LATVIJAS HIDROEKOLOĢIJAS INSTITŪTS

Eiropas savienības Eiropas Jūrlietu un zivsaimniecības fonda Rīcības programmas zivsaimniecības attīstībai 2014.-2020.gadā prioritātes "Veicināt integrētās jūrlietu politikas īstenošanu" atbalstāmā pasākuma "Zināšanu uzlabošana jūras vides stāvokļa jomā" projekta Nr. 17-00-F06803-000001 ietvaros noslēgtā (iepirkuma identifikācijas Nr. VARAM 2016/54)

Līguma Nr IL/106/2017

NOSLĒGUMA ZIŅOJUMS

LATVIJAS JŪRAS ŪDEŅOS NOVĒROJAMĀ TROKŠŅU, T.SK., ZEMŪDENS TROKŠŅA, LĪMEŅA NOVĒRTĒJUMS (D11)

Izpildes termiņš: 20.06.2022

Rīga, 2022

Saturs

KOPSAVILKUMS

Eiropas Savienības Eiropas Jūrlietu un zivsaimniecības fonda projekta Nr. 17-00F06803-000001 ietvaros noslēgtā līgumdarba "Zināšanu uzlabošana jūras vides stāvokļa jomā (Līguma Nr. IL/106/2017) (turpmāk tekstā – Līgumdarbs) ietvaros tika veikts pētījums, lai celtu zināšanu kapacitāti un iegūtu nepieciešamo datu materiālu 11. Raksturlieluma "Enerģijas ievades, tostarp zemūdens trokšņa, pakāpe nerada nelabvēlīgu ietekmi uz jūras vidi" vides stāvokļa novērtēšanai.

Saskaņā ar zemūdens trokšņa mērījumu un modelēšanas rezultātiem, zemūdens trokšņa līmenis Rīgas līcī ir salīdzinoši zems. Latvijas teritoriālajos un EEZ ūdeņos Baltijas jūrā trokšņa līmenis ir salīdzinoši augstāks, bet jūtami zemāks kā Zviedrijas EEZ ūdeņos, kur telpiski atrodas galvenais kuģu satiksmes koridors. Salīdzinot trokšņa telpiskās izplatības laukus ar potenciāli ietekmēto sugu populācijas izplatības areālu, var konstatēt, ka potenciāli jūtīgo sugu izplatības areāls nepārklājas ar intensīvākajiem trokšņa izplatības laukumiem. Tomēr, izdar't secinājumus par to vai kāda no potenciāli ietekmētajām sugām ir reāli ietekmēta vai nav šobrīd nav iespējams, jo EK TG-Noise grupā joprojām tiek strādāts pie laba vides stāvokļa robežvērtību definēšanas.

IEVADS

Eiropas Savienības Eiropas Jūrlietu un zivsaimniecības fonda projekta Nr. 17-00F06803-000001 ietvaros noslēgtā līgumdarba "Zināšanu uzlabošana jūras vides stāvokļa jomā (Līguma Nr. IL/106/2017) (turpmāk tekstā – Līgumdarbs) ietvaros tika veikts pētījums, lai celtu zināšanu kapacitāti un iegūtu nepieciešamo datu materiālu 11. Raksturlieluma "Enerģijas ievades, tostarp zemūdens trokšņa, pakāpe nerada nelabvēlīgu ietekmi uz jūras vidi" vides stāvokļa novērtēšanai. Pētījums galvenokārt fokusējās uz 11. Raksturlieluma kritēriju: D11C2 (primārais kritērijs) – Antropogēnas, nepārtrauktas zemas frekvences skaņas telpiskā izplatība, ilgums un līmenis nepārsniedz līmeni, pie kura rodas nelabvēlīga ietekme uz jūras dzīvnieku populācijām.

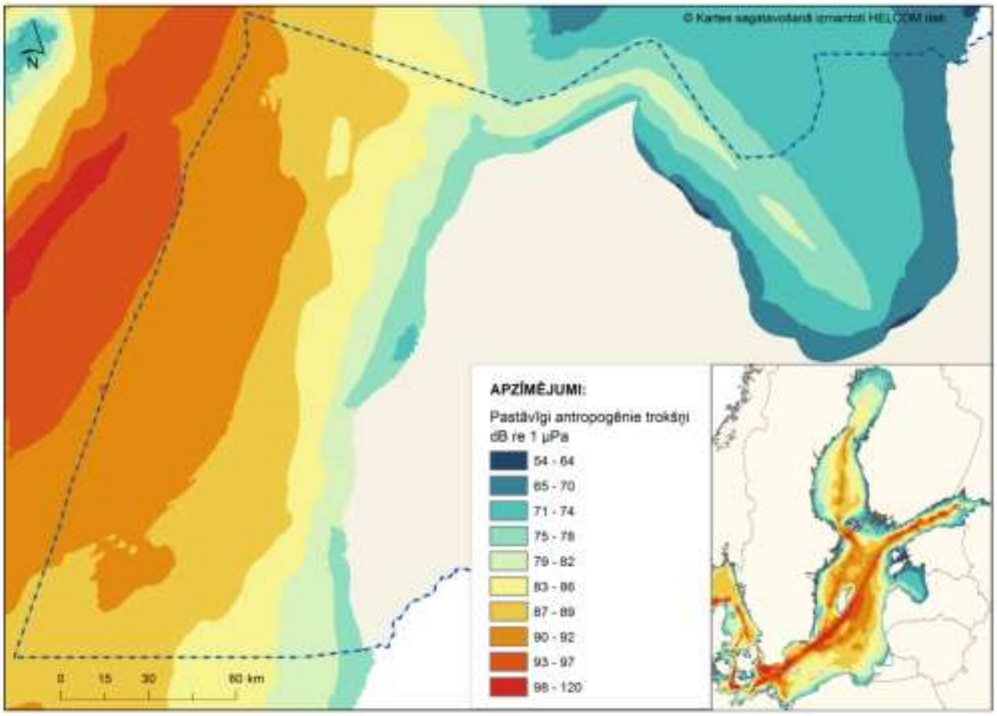
Zemas frekvences skaņas jūrā parasti tiek asociētas ar kuģu radītajiem trokšņiem. Baltijas jūrā projekta BIAS (*Baltic Sea Information on the Acoustic Soundscape*) ietvaros tika adaptēts JSD raksturlielums D11 Baltijas jūras reģionam, kā arī tika veikti trokšņu mērījumi un trokšņu modelēšana. Attiecīgi Baltijas jūrai ir pieejama informācija par zemas frekvences trokšņa telpisko izplatību. Tomēr uz atskaites sagatavošanas brīdi joprojām tiek strādāts pie zemūdens trokšņa ietekmes uz dzīvajiem organismiem novērtēšanas. Šī pētījuma ietvaros ir veikts pilotpētījums, lai apzinātu slodzes (zemas frekvences zemūdens troksnis) un bioloģisko organismu, kurus šis troksnis varētu potenciāli ietekmēt, savstarpēju sasaisti.

1. ZEMŪDENS TROKŠŅA LĪMEŅU NOTEIKŠANA

Lai noteiktu zemūdens trokšņu līmeni, praksē par visprecīzāko metodi tiek uzskatīta mērīšana ar hidrofonu, ar kura palīdzību var noteikt konkrēta zemūdens apgabala trokšņu līmeni laikā. Tā kā šādi mērījumi ar hidrofoniem ir salīdzinoši dārgi un aptver salīdzinoši nelielu teritoriju, trokšņu līmeņa aprēķiniem bieži tiek izmantoti dažādi empīriski modeļi vai tiek veikta trokšņu līmeņa modelēšana (izmantojot datorprogrammas), kurās par pamatu tiek izmantots un pielāgots kāds no empīriskajiem modeļiem.

Izmantojot hidrofonus, visaptverošākie trokšņu mērījumi par Baltijas jūras reģionu tika veikti projekta BIAS ietvaros 2014. gadā, kad 36 novērojumu stacijās tika veikts trokšņu monitorings. Trokšņu mērījumi tika veikti 7 valstu teritoriālajos ūdeņos, taču, tā kā Latvija nebija iesaistīta šī projekta īstenošanā, trokšņu mērījumi Latvijas teritoriālajos ūdeņos netika veikti. Šī projekta ietvaros pilotpētījuma veidā tika veikti trokšņu mērījumi ar hidrofonu. Tomēr, tā kā šie mērījumi tika veikti jau pēc BIAS modeleto rezultātu publicēšanas, Latvijas ūdeņos iegūtie dati netika izmantoti. Izmantojot datus no hidrofoniem, informāciju par kuģu satiksmi u.c., BIAS projekta ietvaros tika izveidota antropogēnas izcelsmes trokšņu karte (*1.1. attēls*).

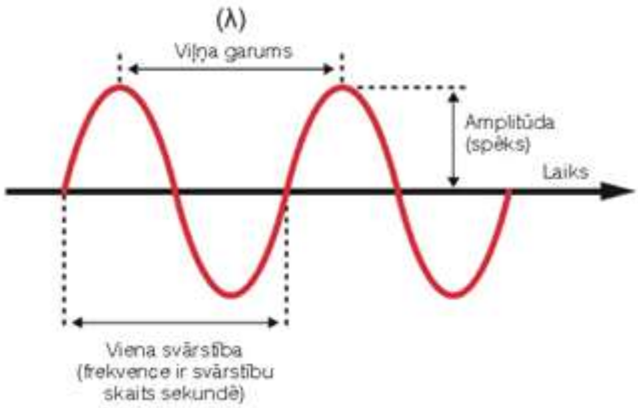
Pastāvīgi antropogēnas izcelsmes trokšņi lielākoties ir saistīti ar kuģu satiksmi un to radītajiem trokšņiem. Baltijas jūrā lielākais trokšņu piesārņojums novērojams tieši ap galvenajiem kuģu satiksmes maršrutiem (*1.1. attēls*), kur var novērot arī trokšņu maksimālās vērtības (98-120 dB re 1µPa). Latvijas teritoriālajos ūdeņos Baltijas jūrā pastāvīgo antropogēno trokšņu līmenis pakāpeniski samazinās virzienā uz krastu – no 90-92 dB re 1µPa reģionos, kuri ir vistuvāk galvenajam kuģu satiksmes ceļam, līdz pārsvarā 75-82 dB re 1µPa piekrastes reģionos. Latvijas teritoriālajos ūdeņos Rīgas līcī pastāvīgo antropogēno trokšņu līmenis ir zemāks nekā Baltijas jūras atklātajā daļā, un tas kopumā nepārsniedz to līmeni, kas tika novērots Baltijas jūras piekrastē (75-82 dB re 1µPa). Līča reģionos, kuri ir tālāk no kuģu ceļa, trokšņu līmenis ir 71-74 dB re 1µPa robežās, savukārt līča piekrastē trokšņu līmenis ir zem 70 dB re 1µPa. Neskatoties uz to, ir jāņem vērā, ka praksē trokšņi (skaņa) Latvijas teritoriālajos ūdeņos nav mērīti, un iegūtie rezultāti ir modelēti, kas nozīmē, ka ir jābūt uzmanīgiem ar šo rezultātu interpretāciju. Piemēram, kuģu satiksmes radītie trokšņi uz/no Ventspils un Liepājas ostām šajā trokšņu kartē neparādās, savukārt Rīgas līcī trokšņu līmenis pie Rīgas ir salīdzinoši mazs (54-70 dB re 1µPa), neskatoties uz to, ka lielākajai daļai kuģu galamērķis ir Rīga.



1.1. attēls. ***Skaņas spiediena līmenis (dB re 1µPa) Baltijas jūrā un Latvijas teritoriālajos ūdeņos 2014. gadā (vidējā vērtība no 63 Hz, 125 Hz un 2 kHz frekvencēm)***

2. SKAŅAS (TROKŠŅA) RAKSTURLIELUMI UN KUĢI KĀ TROKŠŅA AVOTS

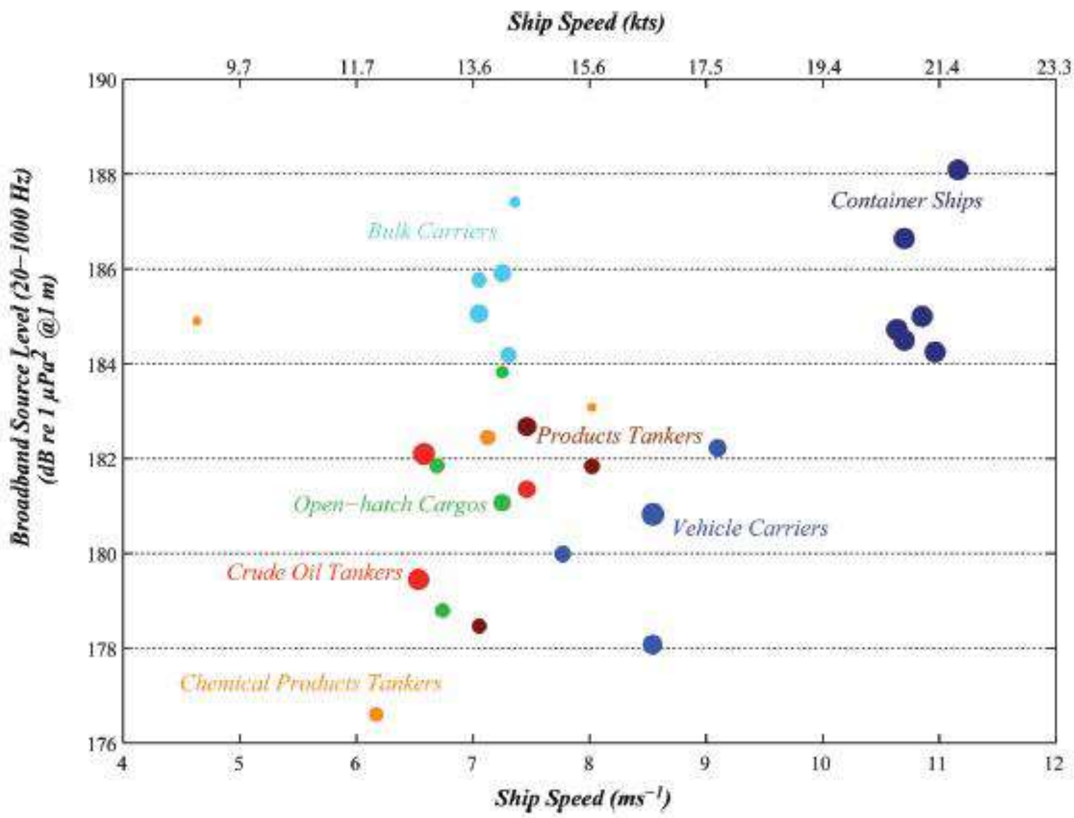
Skaņa tiek definēta kā mehāniskas svārstības, kas var norisināties dažādās vidēs. Tā var izplatīties gan garenviļņu (daļiņas izplatās viļņa kustības virzienā), gan šķērsviļņu veidā (daļiņas izplatās perpendikulāri viļņa izplatīšanās virzienam). Enerģijai saskaroties ar vides molekulām, rodas svārstveida vibrācijas un rodas skaņas vilnis, kas vada skaņas enerģiju. Skaņas vilni pamatā raksturo tā garums, frekvence un amplitūda (*2.1. attēls*).



2.1. attēls. ***Skaņas viļņa shēma***

Skaņas viļņu enerģiju raksturo skaņas intensitāte, taču praksē mēra skaņas intensitātes līmeni, kuru izsaka decibelos (dB). Ūdenī skaņu raksturo skaņas spiediena līmenis - skaņas spiedienu mēra paskālos (Pa), bet skaņas spiediena līmeni decibelos. Dažkārt zemūdens trokšņu raksturošanai izmanto tādu parametru kā skaņas(trokšņu) avota līmenis, kas apzīmē, skaņas stiprumu, kurš mērīts no atskaites distances. Pamatā šī distance ir 1 m, kas aprēķinos parādās pie skaņas spiediena līmeņa mērvienības šādā formā - dB re 1m, 1µPa.

Zemūdens trokšņi tiek klasificēti 2 grupās - antropogēna impulsīva skaņa ūdenī un antropogēns, zemas frekvences troksnis ūdenī. Kuģu satiksmes radītie trokšņi ir visizplatītākais un biežākais antropogēno trokšņu veids jūras vidē, kurus klasificē kā ilgstošus zemas frekvences trokšņus (D11.2). Tos galvenokārt rada dzenskrūvju kavitācija, dzinēja sistēmas un pats kuģa korpuss, bet to stiprums ir atkarīgs gan no kuģa konstrukcijas īpašībām (dzenskrūvju parametriem, kuģa izmēriem un tipa, dzinēju parametriem, kuģa izspaida u.c.), gan pārvietošanās ātruma. Kuģu satiksmes radītie trokšņi var būt gan zemas frekvences (1-10 Hz), vidējas frekvences (10- 1000 Hz), vai arī augstas frekvences (1000 Hz līdz 20 kHz), taču lielākoties kuģu radītie trokšņi ir frekvencēs no 10-1000 Hz, tāpēc kuģu radītos trokšņus parasti raksturo kā zemas vai vidējas frekvences.



*2.2. attēls. **Kuģu radītais skaņas spiediena līmenis attiecībā pret to pārvietošanās ātrumu** (McKenna et.al., 2012)*

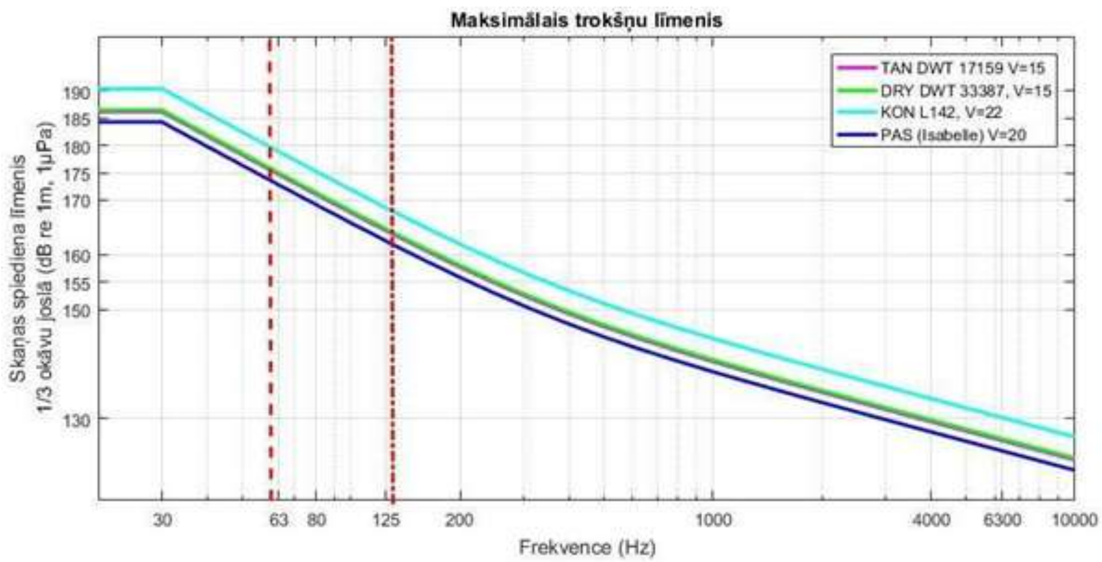
Iepriekš veiktos pētījumos par kuģu zemūdens trokšņiem kuģi sākotnēji klasificēti pēc to tipa - tas ir viens no faktoriem, kas ietekmē radīto trokšņu daudzumu. Par trokšņainākiem kuģiem tiek uzskatīti konteineru kuģi, mazāk trokšņaini kuģi ir ķīmisko produktu tankkuģi (*2.2. attēls*). Faktori, kas konteineru kuģus padara tik trokšņainus, ir tas, ka tie pārvietojas ar lielāku ātrumu, tie bieži vien izmēros ir lielāki un ar lielāku kravnesību. Visi šie faktori nosaka to, ka lielākam kuģim ir nepieciešama lielāka dzinēja jauda, kas ir viens no galvenajiem trokšņu radītājiem. Pie viena no būtiskākajiem faktoriem ir jāmin arī kuģa pārvietošanās ātrums, kas ir cieši saistīts ar kavitācijas procesa ierosināšanu (jo ātrums pēc iespējas tuvāks ekspluatācijas ātrumam, jo kavitācija būs spēcīgāka), tādējādi palielinot kuģa emitēto trokšņu līmeni.

Pētījumā par kuģu emitētajiem trokšņiem un kuģu satiksmi Rīgas līcī (Berga, 2017) tika aprēķināts minimālais un maksimālais skaņas spiediena līmenis (pēc SONIC modeļa) atkarībā no kuģa tipa, tā pārvietošanās ātruma u.c. parametriem (*2.1. tabula*).

2.1. tabula. ***Emitētais skaņas spiediena līmenis atkarībā no kuģa tipa***

Kuģa tips	Skaņas spiediena līmenis (dB re 1µPa)	
	63 Hz frekvence	125 Hz frekvence
Tankkuģi	153-175	143-164
Sauskravu kuģi	155-175	145-165
Konteineru kuģi	161-179	151-168
Pasažieru kuģi	162-172	152-161

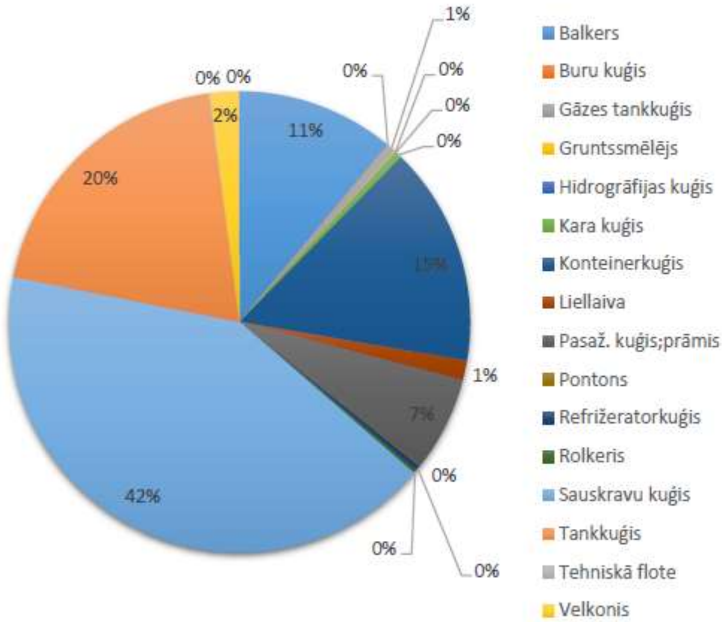
Iegūtie rezultāti apstiprināja literatūras avotos aprakstīto un parādīja, ka konteineru kuģi ir kuģu tips, kas potenciāli emitē vislielāko skaņas spiediena līmeni (*2.3. attēls*).



2.3. attēls. ***Maksimālais emitētais skaņas spiediena līmenis atkarībā no kuģa tipa (TAN – tankkuģi, DRY – sauskravu kuģi, KON – konteineru kuģi, PAS – pasažieru kuģi)***

3. KUĢU SATIKSME RĪGAS LĪCĪ UN BALTIJAS JŪRAS LATVIJAS TERITORIĀLAJOS UN EEZ ŪDEŅOS

Rīgas līcī lielākoties kuģu satiksme notiek uz Rīgas ostu un no tās uz citiem galamērķiem. Pētījums par kuģu satiksmi 2015. gadā (Berga, 2017) parādīja, ka 5 kuģu tipi sastāda 95% no visiem Rīgas ostā ienākošajiem kuģiem (*3.1. attēls*).

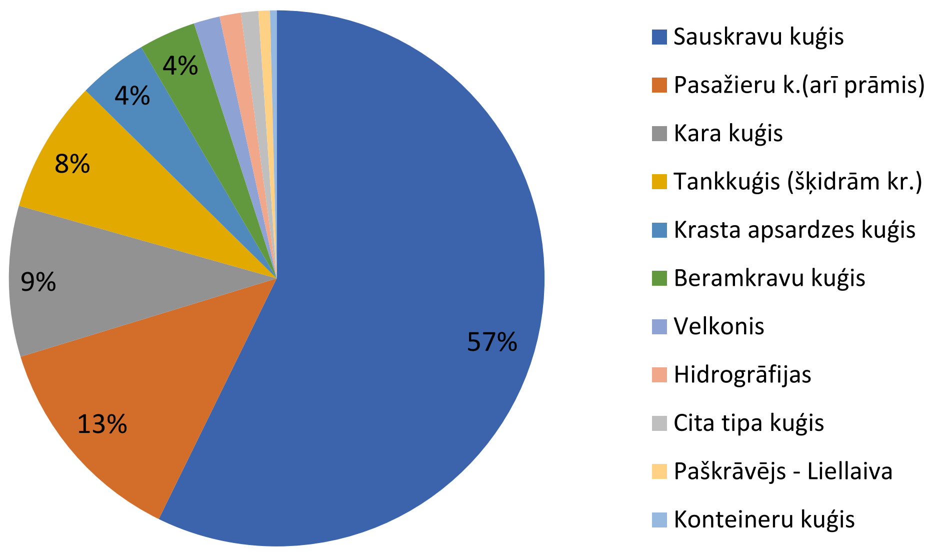


3.1. attēls. ***Ienākošo kuģu sadalījums pēc to tipa Rīgas ostā 2015. gadā***

Procentuāli lielāko daļu sastāda sauskravu jeb ģenerālkravu kuģi, savukārt apmēram uz pusi mazāk Rīgas ostu ir apmeklējuši tankkuģi. Trešajā vietā ir konteinerkuģi, ceturtajā - beramkravu kuģi, bet kā piektais kuģa tips ir pasažieru kuģi. Kopējais ienākošo kuģu skaits Rīgas ostā 2015. gadā bija 3670.

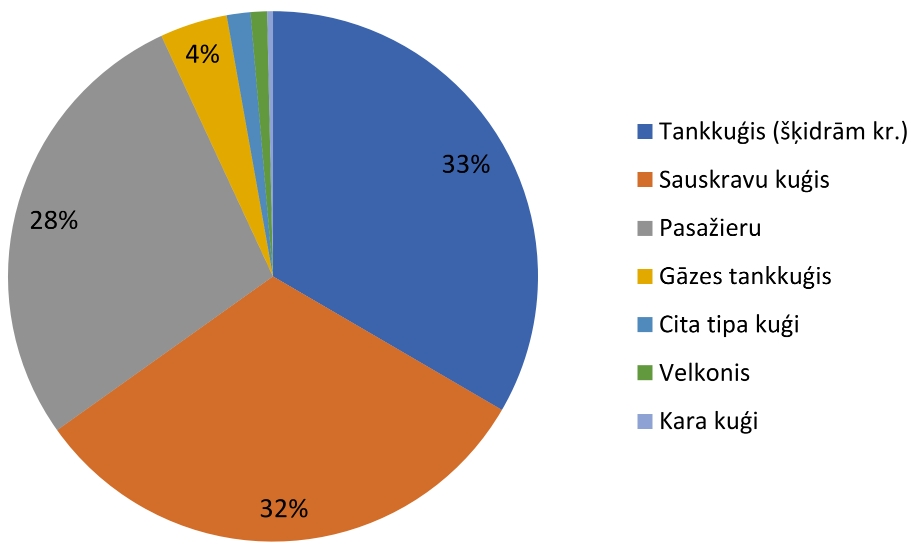
Kuģu satiksmes intensitāte Rīgas līcī tiek raksturota ar kuģu kustību skaitu konkrētajā gadā. Ja 2015. gadā Rīgas līcī kopā ienāca 3670 kuģi, tad kustību skaits ir divreiz lielāks (7340), ņemot vērā, ka katrs kuģis šķērso līci divas reizes (ieejot Rīgas ostā un izejot no tās).

Baltijas jūras piekrastē atrodas divas lielas ostas – Liepāja un Ventspils. Laika posmā no 2014.-2016. gadam Liepājas ostā kopā ienāca 4761 kuģis, līdz ar to kuģu kustību skaits šajā laika periodā bija 9522. Līdzīgi kā Rīgas ostā arī Liepājas ostā procentuāli lielāko daļu no ienākošo kuģu skaita veido sauskravu kuģi. Pārējie kuģu tipi Liepājas ostā ir ienākuši krietni retāk (*3.2. attēls*) – pasažieru kuģi/prāmji, kara kuģi un tankkuģi. Vēl mazāk Liepājas ostā ir ienākuši krasta apsardzes kuģi un beramkravu kuģi, savukārt pārējie kuģu tipi veido vēl mazāku īpatsvaru.



3.2. attēls. ***Ienākošo kuģu sadalījums pēc to tipa Liepājas ostā 2014.-2016. gadā***

Ventspils ostā laika posmā no 2014.-2016. gadam ienāca par 267 kuģiem mazāk nekā Liepājā, un kopējais ienākošo kuģu skaits bija 4494, līdz ar to kuģu kustību skaits šajā laika periodā bija 8988. Atšķirībā no Liepājas ostas, kur 57% no ienākošajiem kuģiem bija sauskravu kuģi,



3.3. attēls. ***Ienākošo kuģu sadalījums pēc to tipa Ventspils ostā 2014.-2016. gadā***

Ventspils ostā var izdalīt trīs galvenos kuģu tipus (*3.3. attēls*), kuri visi veido aptuveni vienādu īpatsvaru no visiem ostā ienākošajiem kuģiem – tankkuģi, sauskravu kuģi un pasažieru kuģi. Pēc šīm trim lielajām grupām nākamā ir gāzes tankkuģi, taču tie veido tikai 4% no kopējā kuģu īpatsvara. Velkoņi, kara kuģi un cita tipa kuģi ir zem 4% no kopējā ienākošo kuģu skaita.

Aplūkojot Liepājas un Ventspils ostā ienākošo kuģu sadalījumu pēc tipiem, var secināt, ka konteinerkuģi, kā potenciāli lielākie trokšņu radītāji, abās šajās ostās ienāk ļoti mazā skaitā. Neskatoties uz to, pasažieru kuģi un sauskravu kuģi veido lielāko daļu no abās ostās ienākošajiem kuģiem, un šie abi kuģu tipi parasti pārvietojas salīdzinoši ātri un tie tiek uzskatīti par nākamajiem lielākajiem trokšņu radītājiem aiz konteinerkuģiem (*2.1. tabula*). Esošā informācija un pētījumi Latvijas teritoriālajos ūdeņos ir nepietiekami (vai nav nemaz), lai spriestu, pirmkārt, par precīzu kuģu emitēto trokšņu līmeni un, otrkārt, par katra kuģa tipa potenciālo ietekmi uz dzīvajiem organismiem. Esošais novērtējums var sniegt tikai virspusēju informāciju par kuģu emitētajiem trokšņiem, balstoties uz kuģu satiksmes datiem.

4. TROKŠŅA IETEKME UZ DZĪVAJIEM ORGANISMIEM

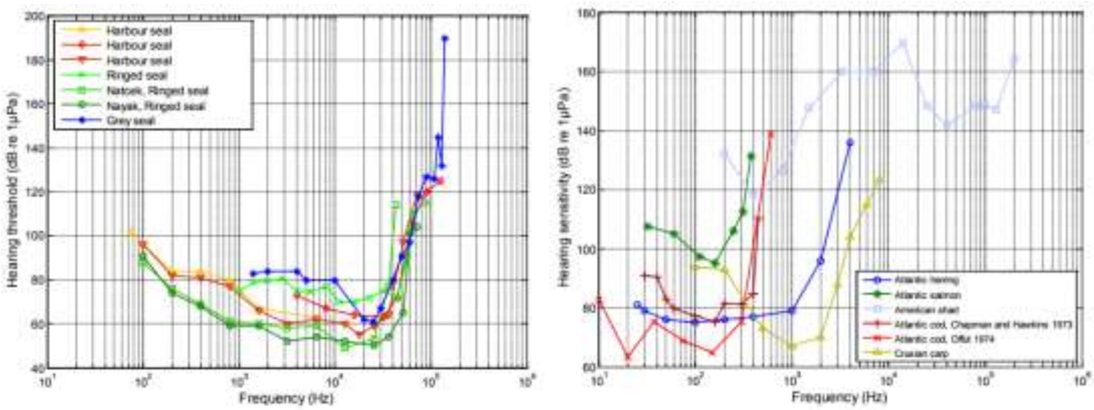
HELCOM koordinētā BalticBOOST projekta ietvaros tika identificētas trokšņu jutīgās sugas Baltijas jūrā, no kurām divas roņu sugas (pelēkais un pogainais ronis) un divas zivju sugas (reņģe un brētliņa) ir raksturīgas arī Latvijas jūras ūdeņiem. Citas pētījumā identificētās trokšņu jutīgās sugas Latvijas jūras ūdeņos nav sastopamas vai sastopamas ļoti nelielā skaitā tikai atsevišķos reģionos.

Trokšņa ietekme uz dzīvajiem organismiem ir atkarīga no paša trokšņa (skaņas) īpašībām, piemēram, no frekvences un trokšņa ilguma. Tāpat trokšņa ietekme lielā mērā ir atkarīga no tā, cik tuvu dzīvais organisms atrodas trokšņa avotam, un, jo tuvāka ir šī distance, jo potenciāli lielāku ietekmi konkrētais troksnis var radīt. Atkarībā no iepriekš minētajiem faktoriem un katra konkrētā dzīvā organisma fizioloģiskajām īpatnībām (piemēram, dzirdamības slieksnis), trokšņa atstātā ietekme var izpausties kā akustiskie traucējumi *(masking - acoustic interference that reduces ability to detect, recognize and understand sounds of interest*), dabiskās uzvedības izmaiņas vai esošās uzvedības pārtraukumi, fizioloģiskā stresa efekti, īslaicīgas vai pastāvīgas izmaiņas dzirdes jutībā un kā fizikāli bojājumi audos. Katrai sugai trokšņa ietekme būs atkarīga arī no katras sugas dzirdamības sliekšņa, taču ir noteikts kāds skaņas spiediena līmenis var izraisīt konkrētu ietekmi uz organismu (Fradelos, 2016):

- 240 dB un skaļāks troksnis var būt letāls;
- 220 dB un skaļāks troksnis var radīt fizikālus orgānu bojājumus;
- 130 dB un skaļāks troksnis var radīt īslaicīgus vai pat pastāvīgus dzirdes orgānu bojājumus;
- 90 dB un skaļāks troksnis liedz savā starpā komunicēt un rada stresu;
- 75 dB un skaļāks troksnis izmaina reakciju un apkārtējās vides uztveri.

JSD pamatā definē, ka trokšņu līmeni ir jāraksturo pie 63 Hz un 125 Hz frekvencēm, taču ne vienmēr šīs izvēlētās frekvences atbilst tām, kuras uztver ūdenī dzīvojošās sugas. Pogainais ronis spēj uztvert skaņas sākot no 100 Hz frekvences, savukārt pelēkais ronis - tikai no aptuveni 1 kHz (*4.1. attēls*).

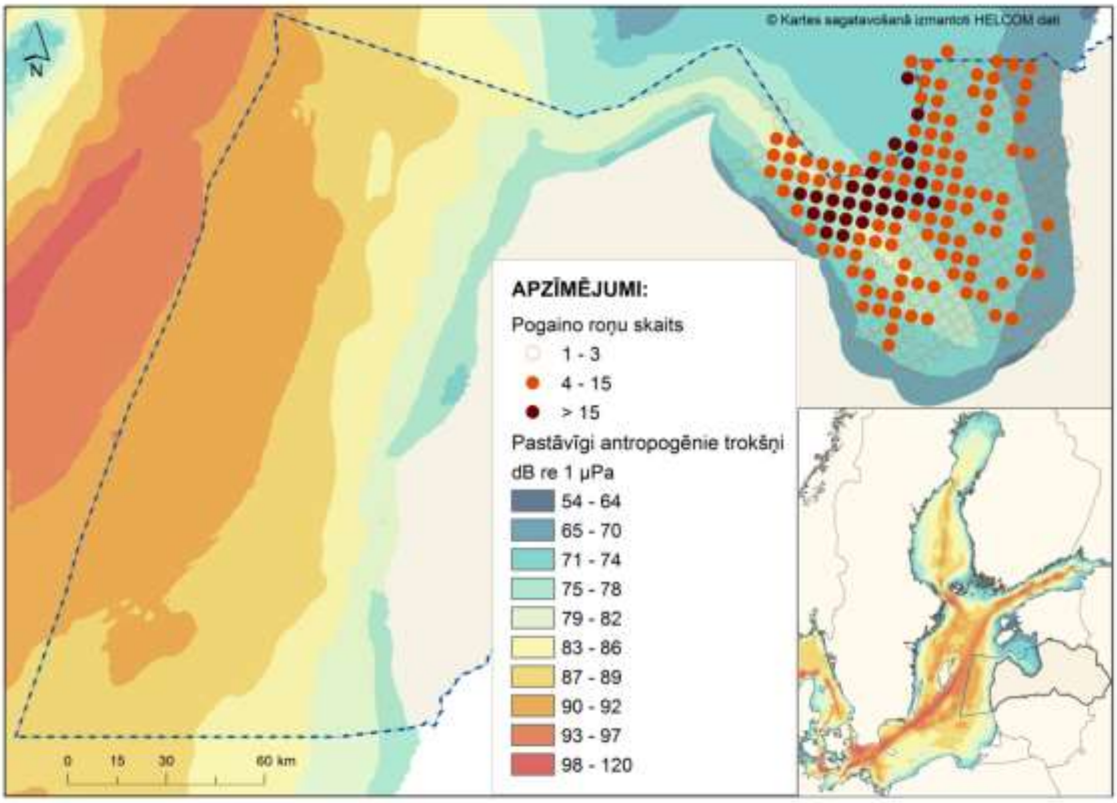
Savukārt reņģes spēj uztvert skaņas frekvences (63 Hz un 125 Hz), pēc kurām JSD iesaka raksturot trokšņu līmeni. Arī brētliņas ir komerciāli nozīmīga zivju suga Baltijas jūrā, taču līdz šim nav veikti pētījumi par brētliņu dzirdamības sliekšņiem pie dažādām frekvencēm. Neskatoties uz to, brētliņas ir radniecīga suga reņģēm un ir veikti anatomiski pētījumi par to, ka brētliņu dzirdes aparāts ir ļoti līdzīgs reņģēm (Shack et.al., 2017), kas nozīmē, ka trokšņu ietekme un dzirdamības sliekšņi brētliņām ir ļoti līdzīgi vai tuvu tiem, kas novēroti reņģēm (*4.1. attēls*).



4.1. attēls. ***Roņu (pa kreisi) un zivju sugu (pa labi) dzirdamības sliekšņi pie dažādām frekvencēm*** *(Shack et.al., 2017)*

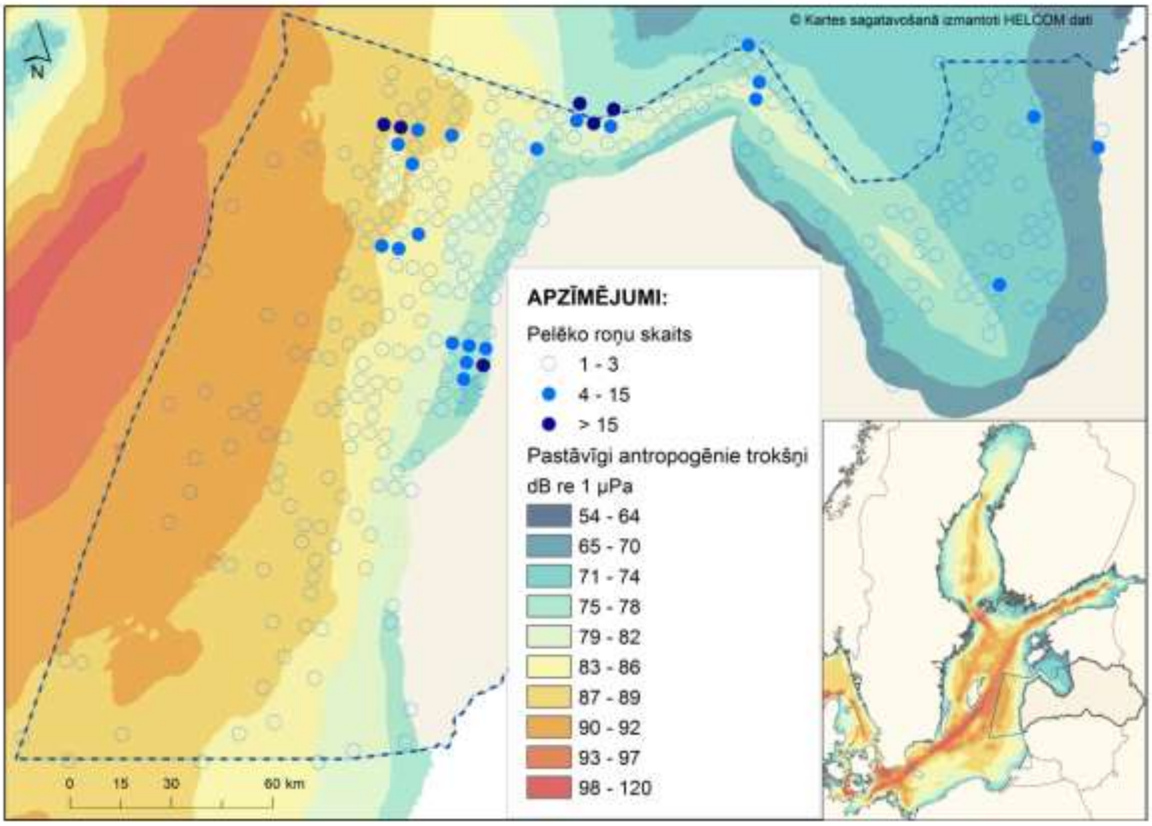
Līdzšinējie pētījumi par trokšņu ietekmi uz dzīvajiem organismiem, kas raksturīgi Baltijas jūras reģionam, tika apkopoti projektā BalticBOOST, sadalot šo ietekmi kritērijos un izvērtējot katra kritērija būtiskuma pakāpi (augsta, vidēja, zema, niecīga un nezināma) attiecībā pret pieejamām zināšanām. Projekta ietvaros tika secināts, ka pastāvīgs antropogēnas izcelsmes troksnis rada vidēju ietekmi uz pogainajiem roņiem, bet zemu ietekmi uz pelēkajiem roņiem. Taču tiek arī uzsvērts, ka esošās zināšanas un pētījumi ir nepietiekami (it īpaši par pelēkajiem roņiem) un tās pārsvarā balstās uz šobrīd nedaudz labāk izpētītajiem plankumainajiem roņiem. Kas attiecas uz zivīm, tad tiek secināts, ka pastāvīgs antropogēnas izcelsmes troksnis rada zemu ietekmi gan uz reņģēm, gan uz brētliņām, kas var izpausties kā akustiskie traucējumi zivīm gadījumā, ja kāda no antropogēnā trokšņa frekvencēm pārklājas ar zivju uztverto skaņas frekvenci. Taču līdzīgi kā ar roņu sugām, nav veikti tieši pētījumi par trokšņu ietekmi uz reņģēm un brētliņām, un tiek uzsvērts, ka iegūto kritēriju būtiskuma pakāpe attiecībā pret pieejamajām zināšanām ir niecīga reņģēm, brētliņām un pelēkajiem roņiem, bet vidēja - pogainajiem roņiem.

Aplūkojot skaņas spiediena līmeni un roņu, un zivju izplatību Latvijas teritoriālajos ūdeņos, varam nonākt pie līdzīgiem secinājumiem, kādi izdarīti BalticBOOST projekta ietvaros. Pogaino roņu, kas pārsvarā raksturīgi tikai Rīgas līcim, izplatību pastāvīgi antropogēni trokšņi ietekmē šķietami maz, neskatoties uz to, ka pogainie roņi lielākā skaitā sastopami tieši līča rietumu daļā, kuru šķērso kuģu ceļš, ap kuru savukārt ir lielāks trokšņu līmenis, un potenciāli lielāka tā ietekme (75-82 dB re 1µPa) nekā citviet līcī (*4.2. attēls*). Par to ļauj spriest apstāklis, ka pogainie roņi spēj uztvert skaņas sākot tikai no 100 Hz frekvences.



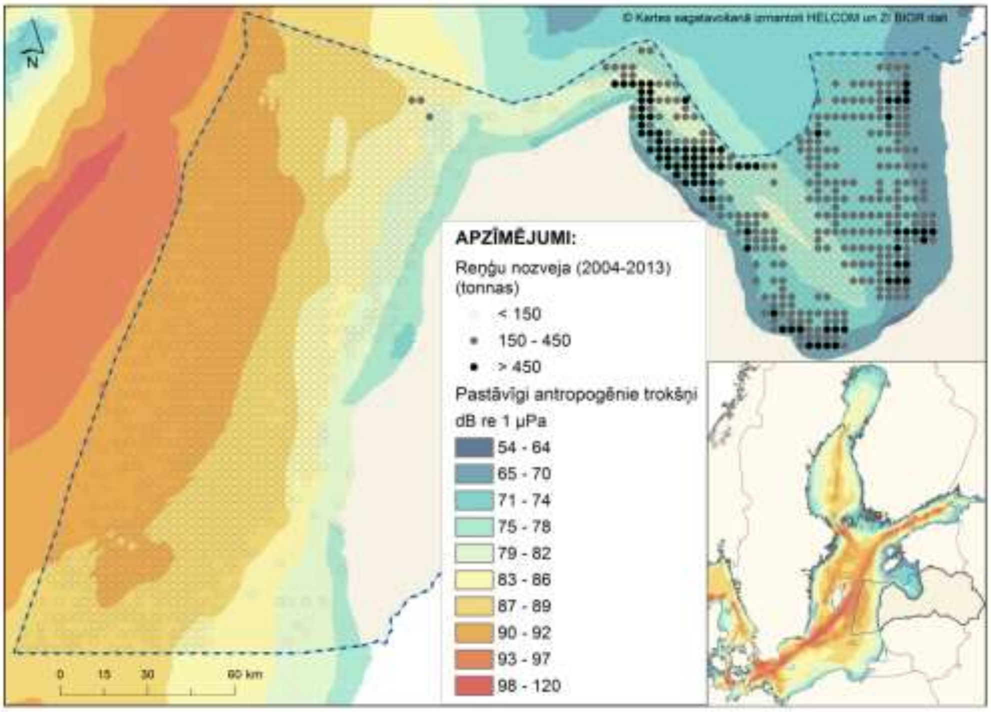
4.2. attēls. ***Skaņas spiediena līmenis (dB re 1µPa) Latvijas teritoriālajos ūdeņos 2014. gadā (vidējā vērtība no 63 Hz, 125 Hz un 2 kHz frekvencēm) un vidējais pogaino roņu skaits no 2011.-2015. gadam***

Pelēkie roņi vairāk ir izplatīti Baltijas jūras reģionā, un Rīgas līcī to izplatība un skaits ir mazāks. Ņemot vērā, ka pelēkie roņi sāk uztvert skaņas sākot no 1 kHz frekvences, var secināt, ka trokšņiem pie JSD atrunātajām trokšņu raksturojošām frekvencēm (63 un 125 Hz) nav ietekmes uz pelēkajiem roņiem, jo tie trokšņus pie 63 un 125 Hz frekvences nav spējīgi uztvert. Tāpat pelēko roņu telpiskā izplatība un skaits Baltijas jūras daļā un Rīgas līcī (*4.3. attēls*) neliek domāt, ka troksnis atstāj jebkādu ietekmi uz šo roņu sugu.



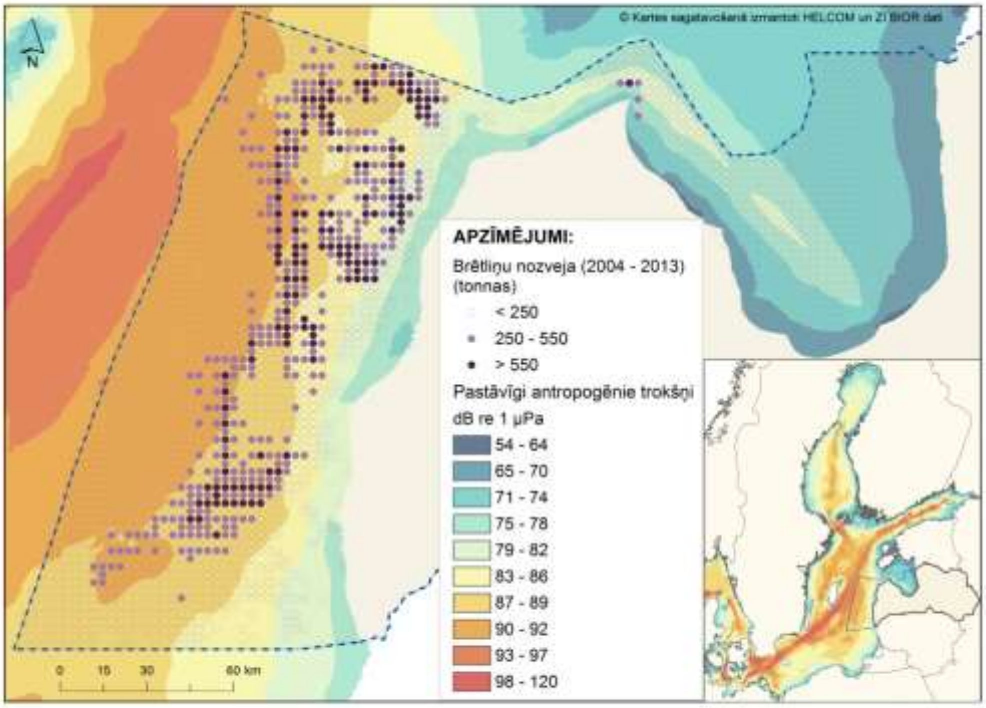
4.3. attēls. ***Skaņas spiediena līmenis (dB re 1µPa) Latvijas teritoriālajos ūdeņos 2014. gadā (vidējā vērtība no 63 Hz, 125 Hz un 2 kHz frekvencēm) un vidējais pelēko roņu skaits no 2011.-2015. gadam***

Kā iepriekš minēts, tad brētliņa ir radniecīga suga reņģēm, kas nozīmē, ka abām šīm sugām trokšņu uztvere un trokšņu iespējamā ietekme uz tām, visticamāk, ir līdzīga. Par brētliņām pieejamie pētījumi ir ļoti ierobežoti, taču par trokšņu ietekmi uz reņģēm ir zināms nedaudz vairāk. Salīdzinot ar jūras zīdītājiem (piemēram, roņiem), reņģes ir daudz jutīgākas uz trokšņiem pie zemām frekvencēm, un kuģu radītie trokšņi lielākoties ir zemas frekvences trokšņi. Reņģe ir jutīga uz trokšņiem migrācijas laikā, kad pastāvīgs troksnis var potenciāli ietekmēt migrācijas īpatnības vai pat migrācijas ceļu (piemēram, ja ir izveidojušās skaņas barjeras). Nārsta laikā troksnis var radīt reņģēm uzvedības traucējumus, kas raksturīgi tieši nārsta periodam, taču konkrētu skaņas spiediena līmeņu analīze uz atsevišķiem indivīdiem līdz šim nav veikta. Līdz ar to ir sarežģīti/nav iespējams objektīvi novērtēt pastāvīgu antropogēnu trokšņu ietekmi uz reņģu izplatību un skaitu (*4.4. attēls*). Saistībā ar brētliņām ir izpētīts, ka šo zivju sugas bari reaģē uz trokšņiem, kas imitē pāļu dzīšanu, kas potenciāli varētu atstāt ietekmi uz atsevišķiem bara indivīdiem un pazemināt viņu izdzīvošanas spējas gadījumā, ja šie indivīdi tiek nošķirti no zivju bara.



4.4. attēls. ***Skaņas spiediena līmenis (dB re 1µPa) Latvijas teritoriālajos ūdeņos 2014. gadā (vidējā vērtība no 63 Hz, 125 Hz un 2 kHz frekvencēm) un reņģu nozveja no 2004.-2013. gadam***

Taču saistībā ar brētliņām un trokšņu ietekmi uz tām, pieejamie pētījumi ir ļoti limitēti, kas, līdzīgi kā reņģēm, nozīmē to, ka ir sarežģīti/nav iespējams objektīvi novērtēt pastāvīgu antropogēnu trokšņu ietekmi uz brētliņu izplatību un skaitu (*4.5. attēls*).



4.5. attēls. ***Skaņas spiediena līmenis (dB re 1µPa) Latvijas teritoriālajos ūdeņos 2014. gadā (vidējā vērtība no 63 Hz, 125 Hz un 2 kHz frekvencēm) un brētliņu nozveja no 2004.-2013. gadam***

IZMANTOTĀ LITERATŪRA

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McKenna, M.F., Ross, D., Wiggins, S.M., Hildebrand, J.A., 2012. Underwater radiated noise from modern commercial shipping. The Journal of the Acoustical Society of America. 131(1), 92-103

Shack, H., Ruiz, M., Andersson, M., 2017. WP 4.1 Deliverable 3: Report on noise sensitivity of animals in the Baltic Sea. BalticBOOST Appendix 1, Theme 4: Noise, 72 pp.

5. LABA VIDES STĀVOKĻA (GES) IZSTRĀDES PROGRESS

Zemas frekvences kuģu radītā trokšņa (angliski lietotais termins – continuous noise) laba vides stāvokļa robežvērtības izstrāde tiek veikta kā ES dalībvalstu kopīgs pasākums. MSFD Kopējās Ieviešanas Stratēģijas paspārnē ir izveidota Zemūdens trokšņa tehniskā grupa (TG-Noise), kuras uzdevumos ietilpst GES robežvērtību opciju izstrāde. Uz atskaites sagatavošanas brīdi GES robežvērtību izstrāde joprojām ir procesā. Ir sagatavots dokumenta TGNoise 21-2002-04 draft DL4 melnraksts (skat. Zemāk), kuru ES dalībvalstis apspriež un komentē.

DRAFT DL4 19 May 2022

"Assembled" by JFBorsani DGDL4; M.Ainslie to keep terminology of the text consistent.

Chapter 1 – Summary
Ex post

Chapter 2 – Introduction
(from JAT)

- GES is to be assessed in larger areas (Marine Reporting Units, MRU's)
- over longer periods (month, year)
- This implies that thresholds for GES are not about noise from individual
- sources or exposures to individual animals
- Basis for the assessment is quantification of how much the current
- condition deviates from the reference condition in a particular area
- (habitat or MRU)
- Conditions for GES allow for some deviation from the reference
- condition

- Too large deviations, too often and over too large geographical areas are
- not consistent with GES
- Thresholds for GES are thus expressed in fractions of time and area etc

Chapter 3 - Directive/Decisions/SWD/DL3
(Directive/Decisions/SWD/DL3 chap from DL3)

Chapter 4 – Setting of LOSE
(Annexes: (1) JAT: worked examples; (2) PS, LW, AP: Choice of LOSE review), (3) MA: A robust assessment of D11C2 with case study.) (from JAT) Three parameters are central in the assessment:

- Level of Onset of Significant Effects (LOSE): Level of noise exposure, above which detrimental effects are likely to occur
- Tolerated duration: Fraction of time LOSE can be exceeded and still be consistent with GES within a habitat/MRU
- Tolerated impacted area: Fraction of an area where LOSE can be exceeded and still be consistent with GES within a habitat/MRU

GES is linked to these parameters and it must be possible to logically trace changes in the parameters and effects on GES status. A lower value set for LOSE should be precautionary, because smaller deviation from the reference condition is permitted. Tolerated duration and tolerated impacted area are linked with GES such that lower tolerated duration and impacted area both should mean improved conditions for the ecosystem. In the choice of the three parameters it is important to assure that these logical links are maintained.

(from PS LW AP)

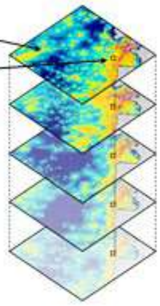
LOSE is an essential part of Descriptor 11. It describes a received sound level (RL), which has shown to cause a serious effect on an indicator species. The LOSE is directly related to the indicator species and should preferably be chosen based on results from evidence-based studies. To facilitate this process, a short list of representative studies has been compiled. Studies were selected based on their importance to the health of the ecosystem and population dynamics, whether the impacts were from vessel noise, and whether RLs were indicated in the papers. This list is not meant to be exhaustive and does not necessarily take the relevance to the indicator species into account nor the quality of the studies. However, it serves as a starting point, to give a sense of the research carried out and results obtained. The list is found in Annex 2.

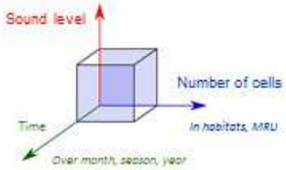
Care must be taken with how to choose the LOSE and how to apply results from studies on the indicator species. The studies that indicate RL may not be relevant for use in the MSFD, as RL is highly variable, and behavioural responses depend on many other factors such as context. Moreover, behavioural responses, even if detectable, may not be the most serious reactions to noise. It should also be remembered that LOSE represents the Level of Onset of biologically Significant adverse Effects (LOSE). Many studies do not focus on the lowest RL to cause biologically significant adverse effects, which what is relevant for the assessment of GES. Regardless, a choice must be made under the language of the MSFD.

Chapter 5 - To renormalize the Grid Cell to fit all (from LC)

Elementary unit assessment

- Computation cell (level of resolution: data unit from modelling or measures)
- Grid cell is the basic building block of the assessment
- Integrate computation cell to assessment grid cell is investigated
- Normalize Grid cell to fit all is investigated
- Computation cell from modelling can be smaller than Assessment grid cell

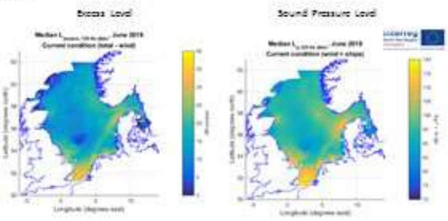




Assess area of exposure

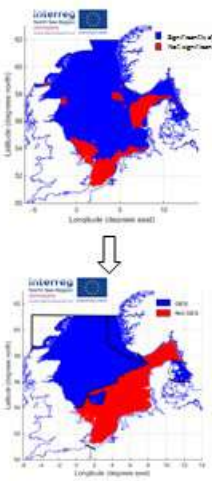
- How to set and define LOSE/LOBE (from biological knowledge)
  - in case scientific studies are available
  - in case of lack of knowledge

  Assessing using:
  - Sound Pressure level
  - Excess level



- Assess impacted area (nb grid cells) over the LOSE/LOBE
  - Using propagation model and/or measurements
- Assess reference condition & current condition
  - uncertainties of non-anthropogenic contribution (wind, waves, biological sound..)

Example of Assessment



At **grid cell** level :
Significantly affected or not

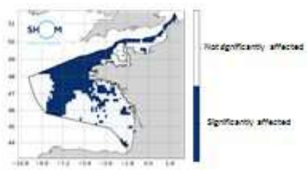
⇩

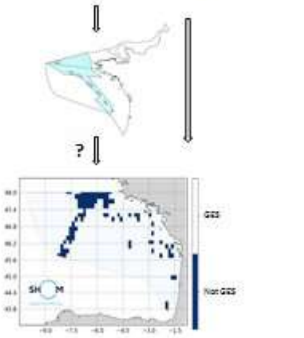
At **habitat** level:
Acceptable or not acceptable

⇩

At **MRU** level:

GES is achieved or not





Chapter 6 – (?) Setting of tolerable area and duration (order time vs space has to be discussed)

6a. using one number for all month or using different numbers for different months?
6b choosing tolerable area based on studies from other areas (birds, land animals)
6c in case there is poor support from experience from other areas

Chapter 7 - How to report GES in MRU

(leave out for the moment)

ANNEX 1

Jakob Tougaard, 11 April 2022

Worked examples of application of DL3 guidance to data from the North Sea

The aim of DL3 and DL4 is to provide advice on how to assess Good Environmental Status (GES) with respect to continuous underwater noise consistent with the Marine Strategy Framework Directive (European Commission, 2008, 2017). DL3 provides the general framework and describes a nine-step process for the assessment. This document provides two examples of how guidance from DL3 can be implemented and how thresholds for GES be applied to the results.

General principles

- GES is to be assessed in larger areas (Marine Reporting Units, MRU's) over longer periods (month, year)
- This implies that thresholds for GES are not about noise from individual sources or exposures to individual animals
- Basis for the assessment is quantification of how much the current condition deviates from the reference condition in a particular area (habitat or MRU)
- Conditions for GES allow for some deviation from the reference condition
- Too large deviations, too often and over too large geographical areas are not consistent with GES
- Thresholds for GES are thus expressed in fractions of time and area

Three parameters are central in the assessment:

- Level of Onset of Significant Effects (LOSE): Level of noise exposure, above which detrimental effects are likely to occur
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- Tolerated impacted area: Fraction of an area where LOSE can be exceeded and still be consistent with GES within a habitat/MRU

GES is linked to these parameters and it must be possible to logically trace changes in the parameters and effects on GES status. A lower value set for LOSE should be precautionary, because smaller deviation from the reference condition is permitted. Tolerated duration and tolerated impacted area are linked with GES such that lower tolerated duration and impacted area both should mean improved conditions for the ecosystem. In the choice of the three parameters it is important to assure that these logical links are maintained.

Both examples are based on the same dataset: the 2019 monitoring of the greater North Sea by the Interreg project Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS). In the first example LOSE is interpreted from DL3 as an excess noise level above the reference condition, thereby addressing impact in the form of masking. The second example interprets LOSE as a fixed level of the current condition, above which behavioural reactions to the noise is considered likely.

Most of the steps of the two examples are identical, as are the selected values of tolerable duration and tolerable impacted area. The differences between methods thus lie in step 2 (definition of LOSE), step 5 (establishing current condition) and step 6 (evaluate conditions of grid cells).

Values for the three parameters LOSE, tolerated duration and tolerated impacted area in the two examples are selected to be illustrative of the method and therefore should not be seen as recommendations for actual selection of values.

Example A: LOSE as an excess noise level

In this example, the definition of LOSE in DL3 is interpreted as an instantaneous deviation of the current condition from the reference condition.

Step 1. Define indicator species and its habitat
In this example a pragmatic approach is taken, where habitat is simply taken as being identical with Marine Reporting Units (MRUs, see step 9). For the North Sea, six habitats were selected, based on areas previously designated by OSPAR as biogeographical subdivisions of the North Sea (Figure 1).

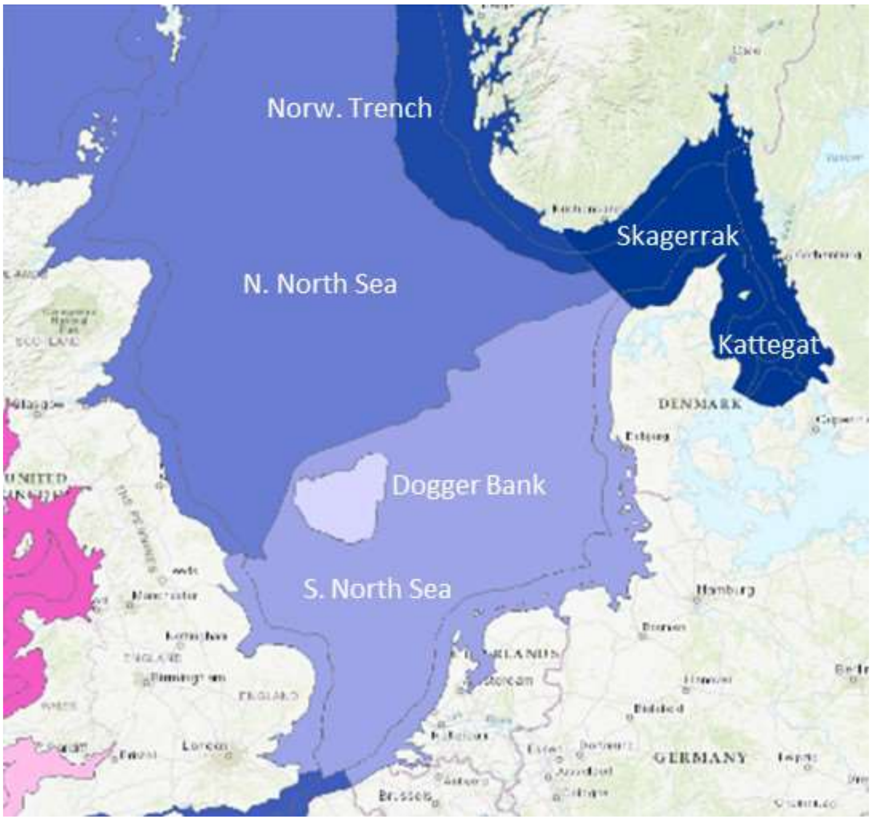

Figure 1 Six habitats in the North Sea, defined by OSPAR: Southern North Sea, Northern North Sea, Dogger Bank, Norwegian Trench, Skagerrak and Kattegat.

Step 2. Define the Level for Onset of Biologically Significant Adverse Effects (LOSE)
LOSE in the example is set at 20 dB excess in the 125 Hz decidecade band, corresponding to current state being 20 dB higher than the reference state. This value has been selected to represent a condition where the maximum communication range of an animal communicating

in the 125 Hz decidecade band is severely limited by the ship noise. Under simplifying assumptions of spherical spreading of the communication signals 20 dB excess corresponds to a decrease in maximum communication range by 90%.

Step 3. Determine time periods for the assessment
The observational period (temporal observation window) is related to the fundamental temporal resolution of soundscape model. In the example, it is set to 1 s, which is the fundamental resolution of the snap-shots of the model used in JOMOPANS (see steps 4-6). The analysis period is related to the evaluation time of the deviation of the current condition from the reference condition. In the example, it is set to one month, which is the period over which snapshots are aggregated to form the statistical distribution used later in the assessment. The assessment period is the period over which GES is assessed and reported. In the example, it is set to one month, but can easily be extended to one year.

Step 4 Assess the acoustic state by monitoring
The reference and current conditions in the North Sea were derived from the results of the JOMOPANS project. The monitoring consisted of measurements of underwater noise at fixed stations in the North Sea, modelling of ambient noise from meteorological data (see step 5), modelling of ship noise from AIS data and source model (see step 6) and verification of modelled data against measurements. In the example, results from the 125 Hz decidecade band is used.

Step 5. Establish the Reference Condition

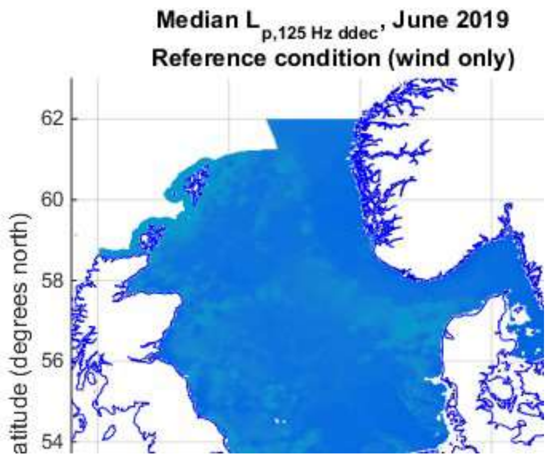

Figure 2. Median of the reference condition for the month of June 2019. Median sound pressure level calculated from 1 second observation windows (snapshots).

The reference condition represents the soundscape in the absence of anthropogenic sound sources and is in this example determined by modelling of noise in the specified frequency band based on meteorological data (wind), which is coupled to underwater noise levels through empirically derived relationships ("Knudsen curves"). The reference condition is specified as percentiles of the monthly distribution of instantaneous level (Lp averaged over one observational interval, equal to 1 s, modelled once for every 2 hours in a month). Spatial resolution of the model is given by the grid cell size, which is 3 arc-seconds longitude by 1.5 arc-seconds latitude (approx. 50 x 50 m).

Step 6. Establish the Current Condition

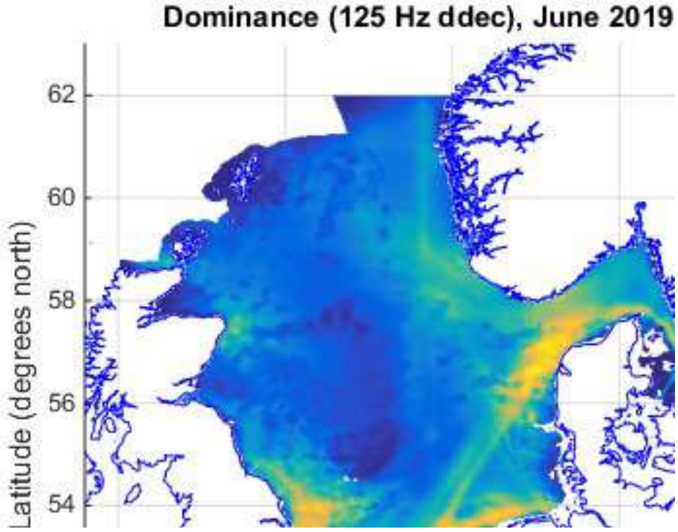

Figure 3. Current condition for June 2019 in the 125 Hz decidecade band. Colour scale represents the time where L_{excess} in each grid cell is above LOSE (20 dB).

The current condition represents the soundscape composed of the reference condition to which anthropogenic sound sources are added. It was modelled snapshot by snapshot by propagating noise from all ships in the North Sea from which AIS information was available and adding this noise to the reference condition. Source characteristics for each ship was modelled from size, speed and ship class information from AIS data by means of a model developed from data of the ECHO project (MacGillivray and de Jong, 2021).

Deviation of current condition from reference condition was quantified for each snapshot by the excess level, defined as Lexcess = current condition – reference condition. Excess level was aggregated monthly for each grid cell by the dominace, which equals the fraction of snapshots where Lexcess was above LOSE.

Step 7 – Evaluate grid cells

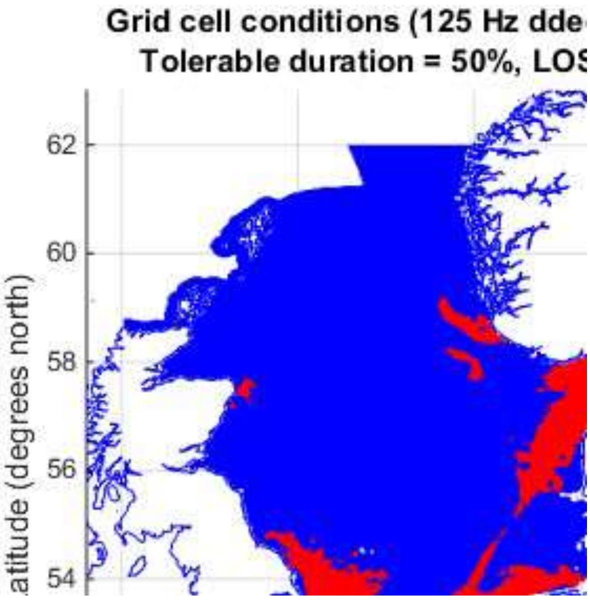

Figure 4 Conditions of individual grid cells indicated by colours for June 2019. Blue: grid cell non-significantly affected (dominance ≤ tolerable duration), red: grid cell significantly affected (dominance > tolerable duration).

The condition in each grid cell is evaluated against the tolerable duration. The tolerable duration in this example is set to 50%. If the dominance of the grid cell is above the tolerable duration, the cell is said to be significantly affected. This is illustrated in Figure 4.

Step 8 and 9. Determine the status of the Habitat and MRU

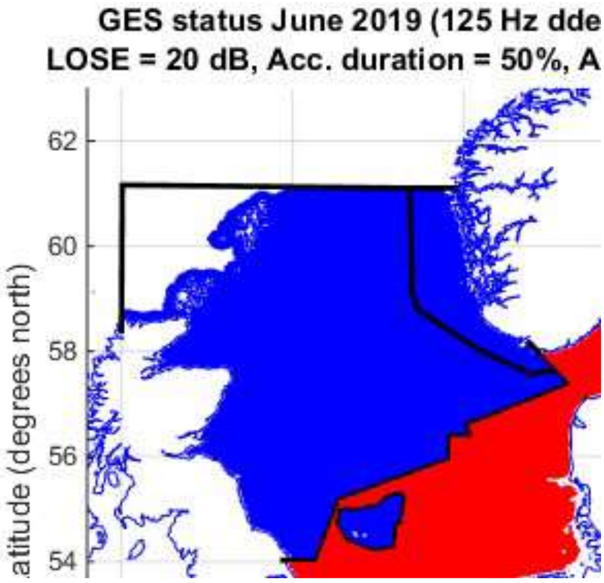

Figure 5. Status of MRUs, which is identical to the status of habitats in the present example. Two MRUs are not in GES: Southern North Sea and Skagerrak, whereas the remaining areas are in GES: Northern North Sea, Norwegian Trench, Dogger Bank and Kattegat.

In this example steps 8 and 9 are identical because habitats and MRUs are identical as well. The status of habitats and MRUs is assessed on the basis of tolerable impacted area, which is expressed as a fraction of the habitat/MRU. The tolerable impacted area in this example is set to 25%, which means that the status of the habitat is tolerable if the fraction of grid cells in the habitat that are significantly affected does not exceed the tolerable impacted area. If this is not the case, the status of the habitat is not tolerable.
Likewise, an MRU is in good environmental status (GES) if the fraction of grid cells in the MRU that are significantly affected does not exceed the tolerable impacted area.

Changing the values of LOSE and tolerable duration

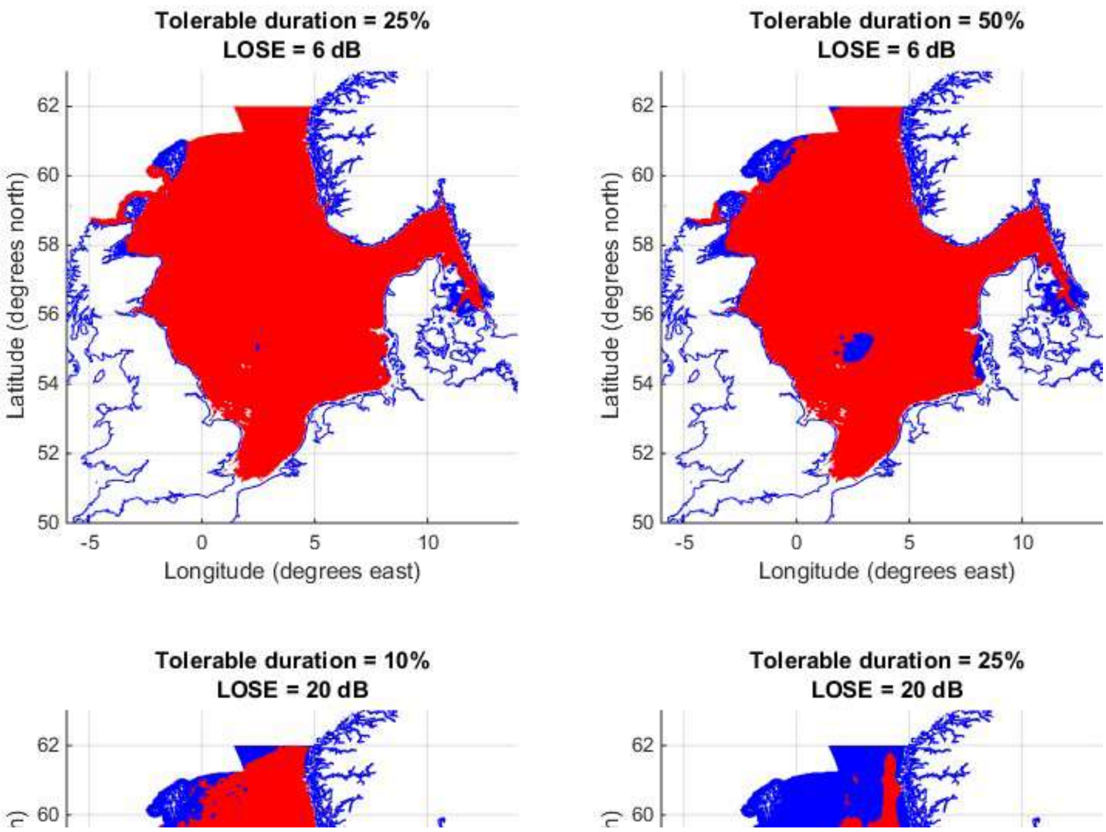

Figure 6. Influence of choice of parameters LOSE and tolerable duration on the evaluated condition of grid cells.Three different tolerable durations (25%, 50% and 90%) and two values of LOSE (6 dB and 20 dB) were used.

The outcome of the assessment, i.e. the MRUs that are assessed not to be in GES is very sensitive to the choice of LOSE and threshold parameters tolerable duration and tolerable impacted area. This is illustrated in Figure 6 where the condition of grid cells were evaluated with different combinations of LOSE and tolerable duration. On top of this comes the evaluation of habitats and MRUs, based on the tolerable impacted area. The maps are very different, but persistent features such as the consistently high impact in the English Channel and along the English, Dutch, German and Danish coasts, are retained across maps. There is no objective way to determine the threshold values. The final choice must be a balance that results in useful maps. Maps that are all red are non-informative, as they do not provide information about where the impact and hence the problem is largest, and maps that are all blue are equally non-informative.

Example B: LOSE as a fixed sound pressure level

In this example, LOSE is interpreted from the DL3 definitions as a fixed level of the current condition. Otherwise procedures are identical to example A.

Step 1. Define indicator species and its habitat
The habitats in this example are identical to example A (Figure 1).

Step 2. Define the Level for Onset of Biologically Significant Adverse Effects (LOSE)
LOSE in this example is set at 100 dB re. 1 μPa in the 125 Hz decidecade band. LOSE in this case is interpreted as a level, above which there is an increased likelihood of behavioural reactions to the noise.

Step 3. Determine time periods for the assessment
Time periods of this example are identical to example A. The observational period is set to 1 s (fundamental resolution of the soundscape model), and both analysis period and assessment period is set to one month.

Step 4 Assess the acoustic state by monitoring
The monitoring data used in example B is identical to the data used in example A.

Step 5. Establish the Reference Condition
In this example the reference condition is not used in the assessment.

Step 6 – Establish current condition

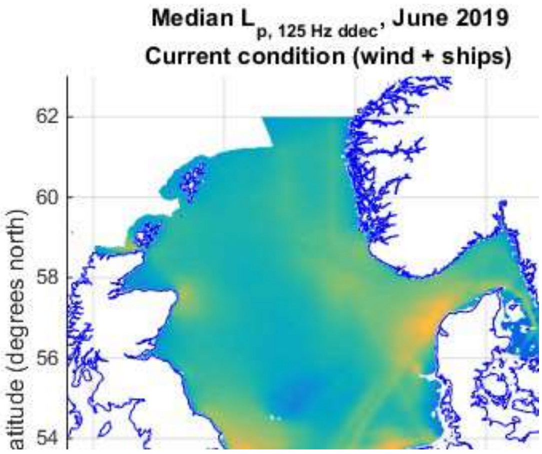

Figure 7. Current condition for the month of June 2019, expressed at the median sound pressure level in the 125 Hz decidecade band.

The current condition is obtained by aggregating the sound pressure levels in individual grid cells and in individual 1 s analysis windows (snap shots) and aggregate these into a distribution. The median (L50) is extracted from the distributions and used to represent the current condition (Figure 7).

Step 7 – Evaluate the condition of the grid cells

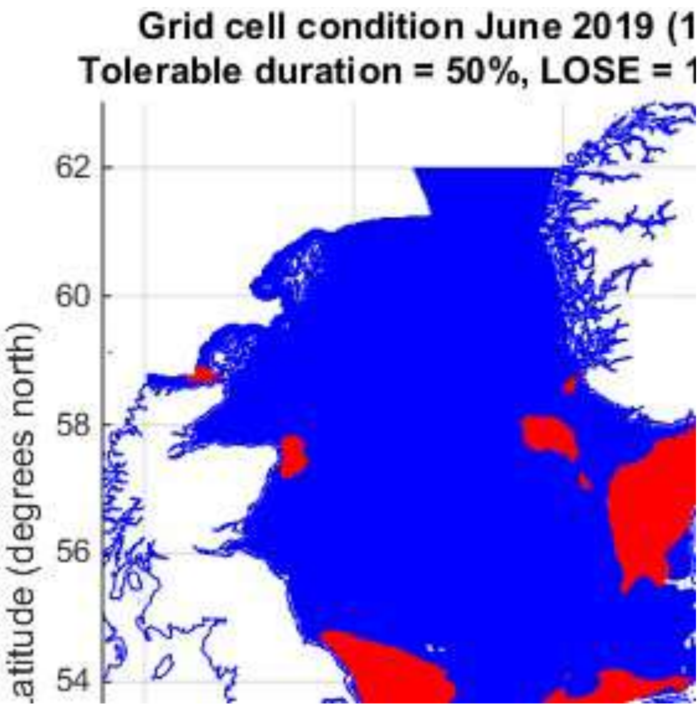

Figure 8. Conditions of individual grid cells indicated by colours for June 2019. Blue: grid cell non-significantly affected (dominance ≤ tolerable duration), red: grid cell significantly affected (dominance > tolerable duration).

The status of each grid cell is evaluated against the tolerable duration, in the same way as in example A. The tolerable duration in this example is set to 50%. This means that if the median sound pressure level (L50, 125 Hz ddec) is larger than LOSE, the cell is said to be significantly affected.

Step 8 and 9. Determine the status of the Habitat and MRU

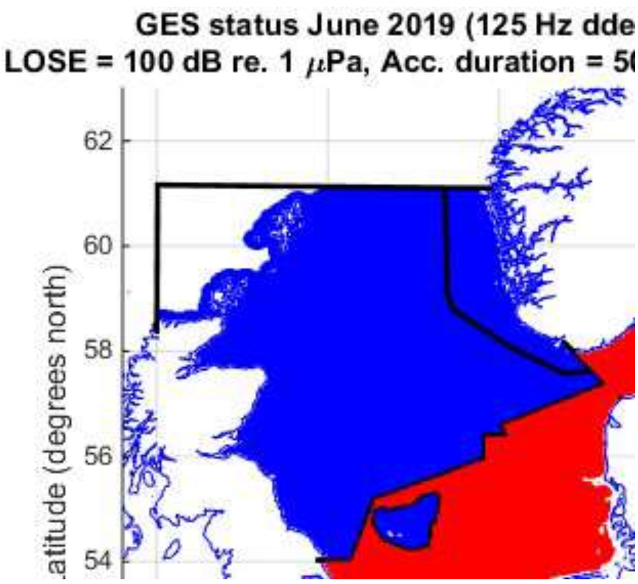

Figure 9. Status of MRUs, which is identical to the status of habitats in the present example. Two MRUs are not in GES: Southern North Sea and Skagerrak, whereas the remaining areas are in GES: Northern North Sea, Norwegian Trench, Dogger Bank and Kattegat.

The assessment of habitat and MRU status is identical to example A. The tolerable impacted area is set to 25%, as in example A. With the choice of LOSE in this example, the assessment in the end turns out to be identical to the assessment in example A (two areas not in GES, four areas in GES). However, the actual assessment is sensitive to the choice of all three parameters, see below.

Changing values of LOSE, tolerated duration and tolerated area

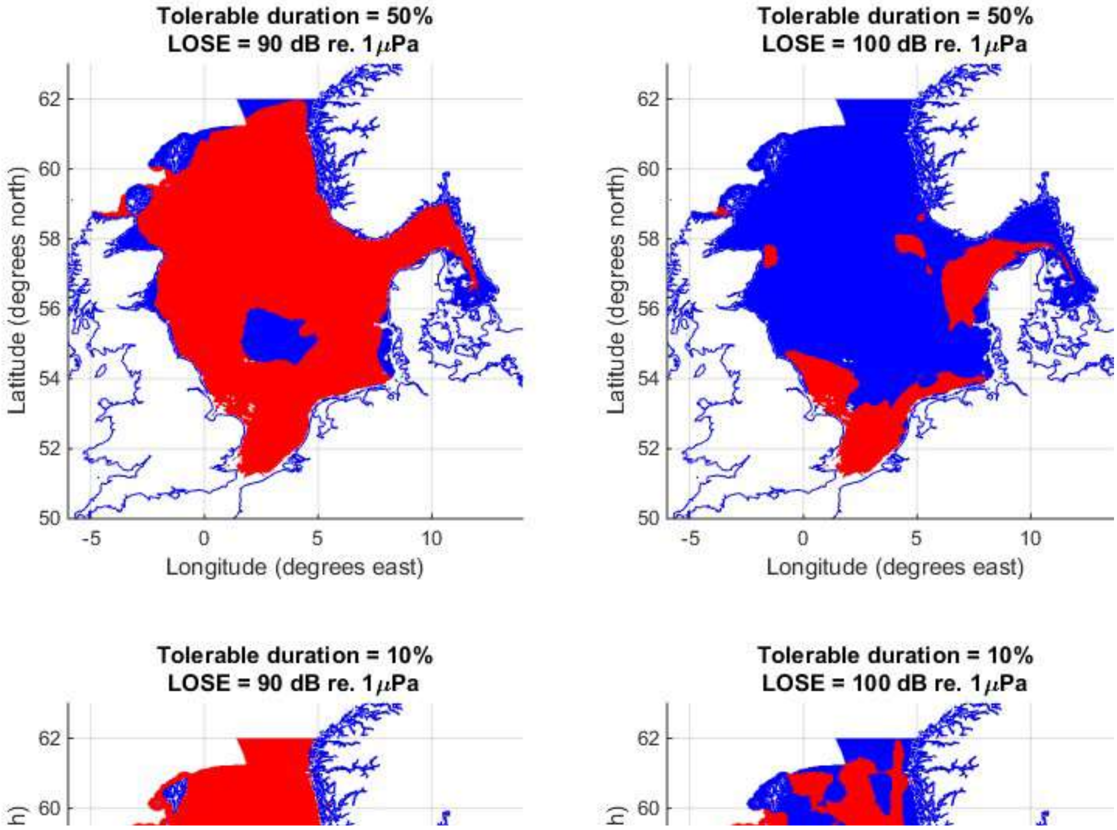

Figure 10. Influence of choice of parameters LOSE and tolerable duration on the evaluated condition of grid cells. Two different tolerable durations (10% and 50%) and three values of LOSE (90, 100 and 110 dB re. 1μPa) were used.

Just as in example A the choice of parameters LOSE, tolerable duration and tolerable impacted area has a large effect on the outcome of the assessment (Figure 10) and as in example A the final parameters must be selected such that a useful map is produced. Jakob Tougaard, with input from Mathias Andersson

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ANNEX 2

Review compiled by Lindy Weilgart, Aristides Prospathopoulos and Peter Sigray for DL4, 12May2022

THE CHOICE AND SETTING OF LOSE

The term Level of Onset of biologically Significant Effects (LOSE) was chosen not to indicate any relation to a specific impact, but indicative of a level above which there is a risk of an effect that can influence the fitness of animals. Fitness is the ability of an individual to successfully reproduce relative to other individuals in the population. If an animal experiences a loss in fitness, it means that its reproductive output is affected negatively, even if only slightly. In general, available evidence shows that noise can reduce communication ranges and mask (obliterate or obscure) important signals, disrupt reproductive and resting behaviours, including of mother-calf pairs, affect energy budgets by interfering with foraging and increasing energy expenditure by increased transiting or stress, and exclude animals from important habitats. In addition, stress responses, which weaken overall health and fitness, have been observed in several species. Noise can also cause temporary or permanent loss of hearing sensitivity, induce physical injury, and, in extreme cases, cause behavioural or physiological responses that may lead to death.

For behavioural disturbance, LOSE is expressed in units of sound pressure level corresponding to a threshold related to a biological response. In practice, there are a limited number of studies that can be used for setting the LOSE, but even if the number of studies is moderate, they may offer an indication of how to set the LOSE. For continuous noise, most studies on impact are presented in the unit of dB re 1μPa. This is also in accordance with the metric of the Reference and Current Conditions.

REVIEWS

There are several studies on mammals that present RLs in dB re 1 μPa where it has been observed that the animal has been affected. Notable is that these levels are determined on single animals or smaller groups. While the RLs that show a detectable response may be highly variable and dependent on many other factors such as context, the RL at which any serious response may begin to occur may provide some guidance. It should be noted that the LOSE has to be larger than the Reference Condition (RC), i.e. allow for an acceptable deviation from the RC. If this is not the case, then the LOSE cannot be used, since it will overestimate the affected area of the habitat. Stocktaking on LOSE shows the following results, irrespectively of weighting, hearing range severity or even the quality of the study.
Southall et al. (2007) presented a summary of observed behavioural responses for various marine mammal groups exposed to noise. For non-pulsed sound (e.g., vessels etc.), the lowest sound pressure level occurred for low frequency cetaceans at 90 - 100 dB re 1 μPa (rms). This relates to a study involving migrating grey whales. The only study for minke whales showed a response at a received level of 100 – 110 dB re 1 μPa (rms). For mid- frequency cetaceans, a response was encountered at a received level of 90 - 100 dB re 1 μPa (rms), but this was for one mammal (a sperm whale). For these species, a response score of 3 was encountered for received levels of 110 – 120 dB re 1 μPa (rms), with no higher severity score encountered. Southall (2015) came to the conclusion for continuous noise that the combined information generally indicates no (or very limited) responses below RLs of 90-100 dB re 1 μPa and an increasing probability of avoidance and other behavioural effects in the range of 120 to 160 dB re 1 μPa.

However, these data also indicated considerable variability in RLs associated with behavioural responses. Southall et al. (2021) note that "It was unrealistic to expect that populations would all respond to various sounds at the same received level. Tyack & Thomas (2019) demonstrate that using an all-ornothing threshold, ignoring the variation inherent even within one population, responding to one signal, can underestimate effects by a factor of 280 for the dose-response function estimated by Miller et al. (2014) for impulsive noise." They also warn of comparing studies, especially repeated or chronic exposures of local populations compared with discrete exposures at the individual level. They summarize that "using simple all-or-nothing thresholds that attempt to relate single noise exposure parameters (e.g., received noise level) and behavioral response across broad taxonomic grouping and sound types can lead to severe errors in predicting effects." Gomez et al. (2016) reviewed of a large number of publications screening against a number of criteria. They showed that there was a clear onset of behavioural response at 110 dB re 1μPa for marine mammals, though again, there were many caveats such as context often greatly influencing responsiveness.
Di Franco et al. (2020) conducted a literature review of the marine noise pollution impacts on Mediterranean fish and invertebrates showing that both chronic and acute noise caused effects on intra-specific communication, vital processes, physiology, behavioral patterns, health status and survival. These effects on individuals can extend to inducing population- and ecosystem-wide alterations, especially when noise impacts functionally important species, such as keystone predators and habitat forming species. Weilgart (2018) carried out a literature review showing that 66 species of fish and 36 species of invertebrates exhibit documented impacts from underwater noise pollution. These include impacts on development, anatomy, physiology, genetics, behaviour, commercial catch rates, and ecological services such as nutrient cycling. Noise also caused masking, which reduced the communication distance of animals.

NATIONAL OR REGIONAL REGULATIONS

National Oceanic and Atmospheric Administration (NOAA) criteria for auditory injury (NMFS, 2018) and its earlier versions (NOAA 2013 and 2015, NMFS 2016) were extensively reviewed by the public, industry, NGOs, and academic scientists. NMFS (National Marine Fisheries Service) currently uses all-or-none SPL thresholds of 120 dB re 1 μPa for non-impulsive sounds for noise-induced behavioral impacts for marine mammals (NOAA 2019). This threshold has also been used in the ACCOBAMS guidelines (ACCOBAMS, 2013). The 120 dB re 1 μPa threshold is associated with continuous sources and was based on studies of behavioural responses of gray whales (Eschrichtius robustus) to oil drilling (NOAA, 2018), referring to Malme et al. (1983, 1984, 1986). Malme et al. (1986) found that drillship noise did not produce clear evidence of disturbance or avoidance for SPLs below 110 dB re 1 μPa, but possible avoidance occurred for SPLs approaching 119 dB re 1 μPa. The 120 dB RMS threshold is also suggested in the Biological Assessment Preparation Manual for Construction Underwater Noise Impact Assessment of the Washington State Department of Transport (WSDOT, 2020) regarding vibratory pile driving disturbance for Cetaceans and Pinnipeds.

For fish (salmon and bull trout), an alternative criterion is presented in the WSDOT (2020). The manual suggests an unweighted sound pressure level of 150 dB re 1 μPa (rms) as the criterion for onset of behavioural effects for fish, based on work by Hastings (2008).

SPECIES SPECIFIC STUDIES

Amorim et al. (2022). Noise playbacks in the wild from ferry boats (rms 122–131 dB re 1 μPa or rms 117–127 dB re 1 μPa calculated in the 0–2 kHz bandwidth) and outboard engine boats (rms 120– 140 dB re 1 μPa, calculated in the 0–20 kHz bandwidth or rms 104–133 dB re 1 μPa, calculated in the 0–2 kHz bandwidth) affected reproductive success in Lusitanian toadfish by decreasing the likelihood of receiving eggs, decreasing the number of live eggs, and increasing the number of dead eggs, compared to control males. Boat noise exposed males also showed a heightened stress response and depressed calling activity. Boat noise has severe impacts on reproductive fitness in Lusitanian toadfish de Jong et al. (2020). Continuous noise with irregular amplitude and/or frequency-content (e.g.heavy ship traffic) were most likely to cause stress, and continuous noise was most likely to cause masking and hearing-loss. Vessel noise can cause strong masking effects even in fish with poorer hearing abilities. Continuous noise may have the potential to do more damage than intermittent noise because of the rapid accumulation of sound exposure level or the absence of recovery periods during continuous noise. The vulnerability of a species to noise-induced stress will mainly depend on:

a) its potential to switch reproduction to more quiet times or locations, and
b) its vulnerability to masking and hearing loss by how important sound communication is to its reproductive behaviour.

Examples include species that use sound to locate spawning grounds and for acoustic communication during spawning. Parental care can be affected if masking or distraction interferes with the timely detection of predators. Species that have restricted spawning grounds and periods that they cannot change will be more affected by noise-induced stress. There was no evidence for differences between laboratory and field studies in the likelihood of different noise types to affect behavioral stress responses, implying that these responses can be detected in the laboratory. Gendron et al. (2020). The pelagic larvae of winter flounder exposed to vessel noise displayed significantly fewer hunting events than controls, and their stomach volumes were significantly smaller. This noise effect was the same at all prey densities used, suggesting that larval feeding behaviour is negatively impaired by anthropogenic noise. The replayed vessel noise in the two aquaria was 129 and 127 dB re 1µPa^2 between 100 and 1,000 Hz. Blom et al. (2019). The continuous vs. intermittent noise treatments increased latency to female nest inspection and spawning and decreased spawning probability. Noise was an average of 34 dB lower for control vs. noise treatments (80-100 dB vs. 110-130 dB). Female spawning decisions were likely delayed by a compromised ability to assess male acoustic signals, rather than just due to stress. The silent periods in the intermittent noise treatment could have provided a respite during which the females could assess the males. Noise, of similar frequency range as anthropogenic boat noise, negatively affects reproductive success, particularly under a continuous noise exposure.
de Jong et al. (2018) tested the effect of low-frequency continuous noise on courtship behavior in two marine fish species, the two-spotted goby and painted goby, using aquarium experiments. With the addition of noise, males of both species exhibited less acoustic courtship. Additionally, painted gobies showed less visual courtship. Female painted gobies were less likely to spawn in the noise treatment (de Jong et al. 2018). Neither species appeared to compensate for the noise by increasing their visual signalling. Noise could have suppressed spawning because females may need to hear male song characteristics to assess male quality and identify the correct species. Interestingly, the increased noise levels of 20-30 dB, comparable to shipping noise and typical of UK coastal waters, did not affect overall activity or nest building in the painted goby, so field populations behaving apparently normally could still have less reproductive success (de Jong et al. 2018). Noise could also change a population's genetic make-up if females prefer different traits in males in the presence of noise. More importantly, a suppression of reproduction is likely to impact the population. For the painted goby, the noise level was 100 dB re 1µPa in the control treatments vs. 125 re 1µPa in the added noise treatments. For the two-spotted goby, it was 104 vs 134 dB re 1µPa. However, because the structure of the continuous experimental noise was different from real sources of anthropogenic noise, the levels used in the experiment cannot be directly translated to thresholds for the onset of effects of specific noise-sources.
Celi et al. (2016). Scientists found that 10 days of vessel noise playbacks in tanks (117-143 dB under 5 kHz, 5-25 dB above background) to gilthead sea bream produced significant biochemical changes in the blood or plasma (cortisol, ACTH, glucose, lactate, hematocrit, etc.) showing clear primary and secondary stress responses to maritime vessel traffic. Jolivet et al.

(2016). Researchers found that a planktonic food cue together with playbacks of lowfrequency ship noise (source level 127 dB re 1 μ Pa between 100 and 10,000 Hz) in the laboratory drastically increased blue mussel settlement by a factor of 4 compared to the control. Settlement levels approached 70% in 67 hrs, compared to more typical settlement success of 20%. While underwater noise increases mussel settlement (causing more biofouling on ships), it also decreases the size of the settler with "potential cascading ecological impacts". Purser et al. (2016). Noise effects can be dependent on the individual's body condition. Only juvenile European eels in poor shape breathed faster and startled less to a looming predator stimulus under the addition of ship noise, while those in good condition did not respond differently to playbacks of ambient coastal noise (control) vs. coastal noise with passing ships (received level, ambient coastal: ~108 dBRMS re 1 μPa; ship noise: ~148 dBRMS re 1 μPa). In fact, eels in the poorest condition displayed about double the change in respiration rate (a secondary indictor of stress) compared to those in the best condition. A decrease in the startle reaction makes eels more vulnerable to predation. These variations in reaction to noise within the population have critical implications for population dynamics and the introduction of management and mitigation measures. Solan et al. (2016) found that Norway lobster (Nephrops norvegicus) exposed to broadband continuous noise in a tank at levels between 135–140 dB re 1 μPa, received levels, demonstrated repressed burying behaviour and bioirrigation, and reduced locomotion. Similarly, the Manila clam showed a stress response at these levels whereby individuals relocated less, stayed on top of the seabed, and closed their valves. Such responses meant the clams couldn't mix the upper layers of sediment and couldn't feed. As a result, ecosystem properties were affected (Solan et al. 2016). Some individual clams also accumulated lactate from keeping their valves closed for an extended period of time, a known avoidance behavior that requires the animal to breathe anaerobically. If soundexposure, which was 7 days, had continued for much longer, these lactate levels would have been harmful (Solan et al. 2016). Noise thus changed the fluid and particle transport that invertebrates provide, which are key to nutrient cycling on the seabed. The authors note that "…exposing coastal environments to anthropogenic sound fields is likely to have much wider ecosystem consequences than are presently acknowledged." (Solan et al. 2016). This study shows that responses to noise can be subtle and may take long periods of time to become detectable at the population or ecosystem level.

Sierra-Flores et al. (2015) played back a linear sweep (100-1000 Hz), SPL of 132.8 dB re 1 μPa (34 dB SNR), to cod in tanks. When broodstock were exposed to noise in a 9-week-long experiment, higher cortisol content in the resulting eggs significantly suppressed the fertilization rate. The addition of noise reduced fertilization rates by 40%, which decreased viable egg productivity by over 50%. This translates to a loss of about 300,000 weaned juvenile cod in a hatchery situation (Sierra-Flores et al. 2015). The long-term sound stressor on the broodstock could have elevated cortisol levels in the females and subsequently transferred the cortisol to the eggs, or produced lower sperm quality in the males, either or both causing the reduction in fertilization success observed. Sierra-Flores et al. (2015) thus found noise to negatively impact cod spawning performance.

Simpson et al. (2015). Juvenile eels experienced higher breathing and metabolic rates, indicators ofstress, in the presence of noise from ship passages (~148 dBRMS re 1 μPa) vs. ambient noise without ships (~108 dB), as shown by experiments in tanks. They also performed worse on spatial tasks. Eels were 50% less likely and 25% slower to startle to a simulated 'ambush predator' and were caught more than twice as quickly by a simulated 'pursuit predator,' during playbacks of noise.

Southall et al. (XXXX). For pinnipeds subjected to non-pulsed sound, one study elicited a significant response on a single harbour seal at a received level of 100 – 110 dB re 1 μPa (rms). Despite limited available data, it appears that exposures between 90 and 140 dB re 1 μPa generally do not appear to induce strong behavioural responses in pinnipeds exposed to continuous sound in water.

Wale et al. (2013a). Researchers played back ship noise (received levels: 148–155 dBrms re 1 μPa) to a marine invertebrate, the shore crab. Playbacks lasted 15 mins. and mimicked two successive ship passes. Crabs subjected to the ship noise used 67% more oxygen than those exposed to ambient noise (received levels: 108–111 dBrms re 1 μPa), with heavier crabs showing a more pronounced response. The increased oxygen consumption of the ship-noise-exposed crabs was not due to greater crab movement but to a higher metabolic rate, which in turn, can indicate higher cardiovascular activity from stress. The size-dependent response may indicate that larger individuals in noisy conditions are less likely to survive, whereas the remaining smaller ones may be less likely to reproduce.

Wale et al. (2013b). When exposed to 7.5 mins. of ship noise (148-155 dBRMS re 1 μPa) compared with ambient noise (103-108 dBRMS re 1 μPa), shore crabs' feeding was interrupted, they were slower to return to shelter after a simulated predator attack, and they righted themselves faster, which also might expose them to increased risks of predation, since by remaining entirely motionless, they could avoid detection by the predator. All of these responses to noise could make starvation and predation more likely.

Buscaino et al. (2010). Researchers exposed European sea bass and gilthead sea bream to a sweep of frequencies that are produced by vessel traffic, for 10 mins. The amount of movement of both species was significantly higher compared to controls. Changes in blood measures (glucose and lactate) showed intense metabolic activity during exposure. The maximum sound pressure level of a single sweep was 150 dBrms re 1 μPa, but levels were mostly 130-140 dB and 5-20 dB above background levels.

Vasconcelos et al. (2007). Noise from ferry boats greatly masked toadfish calls, especially because this noise was in the most sensitive hearing range of this species. If the function of an acoustic signal is to assess an opponent's fighting ability, masking such signals could lead to misleading information and escalated contests. Ambient noise was 111.4 dB and the maximum instantaneous SPL of ship noise (LLSP) measured at 20 m distance was 130.8 dB. Spectral energies of the ship noise were approximately 40 dB above those of ambient noise between 300 Hz and 4 kHz.

Aguilar Soto et al. (2006). Shipping noise increased the noise floor by 15 dB which reduced the whale's sonar detection range to 42% of its normal value and the maximum communication range to 18% of its normal value.

Kastelein et al. (2006) performed experiments in a pool on nine harbour seals subjecting them to four different tones at about 12 kHz. Response was noted at 107 dB re 1 μPa, which was named the discomfort threshold. The seals responded by moving to quieter part of the pool still keeping the head in the water.

Wysocki et al. (2006). The researchers played back underwater ship noise at realistic levels (the equivalent continuous SPL (LLeq) was 153 dB re 1 μPa) for 30 min to three European freshwater fish species: one hearing generalist (European perch) and two hearing specialists (common carp, gudgeon). Another experiment used white noise played back at 156 dB re 1 μPa. On average, cortisol increased 99% over control values in the perch, 81% in the carp, and 120% in the gudgeon for the shipping noise playback, though white noise did not cause a significant change compared to the controls. The authors theorized that this may be due to the greater unpredictability (changes in frequency and level) of shipping noise compared to the continuous white noise. There were no differences in cortisol levels relative to fish hearing ability, i.e. between generalists and specialists.

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ANNEX 3

A robust approach to assessment of D11C2

M A Ainslie, 19 May 2022

Overview

Maps based on the median or other percentile are unstable. A robust assessment can be achieved
using the arithmetic mean instead.
Structure:

- motivation
o dose-response curves
o temporal and spatial averaging (15 dB spread)
- way ahead
o terminology
o choice of effect
o choice of metric
o choice of threshold (LOSE)
- summary and recommendations
- case study

Dose-response curves

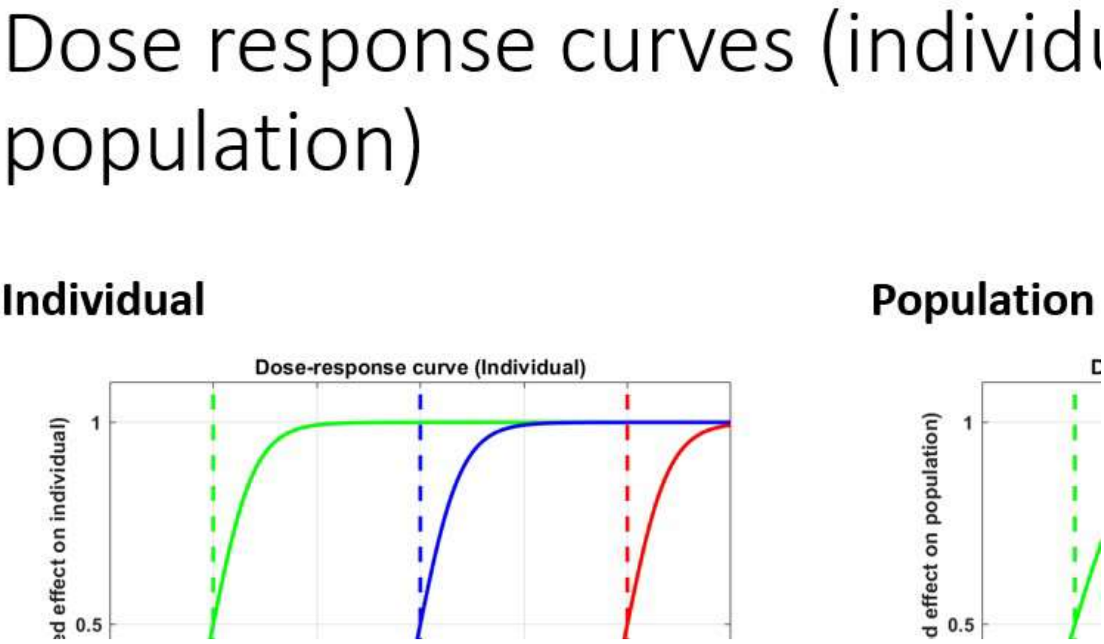

Figure 11. Hypothetical dose-response curves (probability of effect vs dose) for an individual (left) and population (right). The dose for an individual could be SPL. The dose for a population is a statistic of SPL to be determined.

Temporal and spatial averaging

Temporal averaging

The choice of LOSE depends on the metric used. There is a 15 dB difference between the median with TOW 1 s and the AM (Figure 12, Table 1). GM and median both depend on TOW. AM is more robust (independent of TOW).

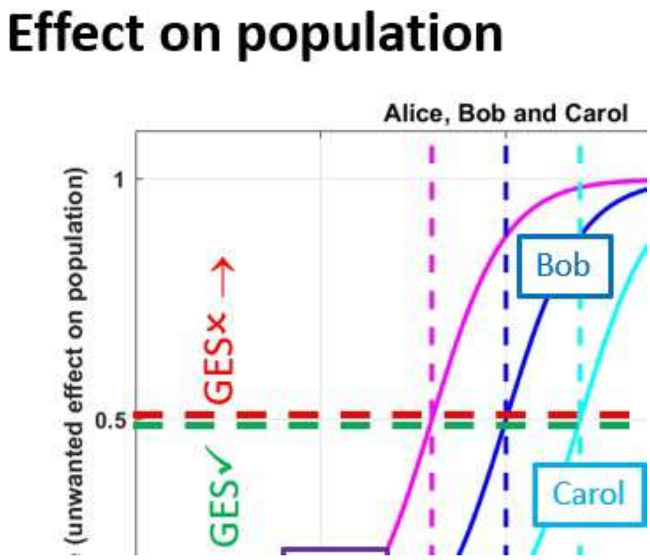

Figure 12. Hypothetical dose-response curves (probability of effect vs dose) for a population calculated using three different methods for identical sound field. The calculated dose depends on the method used.

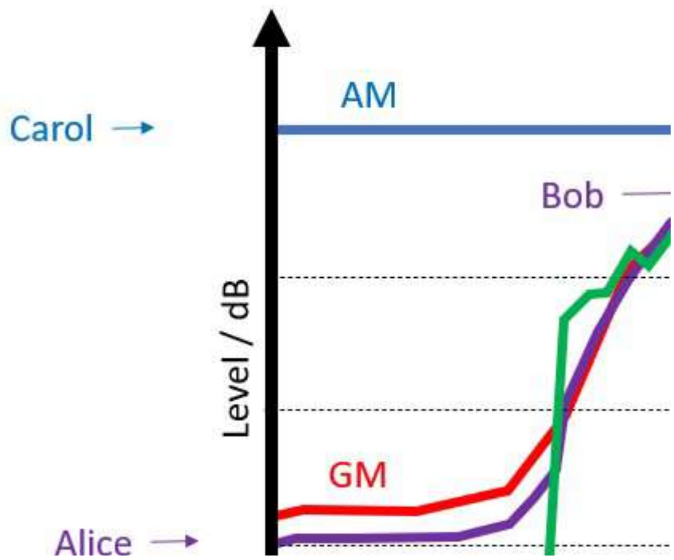

Figure 13. Dependence on TOW. original caption (Merchant et al 2012) "(a) Average SPLs in 125 Hz band for each month; averages with February ship signature [see Fig. 1(b)] omitted are plotted in gray. Integration time: 1 s. (b) Total average SPL for 125 Hz band vs averaging time. "Parks mode" refers to the averaging method in Ref. 4."

Spatial averaging

different approaches
- mean over depth
- mean over volume
- median over depth (and time)

difference
- not quantified
- can depend on order of averaging

careful definitions needed

Way ahead

Terminology

A common understanding of terms and their definitions is a pre-requisite for making further progress. Available resources include:
- ADEON terminology standard (Ainslie et al)
- JOMOPANS terminology standard (Robinson & Wang)
- SATURN terminology standard (first draft, Aug 2021)
- ISO 7605 ‘Measurement of ambient ocean sound’ (scheduled for publication in 2024)

Examples of terms defined by SATURN:
• Acoustic habituation

Acoustic sensitization
• Acoustic tolerance
• Acoustic disturbance
• Dose-response curve
• Temporal observation window (TOW)
• Temporal analysis window (TAW)
• Spatial observation window (SOW)
• Spatial analysis window (SAW)
• Sound map

Choice of effect

D11C2 has long been associated with masking (Tasker 2010, Dekeling 2014, BIAS, JOMOPANS).
Behavioural effects are covered by D11C1.
Proposal: Restrict attention in DL4 to masking.

Choice of metric

We need to either recommend one of the metrics or accept a 10-15 dB difference in assessment
methods for identical sound field
The recommended metric could be
- median for a specified TOW and SOW
- AM (more robust)

See annex (ppt) for examples of AM.

AM simplifies assessment. Area and duration are interchangeable. AM naturally trades area for duration. Obviates need for tolerable duration or tolerable area (Figure 14)
Median is problematic (think of ferry crossing once every 30 min in a remote region).

Choice of threshold (LOSE)

The threshold can be chosen pragmatically (pressure indicator) or by choosing a threshold for an undesirable effect.

Summary and recommendations

Terminology: SATURN Effect: masking
Metric: AM. Always report AM, even if not used in assessment.
LOSE
pragmatic choice/expert judgement
110 dB < LOSE < 120 dB?

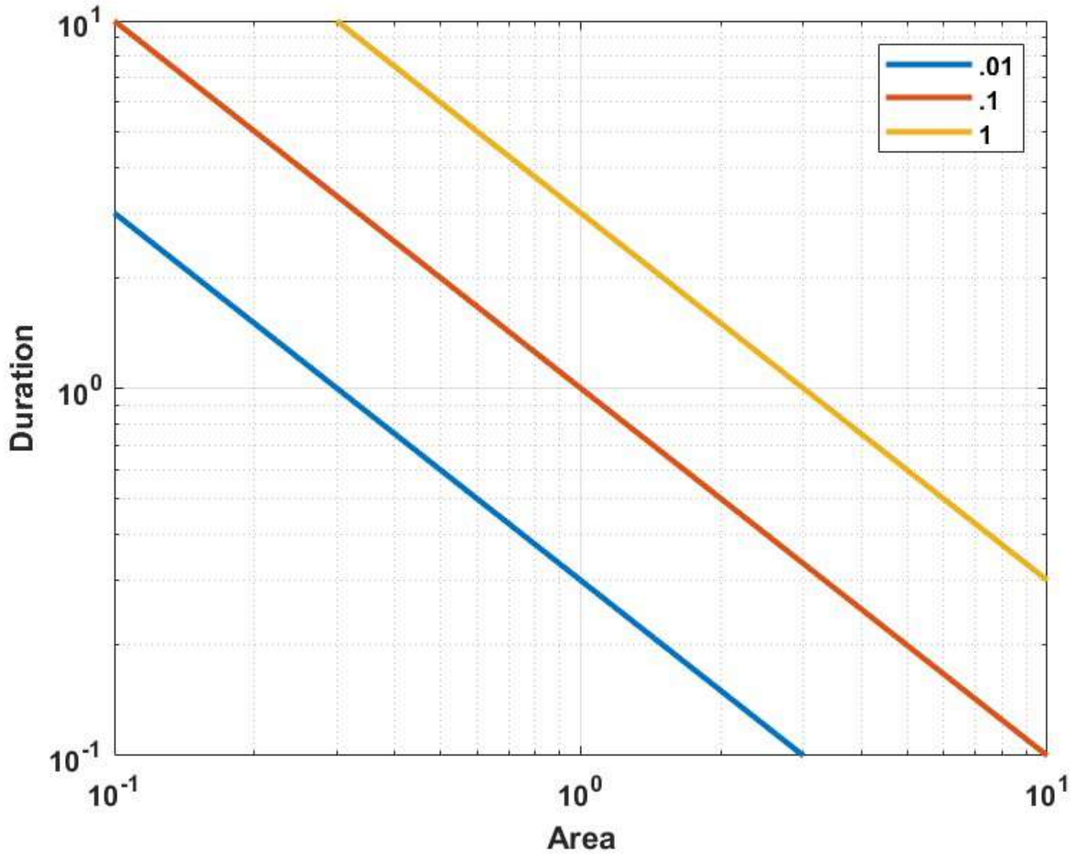

Figure 14. Affected area vs affected duration for fixed AM. There is no need for a Tolerable Affected Duration or Tolerable Affected Area. All that is needed is the value of LOSE.

Case study

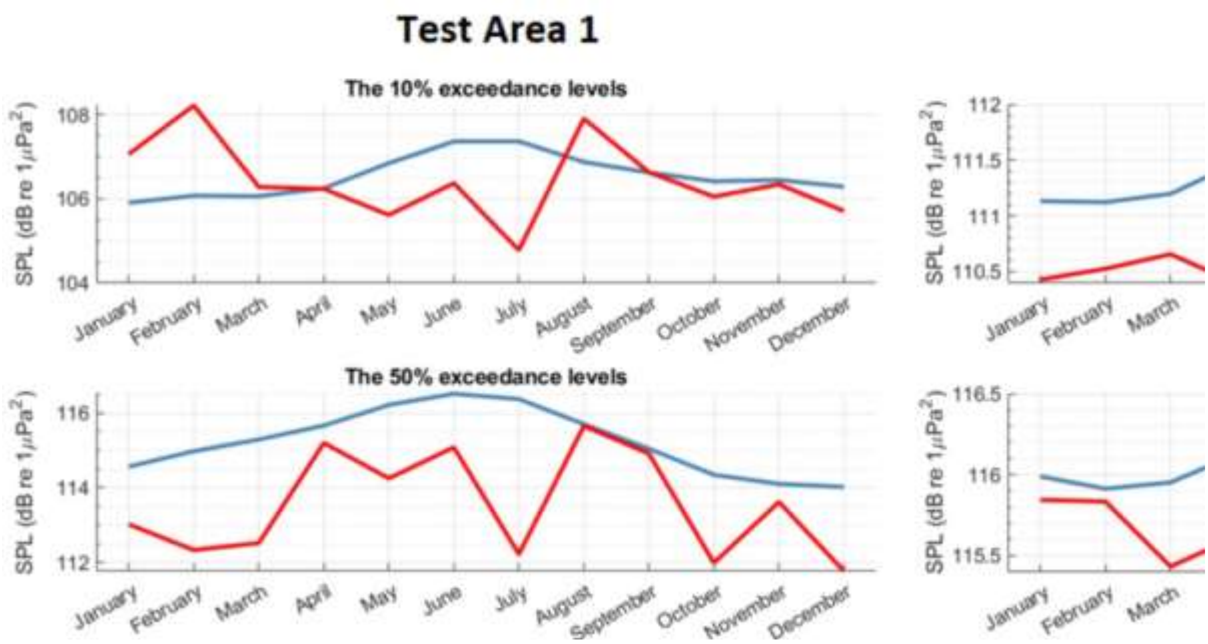

Figure 15. In 2020, the spatially averaged SPL was lower than the average over the 3 previous years in both test area 1 (southern North Sea) and test area 2 (northern Adriatic Sea).

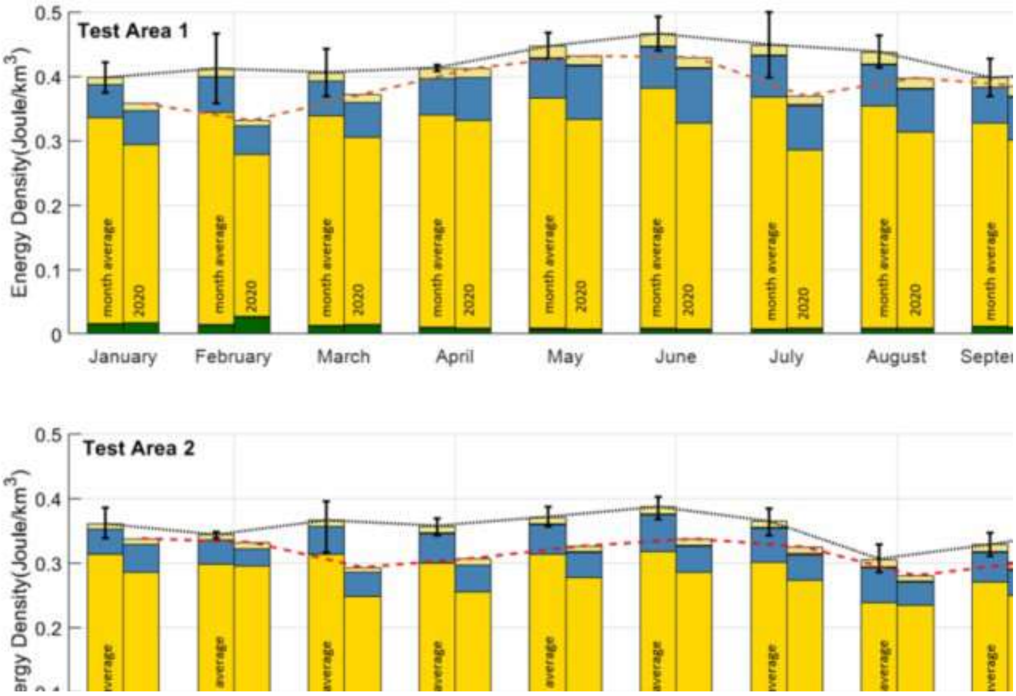

Figure 16. In 2020, the spatially averaged sound energy density was lower than the average over the 3 previous years in both test area 1 (southern North Sea) and test area 2 (northern Adriatic Sea). The benefit of converting to energy density is that one can construct an energy budget, identifying the ratio of sound energy from wind (green bars) to sound energy from cargo ships (yellow) or tankers (blue).

Proposal to use arithmetic mean in time and space

Show that the answer is the energy density (but don't call it that, yet). Can be expressed in J/m3 or (if preferred) converted to "SPL", except it's not SPL, it's the level of the spatially averaged mean-square sound pressure. It's not the same thing (contrast arsenic concentration example).

The proposal to use AM in time is not new. It was made in Dekeling 2014. What is new is the proposal to use it in space too.