NOAA FISHERIES

Northwest Fisheries Science Center

Effects of Noise

Science to Support the Recovery of Southern Resident Killer Whales

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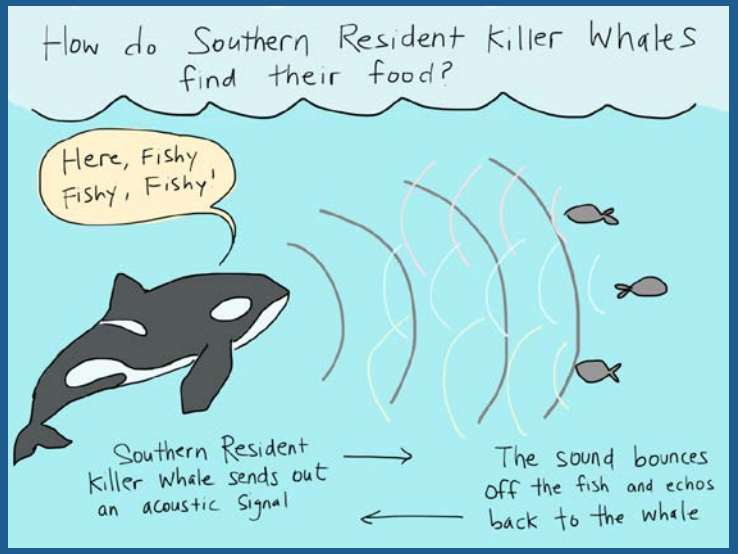
Review of NOAA Fisheries' Science on Marine Mammals & Turtles
Southwest and Northwest Fisheries Science Centers, NOAA Fisheries
July 28, 2015

Effects of Noise on SRKWs

- SRKWs use sound for critical life functions
  - Echolocation for finding prey
  - Calls/whistles serve social functions
  - Passive listening

- Noise, especially from vessels, identified as a key threat of SRKW survival and recovery

- Studies to address management needs
  - Activities under Section 7
  - Proposed vessel regulations
  - Evaluation of existing regulations



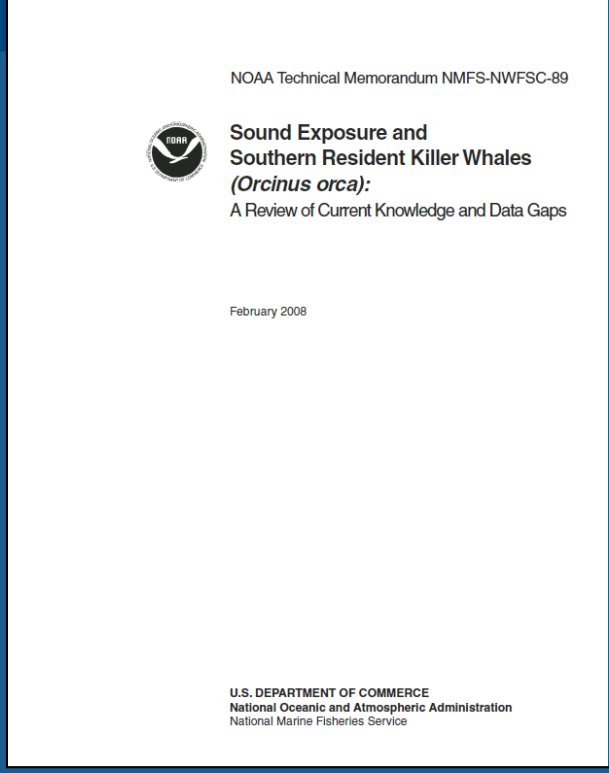
Work Prior to 2007

Reviewed in Tech Memo, Holt 2008

- Characterizing sound & propagation
  - Ambient noise - Veirs & Veirs 2005
  - Sound propagation model - Jones & Wolfson 2005
  - Whale-watching vessels - Hildebrand et al. 2006

Additional Content:

- Basic concepts
- SRKW sound use
- KW auditory capabilities
- Effects of sound exposure
- Likelihood of effects
- Recommendations for future work


NOAA Technical Memorandum NMFS-NWFSC-89

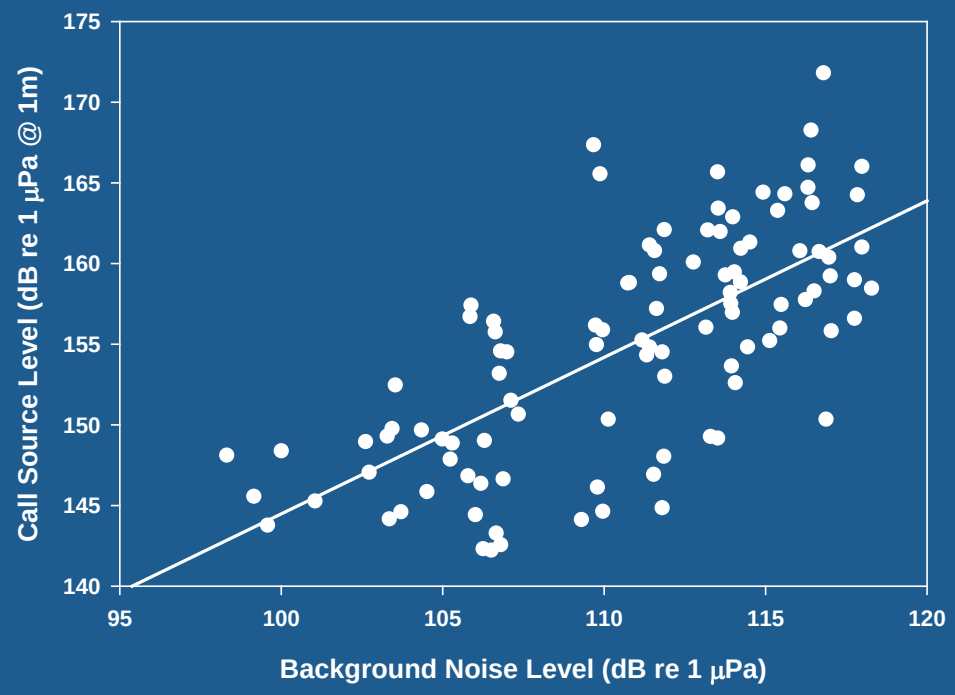
Sound Exposure and Southern Resident Killer Whales *(Orcinus orca)*:
A Review of Current Knowledge and Data Gaps

February 2008

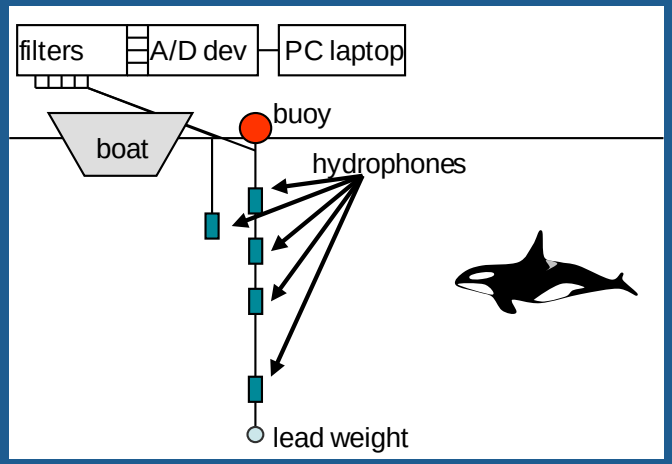
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

SRKW Acoustic Responses to Noise

Holt et al. 2009, 2011



From *Holt et al. 2009*



- 1 dB increase in call level for 1 dB increase in noise level
- Noise levels related to vessel counts

Metabolic Cost of Sound Production & Vocal Changes

- Open-flow respirometry - O_2 consumption in two bottlenose dolphins
  1. Social sound production (whistles & squawks) - Noren et al. 2013
  2. Changes in vocal effort of social sounds - Holt et al. 2015
  3. Click production - Noren et al. in prep

- Vocal behavior acoustically recorded

Funded by the Office of Naval Research

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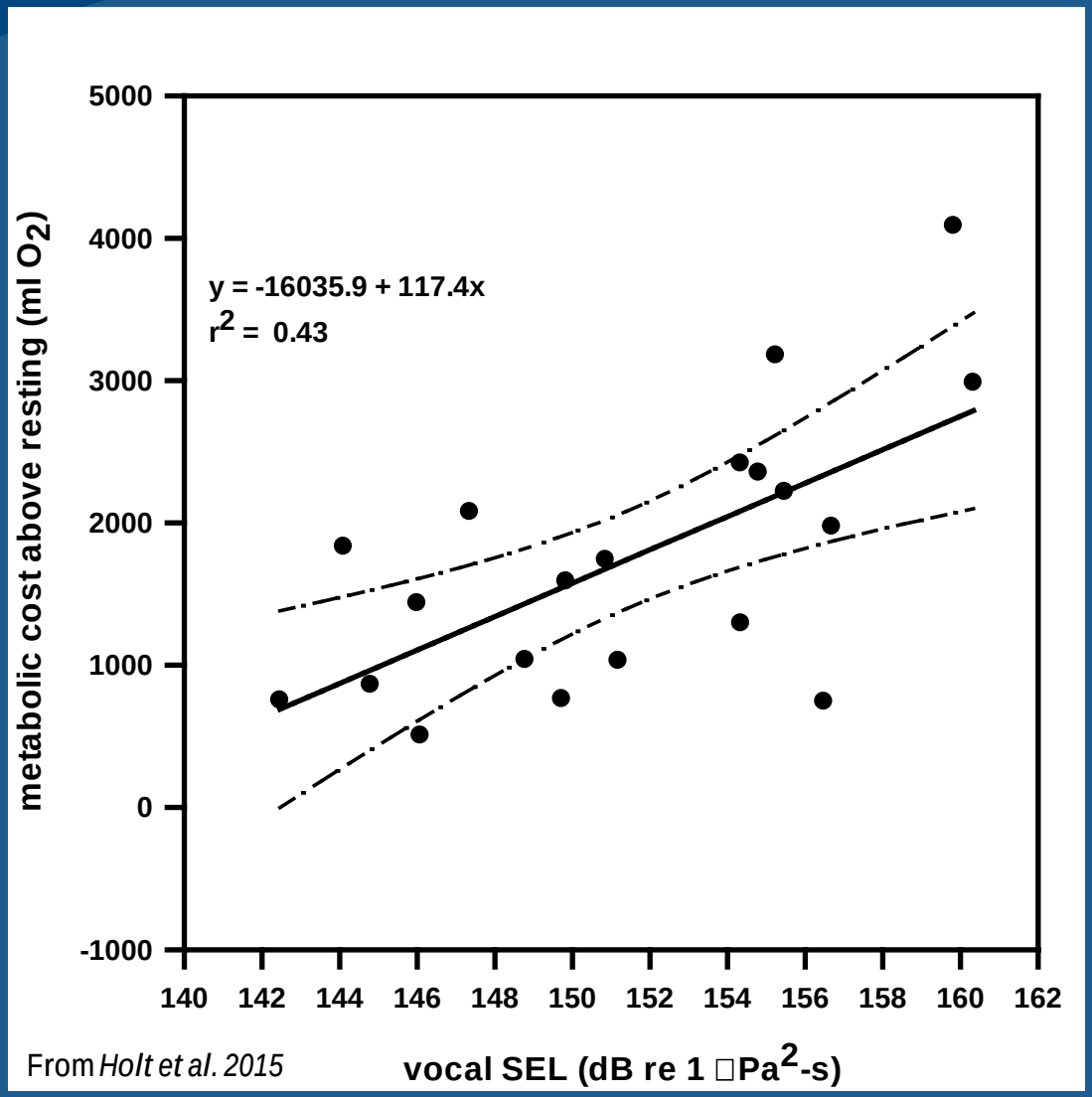
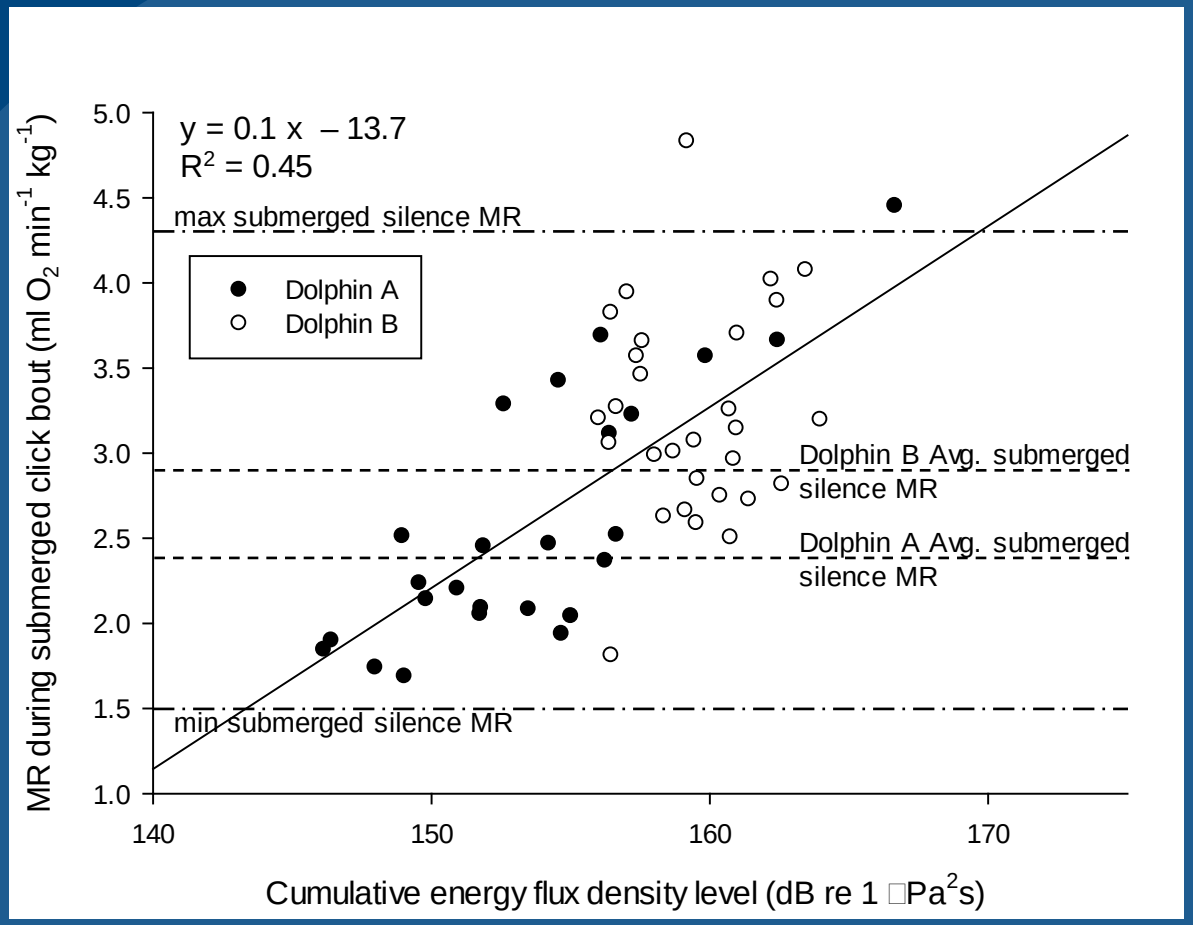
Cost of Changes in Vocal Effort



From *Holt et al. 2015*

Effect of Click Energy Level on MR



Cost comparisons between sound types:

- For equal acoustic energy production
  - ➢ Clicks = only 5% of whistle costs

Vessel Sound Exposure & Effects on Behavior

Current work using DTAGs

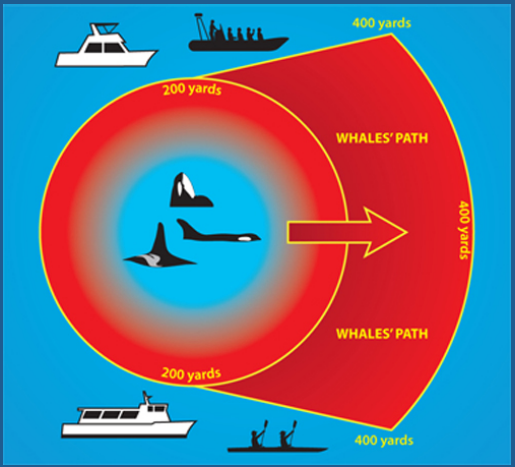
Goals

1. Quantify received noise that individual SRKWs experience → compare before/after vessel regs - Holt et al. in prep
2. Determine the relationship between vessels and their attributes and received noise level (NLs) - J. Houghton et al. submitted, M.S. Thesis (UW)
3. Investigate detailed SRKW *subsurface* behavior during different activities (foraging, traveling, etc.)
4. Determine potential effects of vessels and associated noise on behavior, especially foraging

Funding provided by the NOAA Ocean Acoustics Program

Do vessel regs reduce noise exposure?

Current analysis



U.S. vessel regulations – effective May 2011:

- Developed to protect kw's from vessel and noise
- WA State regulations prior (2008-2011)
- Only guidelines in Canada

- Compare noise levels before/after vessel regulations
  - Sound loses strength when it propagates
  - All else being equal, if all vessels go from 100 to 200 yd then
    - Noise level ↓ 6 dB, under spherical spreading assumption

DTAG Data collection

Transboundary Waters of San Juan Islands

- 4 field seasons

DTAG (Digital Acoustic Recording Tag)

- 2 hydrophones - acoustic data
- movement sensors - pitch, roll, heading, depth

Conduct focal follow

- Whale data:
  - ID, location, behavior, prey and fecal samples, etc.
- Vessel data within 1.5 km:
  - Location, distance, type, class, ID, speed, orientation, count

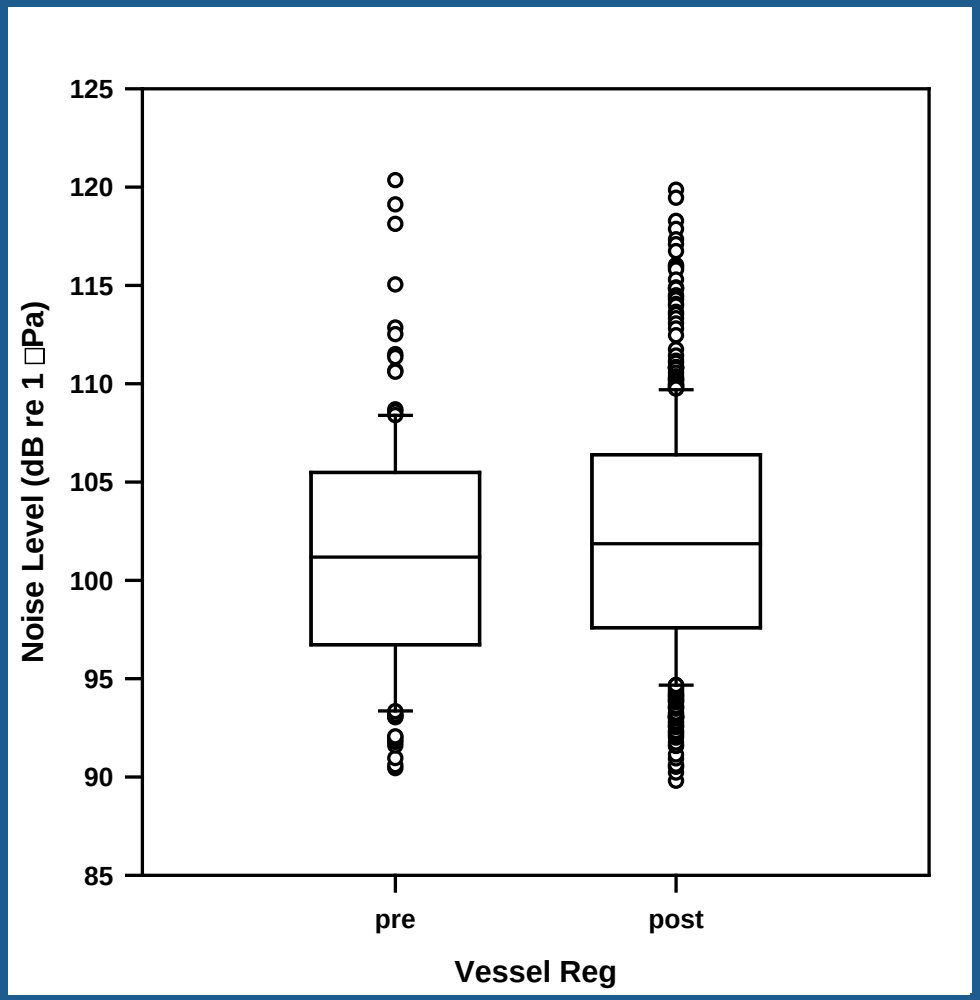
29 Tags Deployed

- 117 hrs total
- All 3 Pods
- 15 males/14 females
- 18 adults/11 juveniles

Noise Level Comparison*

- Receive NL dB re 1 μPa (1-40 kHz)
  - N = 624
- No difference before/after vessel regs
- Differences by year
- Pairwise comparisons:

Comparison	P-value	Diff?
2012 vs 2011	<0.001	Yes
2012 vs 2014	<0.001	Yes
2012 vs 2010	<0.001	Yes
2010 vs 2011	0.007	Yes
2010 vs 2014	0.925	No
2014 vs 2011	0.160	No



*using nominal hydrophone sensitivity plus gain, tags not calibrated

→ preliminary results!

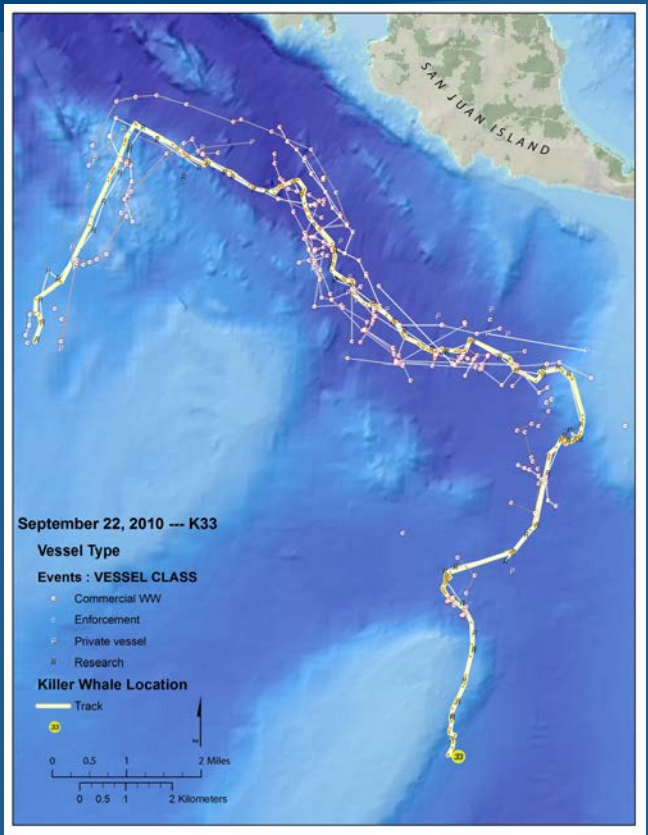
Linear mixed model analysis

N = 449

Predictors of received NL tested

- Fixed Effects
  1. Year (as factor, numeric, before/after reg)
  2. Country (as factor, US or CAN)
  3. Vessel Count (linear or log)
  4. Average Vessel Distance (linear or log)
  5. Average Vessel Speed (linear)

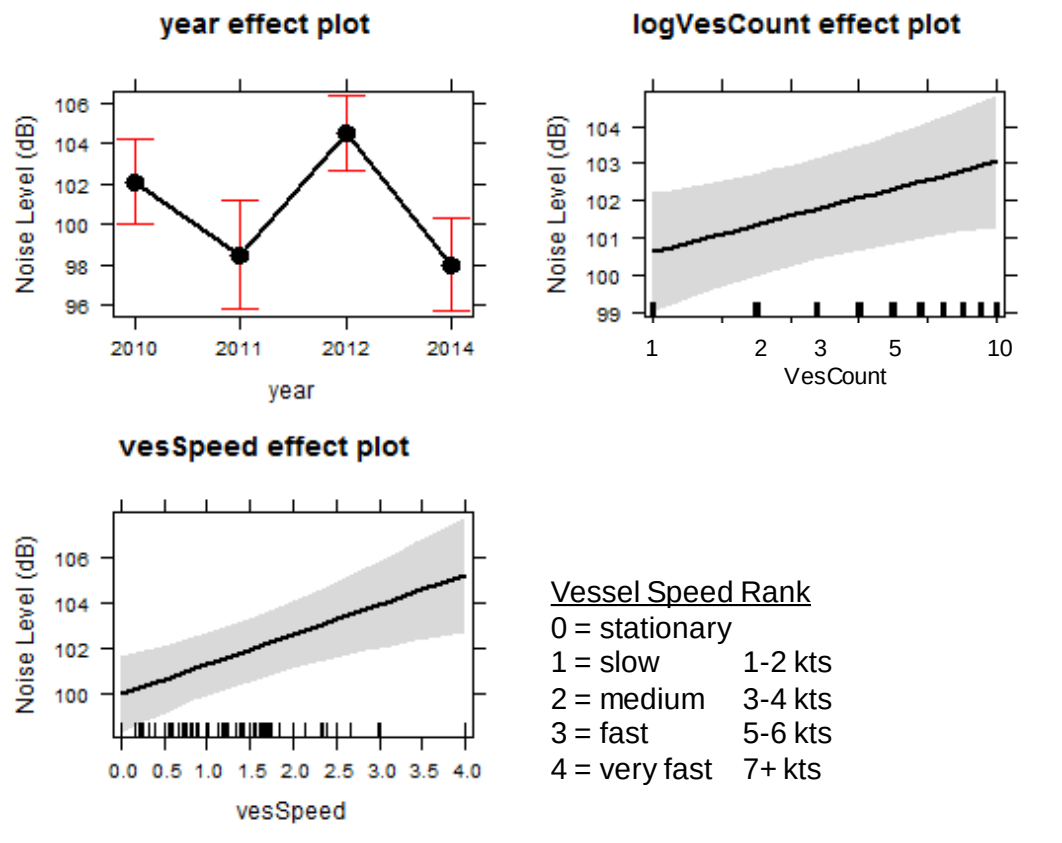
- Random Effects (random intercept structure)
  - Animal related
    - Animal ID, Sex, Age class
  - Temporally related
    - julian day, month, day, hour, weekend
  - Tag related:
    - tag type, tagID, minTagon



Best Model using AIC selection

noise (dB) = year + logCount + speed + 1|AnimID + 1|hour + 1|minTagOn

- Best random components structure includes:
  - animID, hour, and minTagOn
- Country, distance not included in best model
- Year with highest noise levels
  - Highest vessel speed
  - 2nd highest vessel count



Vessel Speed Rank

0 = stationary	
1 = slow	1-2 kts
2 = medium	3-4 kts
3 = fast	5-6 kts
4 = very fast	7+ kts

Summary

- SRKW acoustically respond to vessel noise
- In other delphinids, this response has a metabolic cost
- No detectable reduction in noise after vessel regulations
  - Results are preliminary
  - Vessel speed and count are predictive of noise levels
  - Change in vessel practices after regulations may explain differences
- Emitted noise is not the only factor involved in vessel disturbance
  - Challenges in assessing trade-offs
- Next step is to determine effects of vessels and noise on behavior, especially foraging

  → address prey scarcity risk factor and biological significance

References

Holt, M.M. 2008. Sound exposure and Southern Resident killer whales (Orcinus orca): A review of current knowledge and data gaps. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-89, 59 p.

Holt, M.M., Noren, D., Veirs, V., Emmons, C., and Veirs, S. 2009. Speaking up: Killer whales (Orcinus orca) increase their call amplitude in response to vessel noise. Journal of the Acoustical Society of America (JASA) Express Letters. 125: EL27-EL32 (Published online 22 Dec 2008).

Holt, M.M., Noren, D., and Emmons, C. 2011. The effects of noise levels and call types on the source levels of killer whale calls. Journal of the Acoustical Society of America 130: 3100-3106.

Holt, M.M., Noren, D.P., Dunkin, R.C., and Williams, T.M. 2015. Vocal performance affects metabolic rates in dolphins: implications for animals communicating in noisy environments. Journal of Experimental Biology, 218: 1647-1654, doi:10.1242/jeb.122424.

Noren, D.P., Holt, M.M., Dunkin, R.C., and Williams, T.M. 2013. The metabolic cost of communicative sound production in bottlenose dolphins (Tursiops truncatus). Journal of Experimental Biology. 216:1624-1629.

Extra slides

Methods for Noise Measurements

- Noise levels averaged across two hydrophones in tag
  - Tags not calibrated → preliminary!
  - Dtag2s used in all years except 2012 used Dtag3s
- Received noise levels (in dB re 1μPa) based on rms pressure
  - averaged over a 1 sec time window
  - frequencies of 1-40 kHz (same as Holt et al. 2009; 2011).
- Flow noise independence
  - Spectrographic and aural assessment
  - High vessel noise reduces ability to tease out flow noise
    - whale speed estimate from depth and pitch
    - different size and housing of the two tag version
      - a priori reason to look at separately

Noise level by estimated whale speed

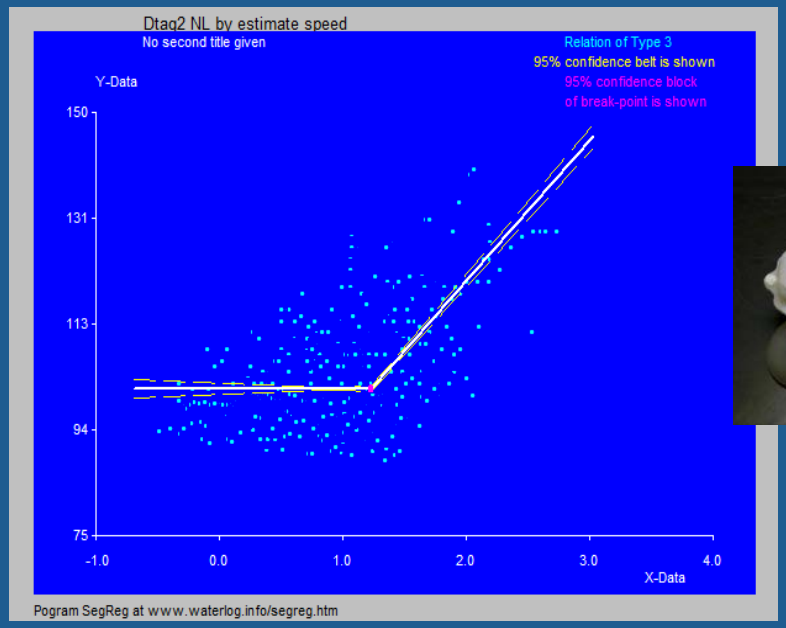
After spectrographic and aural assessment of flow noise absent periods:

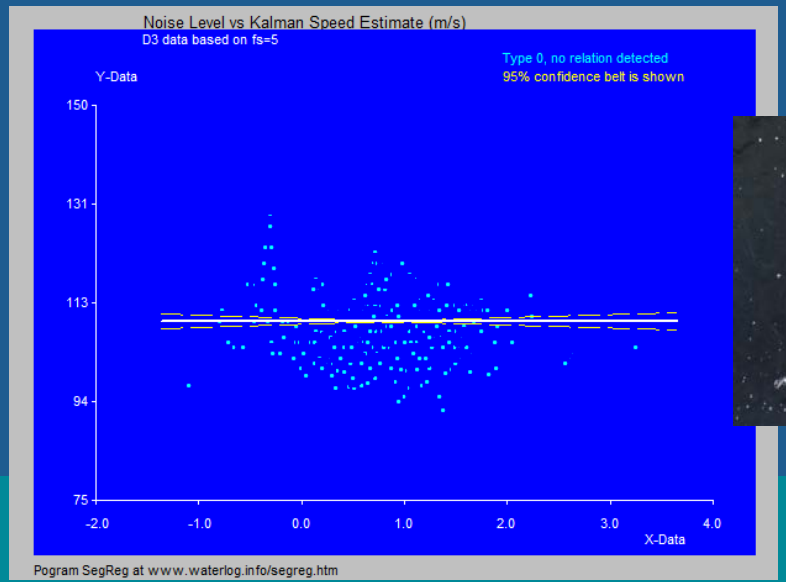
D2 tags:

- Breakpoint at 1.23 m/s
- Noise levels uncorrelated with speed below 1.23 m/s
- All NL data excluded for speed estimates > 1.23.

D3 tags:

- Noise levels uncorrelated with all speeds
- All NL data included





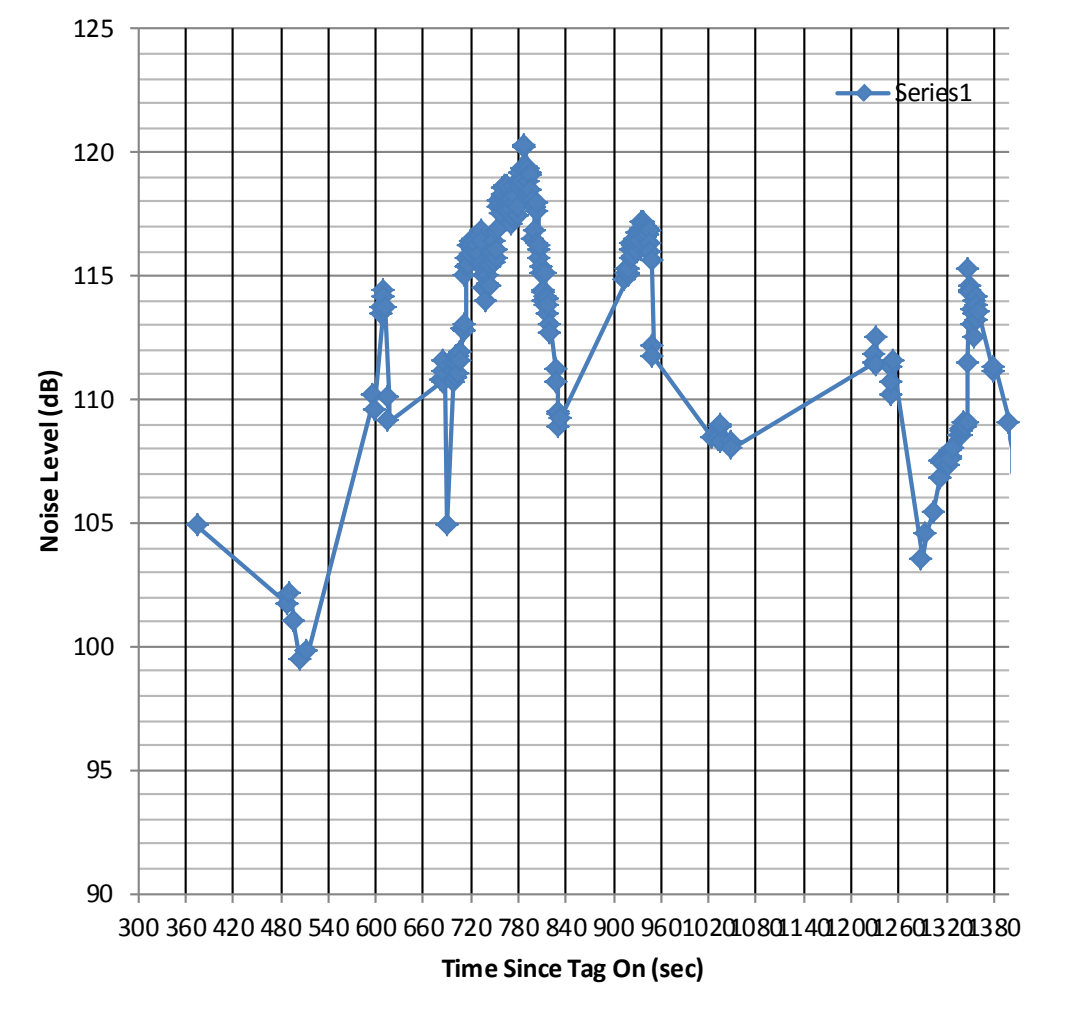
DTAG -2 external polyethylene housing

DTAG -3 encased polyurethane housing

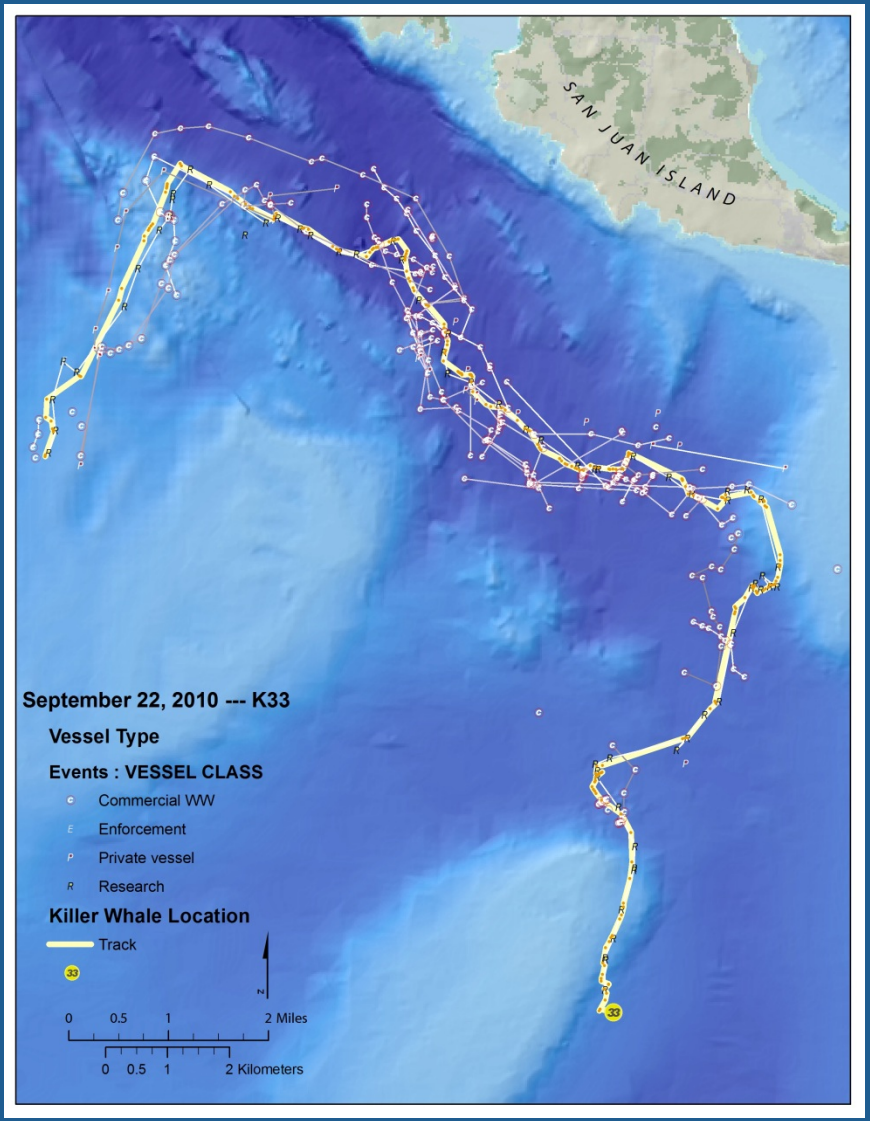
Noise Level Independence

NLs can fluctuate substantially

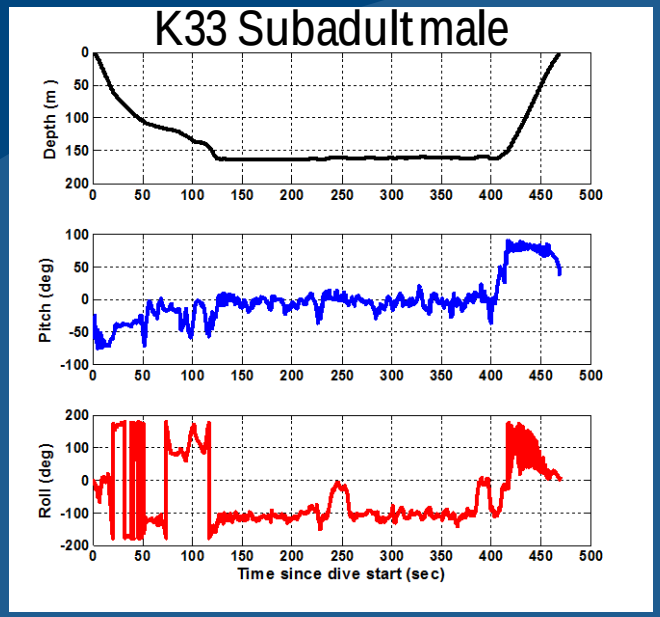
- Frequent vessel maneuvering during whale watching
- But time series from tag data shows NLs are highly correlated in time
- Inspection of data→ temporal independence for NLs separated by at least 30 sec
  - Reduced N= 624 (from 3698).

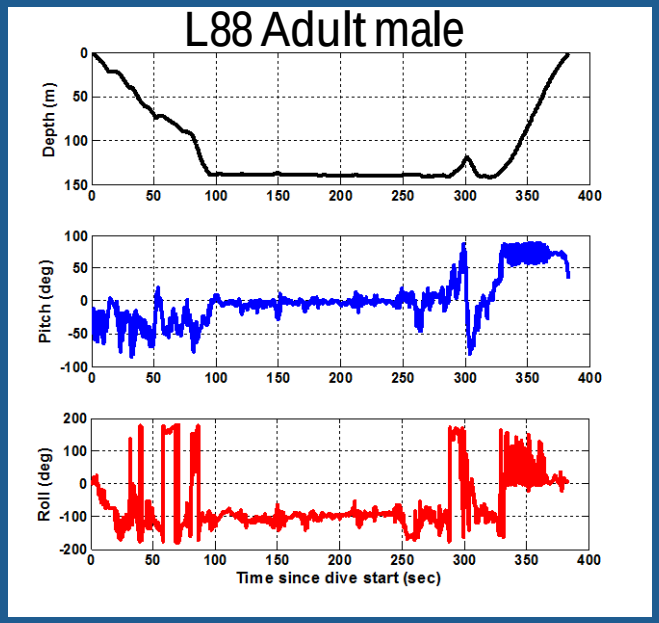


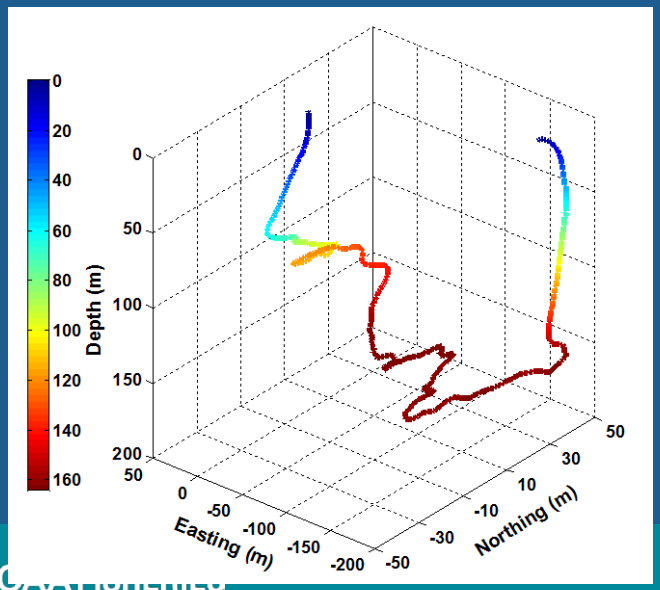
Vessel locations during tag deployment

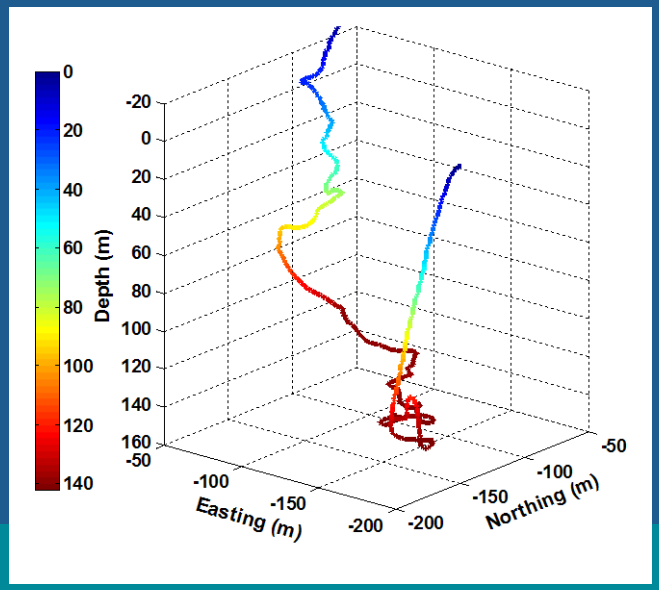


Foraging Dive Movement





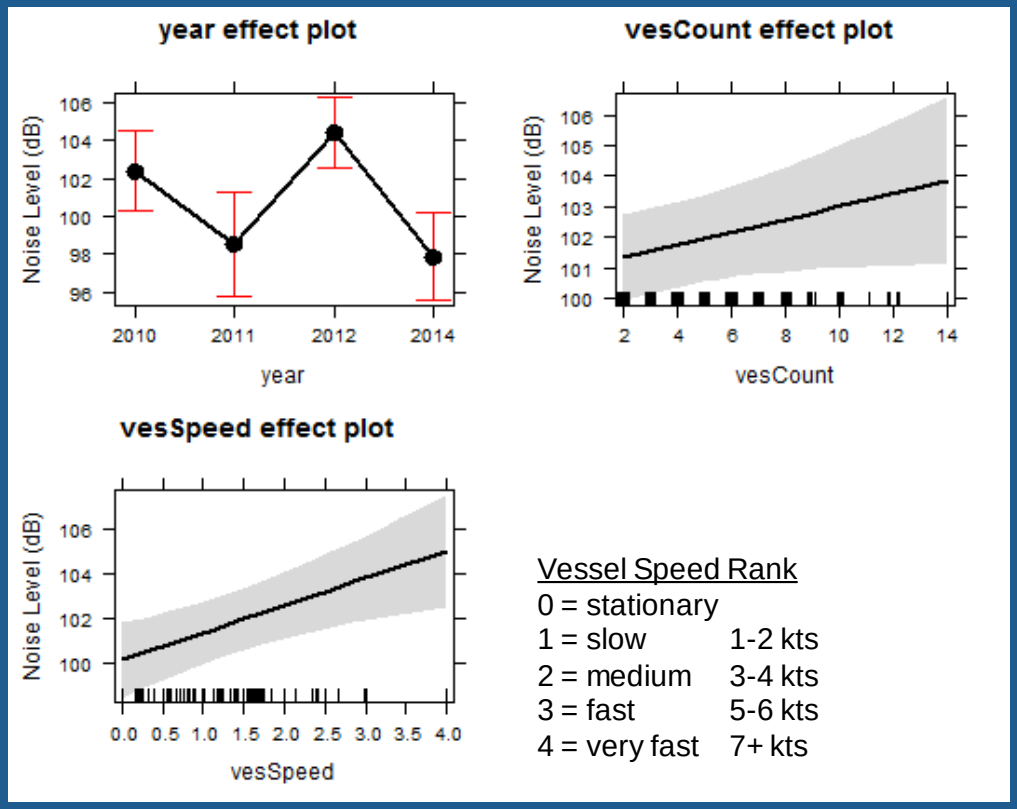




Best Model using linear count data

noise (dB) = year + count + speed + 1|AnimalID + 1|hour + 1|minTagOn

- Best random components structure includes:
  - AnimID, hour and minTagOn
- Country and distance not included in best model
- Fixed effects in best model "significance level"
  - year***
  - count (p = 0.07)
  - speed**



Vessel Speed Rank

0 = stationary	
1 = slow	1-2 kts
2 = medium	3-4 kts
3 = fast	5-6 kts
4 = very fast	7+ kts

Best Model excluding RV only intervals

noise (dB) = year + logCount + speed + 1|AnimalID + 1|hour + 1|minTagOn

- Best random components structure includes:
  - AnimID, hour and minTagOn
- Country and distance not included in best model
- Fixed effects in best model "significance level"
  - year***
  - logCount (p = 0.22)
  - speed**

Random effects:

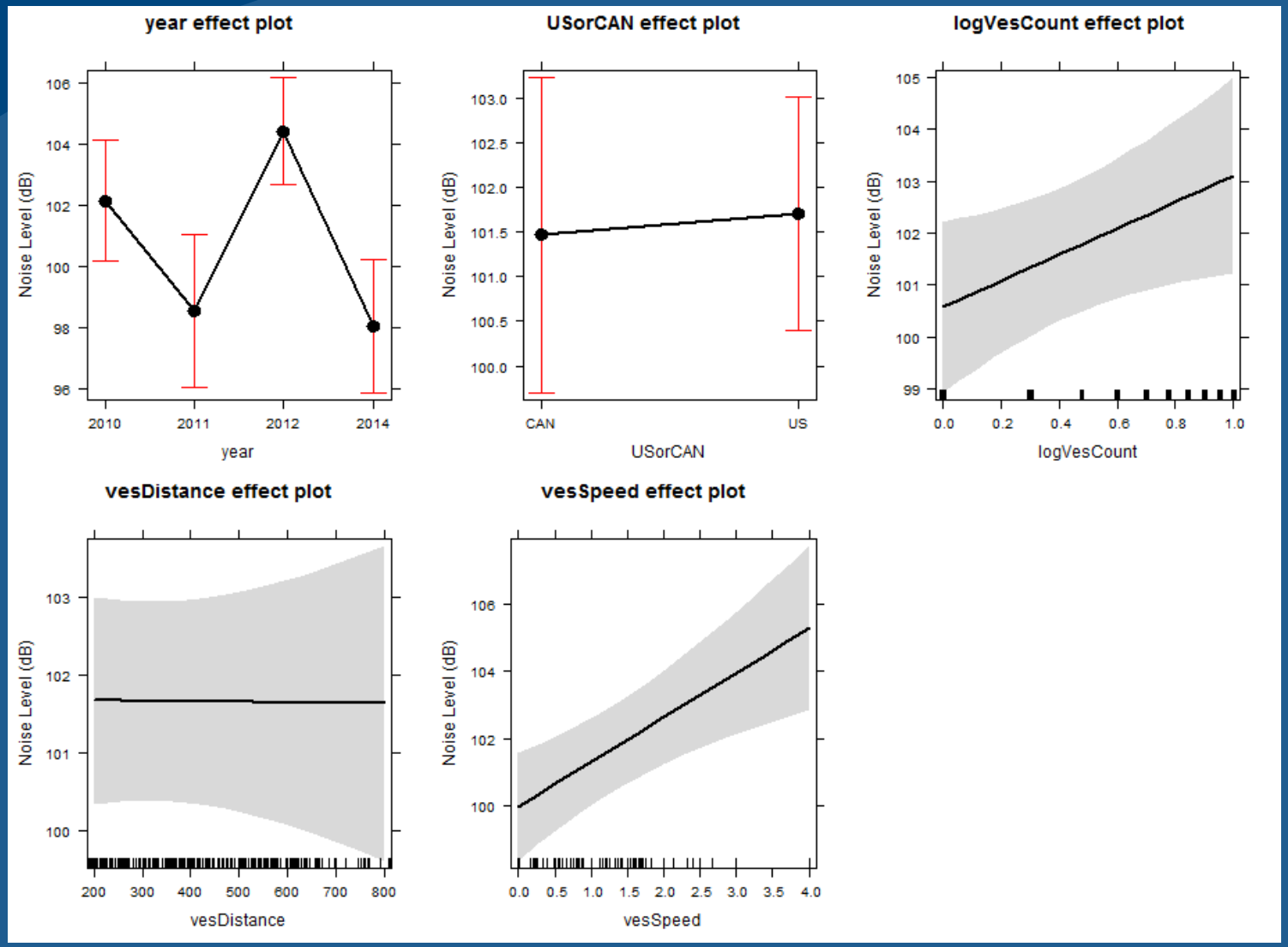
Groups	Name	Variance	Std.Dev.
minTagOn	(Intercept)	3.350	1.830
AnimID	(Intercept)	5.404	2.325
hour	(Intercept)	1.300	1.140
Residual		20.412	4.518

Number of obs: 331, groups: minTagOn, 196; AnimalID, 22; hour, 12

Fixed effects:

	Estimate	Std. Error	t value
intercept	99.7401	1.6123	61.86
2011	-5.3432	1.8365	-2.91
2012	1.0091	1.5166	0.67
2014	-5.0837	1.6939	-3.00
logCount	2.5791	1.5135	1.70
speed	1.7483	0.4903	3.57

Full Model Effects Plot



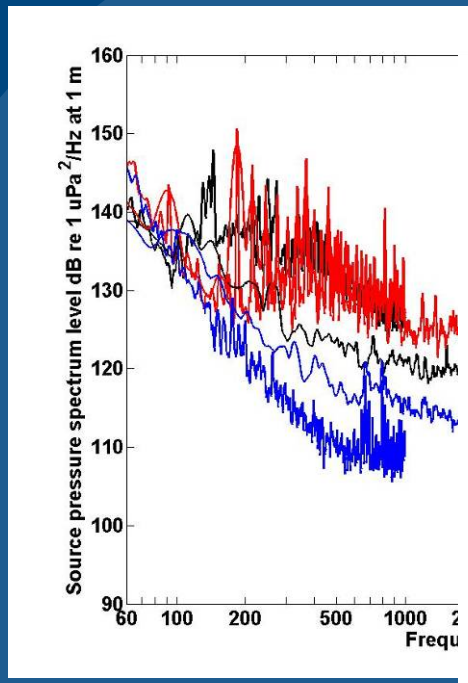
Whale-watching boat source spectra

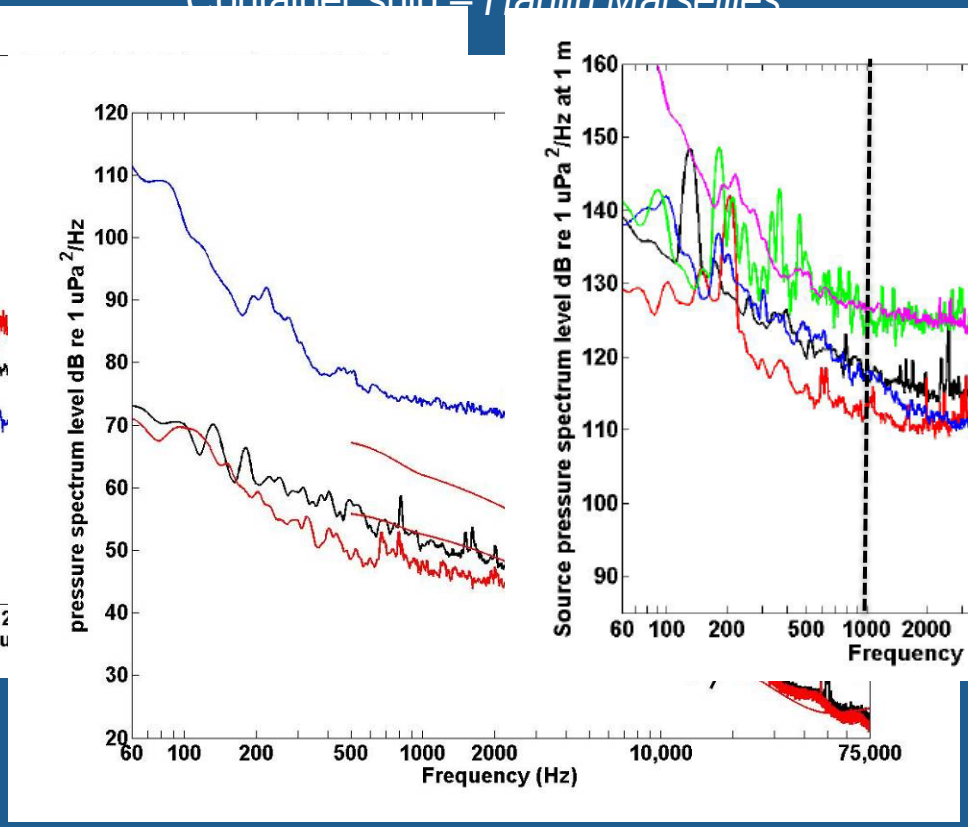
Controlled passes and ship received spectrum (Hildebrand et al. 2006)

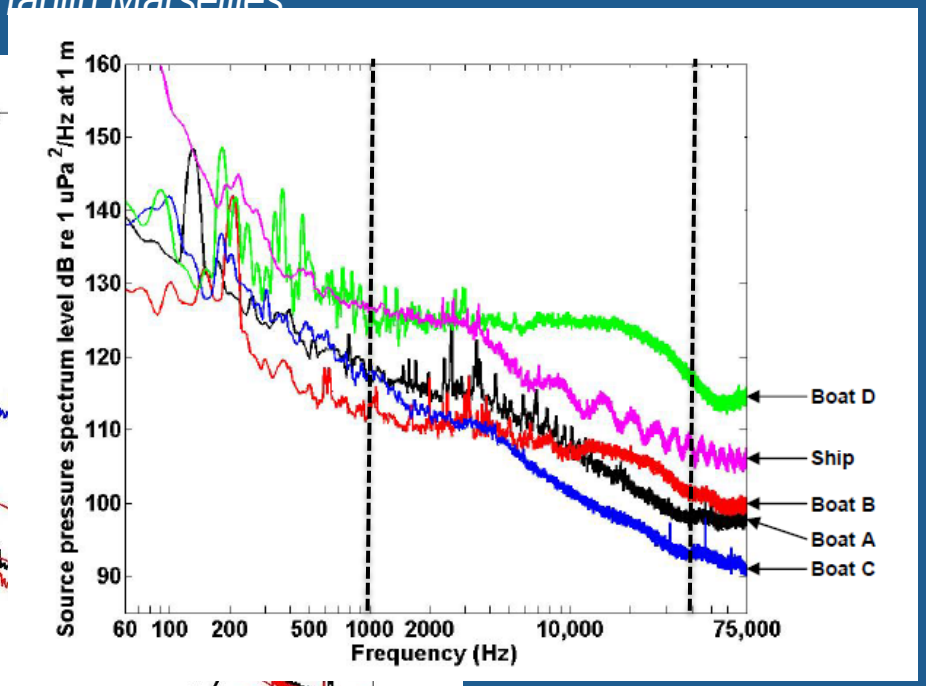
Boat D

Comparison for cruise

Container ship – *Hanjin Marseilles*







10 sec averages

cruise speed: 21-31 kt

power: accelerating from idle to full cruise → most intense measurement