Does moderate anthropogenic noise disrupt foraging activity in whales and dolphins?

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Recent research (2007-9)

Subtle yet perhaps significant behavioral responses to moderate noise

Foraging interruptions seen in many species, many noise sources

Foraging disruption is the behavioral impact most likely affect long-term health of individuals or populations.

Repeated observations of:

- Staying at surface near active airguns
- Decreased foraging in response to boats and sonar

Context: Behavioral disruption seen at relatively low received levels

120-150dB can trigger behavioral changes that are not necessarily minor — and occur far from noise sources.

Baleen whales response to multiple pulsed sounds (e.g. airguns) showed a dramatic threshold:

- •110-120dB: 60 out of 75 responses rated Level 0 (no response)
- •120-130dB: 47 out of 72 rated Level 6 on a scale of 9 (avoidance, brief cessation of reproductive behavior, extended changes or cessation in vocalizing)

Note: There are many complementary, contradictory, and generally confounding ways to look at these charts, but indications are clear that behavioral responses are not uncommon at low received levels

Southall, et al. Marine Mammal Noise Exposure Criteria: Initial Recommendations. Aquatic Mammals, Volume 33, Number 4. 2007

Seismic surveys and foraging

Some recent studies based on Marine Mammal observations aboard seismic survey vessels have noted a surprising INCREASE in the number of whales seen within visual observing range when airguns are active.

Caroline Weir. Overt Responses of Humpback Whales (Megaptera novaeangliae), Sperm Whales (Physeter macrocephalus), and Atlantic Spotted Dolphins (Stellena frontalis) to Seismic Exploration off Angola. Aquatic Mammals 2008, 34 (1), 71-83.

Potter, J. R., Thillet, M., Douglas, C., Chitre, M.A., Doborzynski, Z. and Seekings, P.J. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. IEEE J. Oceanic Engineer, 32: 469-483

Seismic surveys and foraging

SWSS included the most explicit evidence that remaining at the surface may indicate suspension of foraging activity:

The one whale that was D-tagged and that experienced sound levels of over 160dB *remained at the surface for the entire two hours* that the survey vessel was active, then *dove to feed shortly after the airguns were turned off (top quartile of normal rest periods was 37min).*

No tagged whale made a deep dive closer than 4km from the array

The authors concluded that "it is more than likely that some decrease of foraging effort may occur" when airguns are active, and calculated that a 20% decrease in overall foraging activity is likely to occur near airguns.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Wursig. 2008. Sperm whale seismic study in the Gulf of Mexico: Synthesis report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-006. 341 pp.

Seismic surveys and foraging

A study off Angola looked at pilot whales' response to airgun ramp-up, and found similarly ambiguous yet suggestive behavior:

A pod of pilot whales began an avoidance response when the survey ship approached to 750m, retreating to 900m aside the vessel's path, and gradually moving to 1.2km while remaining at the surface and orienting toward the vessel as ramp-up continued. The author notes that "despite a four-fold increase in source volume...the whales exhibited behavior best described as milling."

Caroline Weir. Short-Finned Pilot Whales (Globicephala macrorhynchus) Respond to an Airgun Ramp-up Procedure off Gabon. Aquatic Mammals 2008, 34(3), 349-354.

Seismic surveys and foraging

Subtle and ambiguous indications of a possible issue in these airgun studies

The possible concerns are reinforced by more concrete observations of foraging disruptions with other sound sources: sonar, boats, airplanes.

In addition, we'll look at important new systematic approaches to assessing and responding to the overarching issue of the lack of a clear dose-response function in behavioral responses.

Beaked whales and foraging

Beaked whales have been shown to be sensitive to a wide array of sound sources

UK Defence Science and Technology Laboratory study monitoring beaked whales on instrumented range during sonar exercises, found "potentially very significant" foraging changes:

"Beaked whale species ... appear to cease vocalising and foraging for food in the area around active sonar transmissions." … "Since these animals feed at depth, this could have the effect of preventing a beaked whale from feeding over the course of the trial and could lead to second or third order effects on the animal and population as a whole."

Reported in Nature, which received the report under a FOIA request, with the author(s) name(s) and location of the study removed.
http://www.nature.com/news/2008/080801/full/news.2008.997.html

Beaked whales and foraging

Beaked whales have been shown to be sensitive to a wide array of sound sources

Installation of pingers on gillnets cut beaked whale bycatch to *zero* over eleven years:

1990-96: 33 beaked whale deaths
1996-2007: 0 beaked whale deaths
260 cetaceans of 11 other species drowned in nets after pingers installed

Carretta, Barlow, Enriquez. Acoustic pingers eliminate beaked whale bycatch in a gill net fishery. Marine Mammal Science, 24(4):956-961 (October 2008)

Beaked whales and seismic surveys

Beaked whales have been shown to be sensitive to a wide array of sound sources

Beaked whales are the only family to have strandings (ambiguously) associated with seismic surveys

Key beaked whale habitat on Scotian Shelf:

Important to assure that mitigation is effective

Foraging disruptions over the course of a survey could lead to significant health and population-level impact

Sensitivity of beaked whales suggests need to clarify what received levels may affect foraging activity

Beaked whales and PAM

Zimmer, et al, 2008 highlights limits to passive acoustic monitoring/detection for beaked whales

High-frequency foraging clicks audible only at short range

High probability of detection: 700m

50%-80% detection: 1.5-3.5km

Long intervals between vocalization

30 minutes of foraging per dive

Up to 110 minutes of quiet between foraging at depth

Monitoring must last 140 minutes, on vessel moving less than 4km during that time.

Zimmer, Harwood, Tyack, Johnson, Madsen. Passive acoustic detection of deep-diving beaked whales. The Journal of the Acoustical Society of America, November 2008, Volume 124, Issue 5, pp. 2823-2832.

Sonar and foraging disruptions

Dramatic foraging disruptions at moderate received levels (160dB)

Orcas in CEE with D-tags:

Group ceased foraging and moved rapidly away

Unusual dive pattern:

Twice as deep (60m) as normal (20-45m)

Reversed ascent at 15m, headed back down to 60m

Kvadsheim, Benders, Miller, Doksaeter, Knudsen, Tyack, Nordlund, Lam, Samarra, Kleivane, Godo. Herring (slid), killer whales (spekknogger) and sonar - the 3S-2006 cruise report with preliminary results. Norwegian Defence Research Establishment (FFI). 30 April 2007

While the nature of airgun and mid-frequency active sonar sounds are very different, their source levels and propagation patterns are not so dissimilar.

Boat noise and foraging disruptions

Boat noise has also been widely
shown to disrupt foraging activity:

Jetskis and bottlenose dolphins:
Half of foraging groups shifted to traveling; traveling groups shifted to milling.

"… an immediate, short-term change in dolphin behaviour, suggesting that an increase in the frequency of high-speed personal watercraft in this area could produce long-term detrimental effects."

Miller, Solangi, Kuczaj II. Immediate response of Atlantic bottlenose dolphins to high-speed personal watercraft in the Mississippi Sound. Journal of the Marine Biological Association of the United Kingdom (2008), 88:1139-1143.

Boat noise and foraging disruptions

Tour boats disrupt foraging common dolphins:

- Proportion of time spent foraging dropped from 35% to 25% in presence of tour boats
- Length of time foraging dropped from 10 min to 6 min
- Time until return to foraging increased 56% (from 9 to 14 minutes)

Similar proportional decrease in foraging activity observed in orcas when boats are within 400m

Stockin, Lusseau, Binedell, Wiseman, Orams. Tourism affects the behavioural budget of the common dolphin Delphinus sp. in the Hauraki Gulf, New Zealand. Mar Ecol Prog Ser 355: 287–295, 2008

Williams, Bain, Smith, Lusseau. Effects of vessels on behavior patterns of individual southern resident killer whales Orcinus orca. Endangered Species Research, Vol. 6: 199-209, 2009.

Energetic Costs of Reduced Foraging

Williams et al, who did these orca studies in both northern and southern resident pods, earlier published a compelling examination of the energy budgets of orcas when boats were and were not present. Their striking findings:

- Overall energy expenditures are *only negligibly increased* in the presence of boats (2-3% increase)
- Total energy taken in via foraging was *reduced by more than 25%*

As regards seismic surveys, the key question would be how large an area the disruption occurs within, and would be particularly relevant in areas with multiple seismic surveys over the course of months.

Williams, Lusseau, Hammond. Estimating relative energetic costs of human disturbance to killer whales (Orcinus orca). Biological Conservation 133 (2006), 301-311.

Energetic Costs of Reduced Foraging

The energy budget impact of foraging disruptions by seismic surveys may be most problematic in baleen whales on summer feeding grounds.

Are there key summer feeding grounds in areas slated for oil and gas development? If so, can surveys take place when whales are not in the region?

Many previous studies indicating baleen whales avoid airguns at greater distances/lower received levels (see LGL reports).

Inconsistent Propagation Issues

SWSS confirmed that simple spherical and geometric spreading models are not reliable in assuring mitigation is effective.

- Sound reflections create areas of increased received levels at 4-8km
- "Absolute received levels can be as high at 12km as they are at 2km." (as high as 160dB peak to peak)

Similarly, a recent (2009) pinger study showed routine variability of 10-15dB (SEL) at many distances, with some occasions of 25-30dB differences

DeRuiter, Tyack, Lin, Newhall, Lynch, Miller: Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (Physeter macrocephalus). J. Acoust. Soc. Am., Vol. 120, No. 6, December 2006, pp.4100-4114.

Madsen, Johnson, Miller, Aguilar Soto, Lynch, Tyack. Quantitative measures of air-gun pulses recorded on sperm whales (Physeter macrocephalus) using acoustic tags during controlled exposure experiments. J. Acoust. Soc. Am., Vol. 120 (4), October 2006, pp.2366-2379

Shapiro, Tougaard, Jorgensen, Kyne, Balle, Bernardez, Fjalling, Karlsen, Wahlberg. Transmission loss patterns from acoustic harassment and deterrent devices do not always follow geometrical spreading predictions. Marine Mammal Science, 25(1): 53067 (Jan 2009)

Inconsistent Propagation and Responses

These propagation variances can wreak havoc with attempts to provide effective mitigation against behavioral effects.

Compounding the problem is that behavioral responses to a given level of sound are consistently found to be inconsistent. (in several of these cited studies, somewhere around half the individuals were affected, while others were not)

What to make of the variable responses?

- Lack of response does not necessarily indicate lack of effect (animals may linger in bothersome sound if options are limited)
- A subset of the population may be more sensitive to sound, and so disproportionately affected by cumulative impacts, leading to potential population-level effects

Peter L. Tyack. Implications for marine mammals of large-scale changes in the marine acoustic environment. Journal of Mammalogy, 89(3): 549-558, 2008.

L.S. Weilgart. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Can. J. Zool. 85: 1091-1116 (2007)

Systemic Responses to Inconsistencies

Matrix approach (NMFS, OSB)

Way to organize existing data and design new studies
Five functional hearing groups, three types of sound
Here's cumulative responses of LF baleen whales to multiple pulses:

Response score	Received RMS sound pressure level (dB re: 1 μPa) 80 to < 90	90 to < 100	100 to < 110	110 to < 120	120 to < 130	130 to < 140	140 to < 150	150 to < 160	160 to < 170	170 to < 180	180 to < 190	190 to < 200
9												
8												
7								1.0 (6)				
6				9.5 (7)	47.4 (7)	2.2 (7)	3.4 (4, 6, 8)	5.8 (1, 2, 3, 6)	4.5 (1, 2, 3, 4, 6)	8.3 (1, 2, 4, 8, 9)		
5					1.0 (7)		1.0 (4)	1.0 (1, 2)				
4												
3									1.0 (1, 2)	1.0 (1, 2)		
2												
1				5.0 (7)	6.0 (7)	1.0 (7)	2.5 (1, 2, 3)	3.0 (5)				
0				59.8 (7)	17.7 (7)	1.1 (7, 9)	0.1 (9)	0.6 (3, 9)	6.8 (1, 2, 3, 9)	6.3 (1, 2, 9)		

Systemic Responses to Inconsistencies

Note threshold mentioned earlier, at 120dB RMS

Yet also see 150-160dB, responses from 0 to 7 on the severity scale
And, significant proportion of responses at 0 for 160+dB

Response score	Received RMS sound pressure level (dB re: 1 μPa) 80 to < 90	90 to < 100	100 to < 110	110 to < 120	120 to < 130	130 to < 140	140 to < 150	150 to < 160	160 to < 170	170 to < 180	180 to < 190	190 to < 200
9												
8												
7								1.0 (6)				
6				9.5 (7)	47.4 (7)	2.2 (7)	3.4 (4, 6, 8)	5.8 (1, 2, 3, 6)	4.5 (1, 2, 3, 4, 6)	8.3 (1, 2, 4, 8, 9)		
5					1.0 (7)		1.0 (4)	1.0 (1, 2)				
4												
3									1.0 (1, 2)	1.0 (1, 2)		
2												
1				5.0 (7)	6.0 (7)	1.0 (7)	2.5 (1, 2, 3)	3.0 (5)				
0				59.8 (7)	17.7 (7)	1.1 (7, 9)	0.1 (9)	0.6 (3, 9)	6.8 (1, 2, 3, 9)	6.3 (1, 2, 9)		

Systemic Responses to Inconsistencies

US Navy's "Risk Function" Analysis

Recent EISs for offshore training ranges MFAS no longer using step function for Level B behavioral impacts (under 160dB no effect, over 160dB always an impact)

Now using a risk function, which accounts for modest proportion of population responding at 120dB, half responding at 165dB, and nearly all responding at 190dB

Obviously, the Navy's sonar data is not directly applicable to seismic impacts. However, propagation patterns and distances are roughly similar.

Systemic Responses to Inconsistencies

US Navy's "Risk Function" Analysis

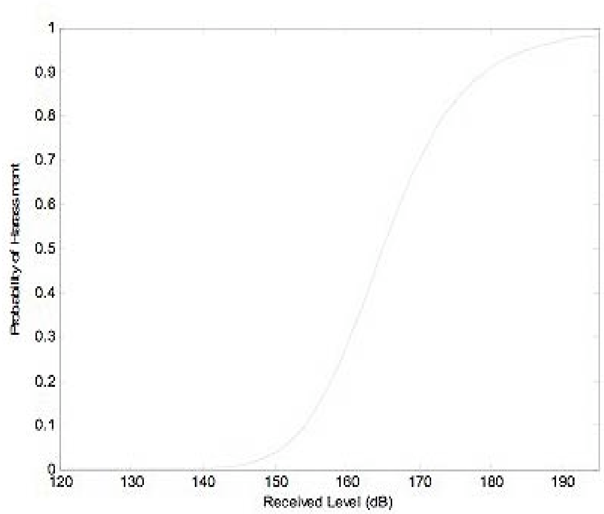

Figure 3.9-7: Risk Function Curve for Mysticetes (Baleen Whales)

Source: NWTRC DEIS, p. 3.9-72

More accurately accounts for the moderate but significant proportion of a local population that may respond to relatively low sound levels by changing their behavior in relatively dramatic ways.

Note: the slope of this curve is under continual review and may be too steep--does not seem to fully address matrix data we just reviewed.

Table D-12. Behavioral Harassments at each Received Level Band from 53C

Received Level (dB SPL)	Distance at which Levels Occur in NWTRC	Percent of Behavioral Harassments Occurring at Given Levels
Below 140	51 km - 130 km	< 1%
140<Level<150	25 km – 51 km	2%
150<Level<160	10 km – 25 km	18%
160<Level<170	3 km – 10 km	43%
170<Level<180	560 m – 3 km	28%
Above 180 dB	0 m – 560 m	< 9%

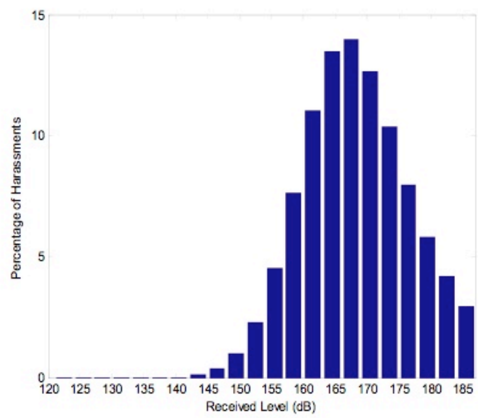

Figure D-26. Approximate Percentage of Behavioral Harassments for Every 5 Degree Band of Received Level from the 53C

56% of Behavioral disruptions occur beyond 3km, many beyond observation range

Majority of exposures are between 160-175dB (though 120-140dB may be underrepresented)

45% of harassments are at 160-170dB, between 3 and 10km

Source: NWTRC DEIS, p. D-50

Recommendations

While our understanding of the mechanism(s) that may contribute to reduced foraging remain murky, marine mammal observations taking place on or around seismic survey vessels hold the promise of providing much-needed clarification of these potential impacts.

Toward this end, it is important to require consistent observation and reporting standards (with particular attention to foraging activity) and the maintenance of a central database of all observations.

Recommendations

There is an important emerging pattern of behavioral responses at received levels that lie beyond visual observation range.

Investigation of this factor, and the implication that foraging activity could be disrupted over a relatively large area, will require the use of monitors (visual and/or acoustic) at some distance around survey vessels, perhaps 2km to 10km or more.

Such monitoring could be part of mitigation requirements, given the current uncertainties. Some initial sampling studies (relatively inexpensively done using small boats near survey vessels) could determine whether there are indications of such impacts, with more extensive studies being initiated only if indications of impacts are seen.

Recommendations

Foraging disruptions in some species may be related to the extended frequency components of airgun sounds

The single whale in the SWSS that ceased foraging was receiving very little sound energy below 500Hz and significant energy from 1-12kHz.

Cetaceans that depend on echolocation may be disproportionately affected by foraging interruptions, though such disruption may occur at relatively close range.

A research and/or mitigation need makes itself obvious here: Observation of echolocating odontocetes species should be increased at distances which frequency spectrum and propagation studies indicate may be problematic.

Recommendations

Ongoing review of new research examining behavioral responses to moderate noise is especially important for regulators charged with developing effective mitigation guidelines.

Recent multi-agency efforts in the US and EU (Southall et al, 2007; Marine Science Board, 2008) are attempting to create frameworks within which the ever-increasing amounts of new data on behavioral responses to anthropogenic noise may be more effectively organized, utilized by stakeholders, and used to design studies to address key knowledge gaps and provide solid foundations for future research.

DFO staff should remain in close contact with their colleagues in the US and EU so as to assure that observations here are incorporated in these efforts, and to respond as is appropriate to new findings from elsewhere.