pile-driving noise (status Sep. 2019) [10]. A categorisation of sound events (pile-driving) is now under discussion in TG Noise as shown in Table 1.

Table 1: Current state of discussion of the categorisation of sources.

Categories	SEL (750 m) dB re 1µPa²s	L_{peak} (750 m) dB re 1µPa
A	141 – 161	163 – 183
B	162 – 171	184 – 193
C	172 – 181	194 – 203
D	182 – 191	204 – 213
E	192 –	214 –

The sound events considered in the present study were in the categories A to C.

It is very well possible to classify the source strength objectively. If this is to be achieved for the sound impact, i.e. the Exposure Index, clear procedures must be defined in order to ensure objective statements. Uncertainties enter the approach, for example, due to the selection of habitats and the weighting of habitats. This also applies for the case when population models are used, as each approach is based on assumptions that are certainly only a limited representation of the ground truth, e.g. since not all individuals were actually monitored during the observation period.

As a conclusion drawn from this study, a direct correlation between the source category and the sound exposure index would be most reasonable. The EI naturally varies with the change in source strength. However, the sound concept that has been put into practice in Germany, see Section 4.5, adds a further component, namely the permissible spatial acoustic radiation at a threshold value of the EEZ and nature conservation area. In Table 2 an example is given which considers the approach to habitat protection in Germany. The entries of EI and a spatial criterion in the form of a percentage of exposed area (EA) are to be seen as a proposal of the concept which motivate further analysis and discussion. A first example of this concept is presented in the following table. However, further details should be examined in a deeper consideration.

Table 2: Example for a possible combination of source categories with the Exposure Index (EI) and the spatial criterion of the percentage of exposed area per day (EA) during the observation period based on received level SEL140 dB re 1µPa²s for nature conservation areas.

Categories	SEL (750 m) dB re 1µPa²s Categories	Allowed EI and EA for EEZ *		Allowed EI and EA for nature conservation area *	
		EI	EA	EI	EA
1	A	<5	<1%	<5	<1%
2	A	<5	<10%	<5	<10%
3	B	…	…	…	…
4	…	…	…	…	…

*during the observation period based on received level SEL140 dB re 1µPa²s

The assessment criteria should be clarified. Under this premise, a categorisation can be successful. From the German point of view, the undercutting of the SEL 160 dB in 750 m is a suitable measure that should also be reflected and depicted in a module for the evaluation of the behavioural disturbance.

5 Conclusion

In this study, some aspects of the assessment of an Exposure Index have been addressed. Further comparative studies are necessary to enable an objective assessment. For the consideration of sound, for example, the frequency weighting must certainly be pursued further.

The study shows that the Exposure Index can in principle describe the profit of using sound abatement systems. The methodology also allows to compare different time periods (e.g. compare different quarter of a year) and to analysis different exposure thresholds.

However, the study displays the dependency of the Exposure Index on several parameters. Assuming that the noise pressure map and the habitat follow the state-of-the-art, the most important parameters to consider are the spatial and temporal resolution. The consequences are that specifications for the spatial and temporal resolution must be made when using the Exposure Index. Otherwise, a global classification will not be possible and the comparability and interpretability of assessment results remains a challenge.

A follow up to the present study will be the analysis of the Exposure Index when different types of sound source activities occur during a given period.

Dr. rer. nat. Andreas Müller

MÜLLER-BBM

BUNDESAMT FÜR
SEESCHIFFFAHRT
UND
HYDROGRAPHIE

„Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive – BeMo“

Technical Report

An example to discuss the assessment methodologies for continuous noise

Andreas Müller

Bundesamt für Seeschifffahrt und Hydrographie
Federal Maritime and Hydrographic Agency (BSH)
Hamburg and Rostock, 2020

Research and Development Project, Order Nr. 10036955

Bundesamt für Seeschifffahrt und Hydrographie (BSH)
Federal Maritime and Hydrographic Agency
Bernhard-Nocht-Straße 78
20359 Hamburg

November 2020 / January 2021 (Version 2)

The main objective of the R&D „ Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive " is to give insights in issues of mitigation applied to reduce impact from percussive pile driving on the marine environment. Information and data in the technical report have been available by the German National Noise Registry and the Informationsystem marinEARS of BSH.

Authors are responsible for the contributions in the technical report.

Authors

Dr. Andreas Müller, Müller-BBM

To be cited as: Müller, A., 2020: An example to discuss
the assessment methodologies for continuous noise. Technical Report , R&D „Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive – BeMo", Order Nr. 10036955, Bundesamt für Seeschiffahrt und Hydrographie (BSH).

Table of contents

1 Situation and task

The TG Noise has been given the task by the EU to develop an Assessment Framework for Continuous Noise. During two workshops in October the contents were discussed controversially. From a neutral observer's point of view, there are two groups which pursue different concepts: those who have developed concepts (designed for masking) at JOMOPANS - and currently HELCOM - and the other group which wants to prepare a superordinate assessment for all influences (masking, disturbance, stress, etc.). An agreement, even a joint consideration of both concepts could not be reached. In the end, the following further course of action, among others, was determined:

Another workshop on DL3 [3] will take place on 4 December. The following is to be prepared for discussion:

- A list of the sound-sensitive key species for the respective regions with information on sound assessment possibilities, see e.g. [6].
- Examples for the assessment of masking.
- Examples for the assessment of " behavioural, stress”.

It is not the aim of this note to go into detailed individual points of previous discussion. Using an example of VHF Marine Mammels, an attempt is made to understand the differences between the concepts and to initiate a possible merging of the concepts.

2 Documents

[1] Minutes: 16th meeting of the EU Technical Group on Underwater Noise (TG Noise), 6th October 2020 – Online Webex

[2] Report: Thematic Sessions: Assessment framework of threshold values for impulsive and continuous noise 7th and 29th October 2020, Online Meeting (Webex),

[3] DL3: Technical Report, Assessment framework for threshold values for continuous sound and setting of threshold values Recommendations from TG Noise MSFD Common Implementation Strategy Technical Group on Underwater Noise (TG-NOISE), October 2020.

[4] Knudsen, V.O., R:S: Alford and J.W. Emling; Underwater ambient noise, J. Mar. Res, No. 7, p 410, 1048

[5] Aide Memoire D´Ácoustique Sous-Marine, Laboratoire D.S.M Du Bruse, Marine Nationale Detection Sous Marine

[6] "HELCOM 2019. Noise sensitivity of animals in the Baltic Sea. Baltic Sea Environment Proceedings N° 167" © 2019 Baltic Marine Environment Protection Commission (Helsinki Commission – HELCOM)

[7] Echolocation signals of wild harbour porpoises, Phocoena phocoena, Anne Villadsgaard, Magnus Wahlberg, Jakob Tougaard, Journal of Experimental Biology 2007 210: 56-64; doi: 10.1242/jeb.02618

[8] Dyndo, M. *et al.* Harbour porpoises react to low levels of high frequency vessel noise. *Sci. Rep.* **5**, 11083; doi: 10.1038/srep11083 (2015).

[9] Adrian Farcas, Claire F. Powell, Kate L. Brookes, Nathan D. Merchant, Validated shipping noise maps of the Northeast Atlantic, Science of The Total Environment, Volume 735,2020,139509, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.139509.

[10] Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.

[11] Kastelein, R. A., and Wensveen, P. J. (2008). "Effect of two levels of masking noise on the hearing threshold of a harbor porpoise (*Phocoena phocoena*) for a 4.0 kHz signal," Aquat. Mamm. **34**, 420–425. https://doi.org/10.1578/AM.34.4.2008.420

[12] Kastelein RA, Wensveen PJ, Hoek L, Au WW, Terhune JM, de Jong CA. Critical ratios in harbor porpoises (Phocoena phocoena) for tonal signals between 0.315 and 150 kHz in random Gaussian white noise. J Acoust Soc Am. 2009 Sep;126(3):1588. doi: 10.1121/1.3177274. PMID: 19739772.

[13] Kastelein, R. A., Hoek, L., de Jong, C. A. F., and Wensveen, P. J. (2010). " The effect of signal duration on the underwater detection thresholds of a harbor porpoise (Phocoena phocoena) for single frequency-modulated tonal signals be-

tween 0.25 and 160 kHz," J. Acoust. Soc. Am. 128, 3211–3222. DOI: 10.1121/1.3493435

[14] Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K., and Dooling, R. (2016). " Communication masking in marine mammals: A review and research strategy," Mar. Pollut. Bull. **103**, 15–38. https://doi.org/10.1016/j.marpolbul.2015.12.007

[15] Southall B L, Finneran J J, Reichmuth C, Nachtigall P E, Ketten D R, Bowles A E, Ellison W T, Nowacek D P, Tyack P L (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. Aquatic Mammals 2019, 45(2), 125-232, DOI 10.1578/AM.45.2.2019.125.

[16] Merchant, N. D., Farcas, A., Powell, C. F. (2018) Acoustic metric specification. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS).

[17] Jones, Esther & Hastie, Gordon & Smout, Sophie & Onoufriou, Joe & Merchant, Nathan & Brookes, Kate & Thompson, David. (2017). Seals and shipping: Quantifying population risk and individual exposure to vessel noise. Journal of Applied Ecology. 54. 10.1111/1365-2664.12911.

[18] DNVGL-RU-SHIP Pt.6 Ch.7. Edition July 2017, Silent E Notation,

[19] Thiele R., Schellstede G., (1980): Standardwerte zur Ausbreitungsdämpfung in der Nordsee. FWG-Bericht 1980-7, Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik.

[20] Moore, B. C. J. (2003). An introduction to the psychology of hearing (5th ed.). San Diego, CA: Academic Press

3 Excess level and attention level

To be able to evaluate the sound effect in relation to continuous sound, possible parameters and metrics are listed without weighting hereafter:

- Hearing Threshold,
- (Critical) bandwidth of the auditory filter,
- Auditory integration time,
- Natural sound,
- Anthropogenic sound,
- Source Level, Received level,

The Sound pressure level SPL or equivalent continuous sound level L_{eq} (or average level) is defined by

$$L_{eq} = 10 \log_{10} \frac{1/T \int_0^T p(t)^2 dt}{p_0^2}$$

with p(t) representing the sound pressure, p_0 the reference pressure 1 µPa and T the averaging time. The value can be displayed as a single number (linear, frequency-weighted) or frequency-dependent (third octave, FFT, ...). Typical integration times for continuous sound are between one and thirty seconds. In the Jomopans project [16], one second was selected and a frequency range from 10 Hz to 20 kHz was chosen.

The definition of the Attention Level is according to [3]:

Sound level above which an adverse behavioural reaction is expected in a specified key species. In this paper we define the Attention Level as L_{AL}.

The definition of the Excess Level, see e.g. [9], is the exceedance of total noise above natural noise

$$\Delta L = L_{\text{Total}} - L_{\text{Natural}}$$

L_{Total} represents the sound pressure level at the point of interest with all sound contributions (shipping, wind, rain, ...) and is a directly measurable variable. L_{Natural} is only the contribution of non-anthropogenic noise (wind, rain, ...). The quantity cannot be measured directly, but can be estimated by statistical evaluation of measurements or by direct modelling.

A question from Helcom to TG Noise, see [1], refers to the cut-off value of the Excess Level:

Cut-off value for excess level. The suggested approach relies on defining a cut-off value for the excess. If the excess level is above this cut-off value, ship noise is considered to dominate. By definition, excess is non-negative (the excess is 0 dB in the total absence of ship noise), so the cut-off value must be a positive value. The EN-

Noise proposes 20 dB as the cut-off level and invites views on this choice. A decrease in SNR of 20 dB constitutes a significant deterioration of conditions for communication and choosing a lower value is likely to introduce more uncertainty in assessments through uncertainty in the soundscape modelling.

The question of the correct choice of cut-off value is not easy to make and one should examine this question in detail in relation to the species. Questions that arise:

- Is the natural background noise really relevant in each case? A comparison with audiograms is probably necessary.
- Is it really acceptable to allow higher sound levels in sea areas with naturally noisier background noise?

From a modelling point of view, I find the choice of 20 dB acceptable, since it can be expected that the prediction inaccuracy, including natural background noise, is not negligible, especially in the frequency range < 400 Hz over the broad frequency range.

I would like to take the opportunity to provide a bridge to merge the different concepts. The cut-off criterion can be expressed in formulas, as follows:

$$\Delta L_{\text{Cutt-off}} = L_{\text{Total}} - L_{\text{Natural}} = 20\,\text{dB}$$

The level thus determined (L_{Total}) is therefore the limit above which communication decreases. This value could be equated with the Attention Level. Shown in formulas:

$$L_{\text{AL}} = L_{\text{Total}} = L_{Natural} + 20\text{dB}$$

From a scientific point of view, I can well understand the consideration of the excess level, but I guess that you also need an absolute reference level.

As an example, the perception of sound in humans and the regulations you have to follow should give you an indication:

The A-weighted sound pressure level is a good measure to assess the human auditory perception. This means that one feels quite comfortable in an environment of 20 dB(A) to 35 dB(A) and can also relax (sleep). At 50 dB(A) acceptable working conditions are still given. Between 60-70 dB(A), communication is considerably more difficult. From 80 dB(A) at the latest 85 dB(A) hearing protection is already required. For noisy working environments, in principle the cumulative SEL is also considered over the day. If one had to apply the Excess Level to humans and chose a criterion of 20 dB above a hearing threshold or a very quiet background, this would certainly be a poor estimator of reduced communication.

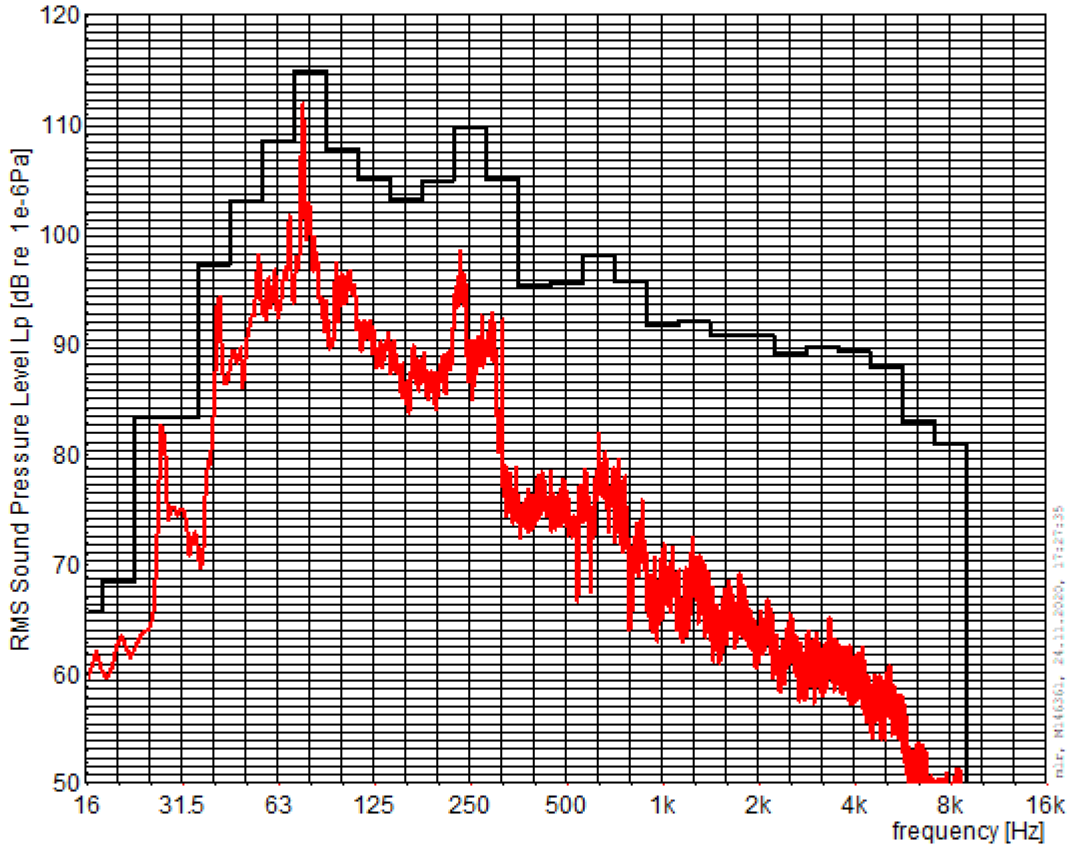


Figure 1: Exemplary diagram of sound pressure spectrum generated by a ship in in unknown distance. The spectrum is shown as FFT and in third-octave bandwidth. In the frequency range significantly below 1000 Hz, spectral lines of the propulsion system with propeller and propulsion engine, gear, etc. are typically observed. In the higher frequency range above 1 kHz the flow and cavitation noises dominate which have a rather broadband frequency character. At high frequencies at several kHz, the spectrum may still increase due to cavitation. Audible cavitation-induced modulations of the propeller speed/blades can be investigated with a modulation analysis.

In addition to the A-weighted sound pressure level, the C-weighting of the sound pressure level, for example, has been introduced for the assessment of sound. The difference between the C-weighted sound pressure level and the A-weighted sound pressure level is a measure of the annoyance of low-frequency sound. These low-frequency "disturbing" contributions of exhaust noise e.g. from ships are well known, especially in urban ports. Very tonal sounds are also perceived as disturbing. Therefore, in regulations there is an explicit "tone addition" in dB to the determined sound pressure levels to appreciate this annoyance.

Figure 1 shows a "typical" frequency spectrum of the emitted sound of a ship. In the frequency range below 1000 Hz, spectral lines of the propulsion system can be seen, in the frequency range above 1000 Hz the spectrum based on the respective thirds is almost equally distributed. This is helpful for the study of the VHF (Very High Frequency) species, as the spectral distribution corresponds to that of the natural background noise.

4 Example for VHF marine mammals

4.1 Preliminary remark

VHF Species have been selected which can hear very well over a wide frequency range up to 160 kHz. The active communication range (echo localisation) of the harbour porpoises occurring in the North Sea and Baltic Sea ranges between 100 and 160 kHz [7] and is thus clearly outside the frequency range of the intended investigations. In some scientific studies the influence of ship noise is pointed out [8] and scientifically investigated with regard to communication masking [14].

Other species such as the harbour seals, which can hear very well in the frequency range up to 10,000 Hz, have been considered in [17].

In the following, a simple academic example is used to apply the methodology to a VHF species. Explanations with greater scientific insight can also be found in [14].

4.2 The simple approach

Figure 2 shows the result of a simple calculation of ship noise (based on power spectrum density level) at a distance from the receiver (VHF Species) of 500 m, 1000 m and 10000 m. For the estimation, the Silent E curve of a classification society [18] was used, which is a good estimate for the mean source level of merchant ships. The sound propagation calculation was carried out with an empirical formula according to Thiele & Schellstede [19], determined for the North Sea, which is valid in the frequency range up to 10,000 Hz and should cover a range of up to 80 km. The result was compared with a Southall *tone* audiogram for VHF Marine Mammels [10]. Furthermore, the critical ratio determined by Kastelein for harbour porpoise is shown [12]. The ambient noise was simulated by a simple Knudsen sea state curve [4] and for the very high frequency range an approximation [5] of the thermal noise was introduced.

Definitions [14] necessary to interpret the example:

Critical Band (CB)

Critical band or auditory filter: one of an array of bandpass filters that are assumed to exist in the peripheral auditory system [20]. The frequency band of sound, being part of a continuous-spectrum noise covering a wide band, that contains sound power equal to that of a pure tone centred in the CB and just audible in the presence of the wideband noise.

Critical Ratio

Critical ratio (CR) The difference between the sound pressure level of a pure tone just audible in the presence of a continuous noise of constant spectral density and the sound pressure spectrum level for that noise expressed in dB.

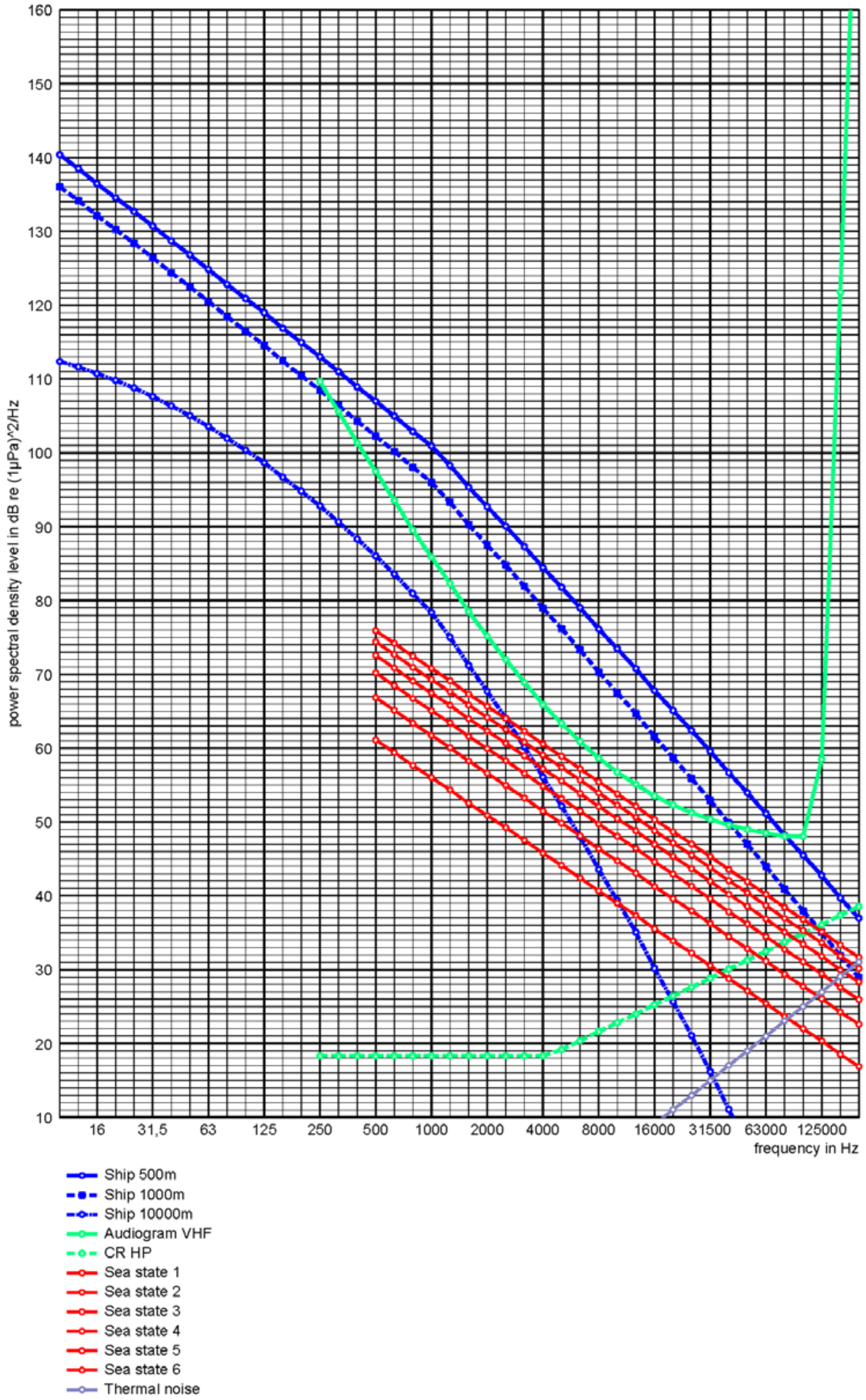


Figure 2: Shipping noise at different distances from the receiver (animal), compared to the hearing curve of VHF marine mammels and natural background noise. CR_HP: *critical ratio* for the harbour porpoise.

Notation: This figure has been updated in this report (version 2) due to an error in the representation of ship noise.

The result shows quite clearly that in the middle frequency range between 2,000 Hz and 8,000 Hz the ship is still audible at a distance of 500 m to 1,000 m. If one takes the critical ratio and the auditory (critical) bandwidth at the respective frequency into account, here using the example of a porpoise (dashed green curve), one is about 35 dB above the hearing threshold. It should be noted, however, that in the case of sea state 6, hearing is limited via the SNR. Because of the background noise, the hearing threshold would be raised, see e.g. [11], and the remaining level difference would be only 15 dB at e.g. 8 kHz. Good to have this 15 dB to recognize a ship.

It is the task of bio acousticians to decide from which level and in which frequency range sound levels are critical for which problem. If only the excess level is considered, the distance of 10 km at 2 kHz would still appear critical. However, the level is only just above the hearing curve.

The impact range of the continuous noise of vessels seems to be small for VHF species. For modelling purposes, it must be assumed that large grids are used. In paper from Farcas [9], a grid of about 1 km^2 was mentioned.

5 Conclusion

The concepts "Attention level" and Excess level can be combined. There is a need to determine appropriate thresholds or frequency weightings for the key species to be identified. It is necessary to consider the respective hearing ability (frequency ranges for hearing, localization, communication) in detail.

The VHF species do not appear to be key species for continuous sound.

Dr. rer. nat. Andreas Müller