Analyzing the Role of Vessel-Based Tourism on Masking on Antarctic Humpback Whales: A Petition for Management Solutions for Underwater Noise and Regulation of Antarctic Tourism

by

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Executive Summary

Antarctica has been an iconic representation of the last true wilderness, terrestrial and marine. However, the enticing nature of this pristine wilderness may unfortunately become a culprit for its demise. Increasing interest in Antarctic tourism has intensified vessel activity in and around the Western Antarctic Peninsula, a critically vulnerable habitat for many polar species (Lynch, 2009). Antarctica was designated as a "natural reserve to promote peace and science" by the Antarctic Treaty establishing a legal framework for environmental protection. To protect this vulnerable ecosystem this legal framework implemented regulations and management, which are being inadequately incorporated and enforced by the tourism industry.

Due to an increase of vessel-based tourism, underwater noise must be incorporated into the threats mitigated and managed through an eco-system-based management approach (Williams et al 2015). Anthropogenic noise has become a ubiquitous pollutant throughout the world's oceans, elevating the acoustic energy and creating noise characteristically different than natural sound sources. Strategies to combat issues with ocean noise call for the characterization of acoustic habitats to quantify changes in the quality of the habitats and properly assess their impacts (Hatch et al 2016).

Marine animals have capitalized on the physics of the ocean as they have evolved the use of sound as a primary sensory modality. Marine animals use sound to forage, find mates, communicate, navigate, and avoid predators. Vessels emit sound frequencies that overlap with those used by animals, leading to potential masking of vital acoustic cues and loss of communication space. Disrupting these behaviors with anthropogenic noise has been shown to cause significant impacts (Scott, 2004). . The United Nations Conventions of the Law of the Sea defines defined "pollution" as "the introduction by man, directly or indirectly, of substances or energy into the marine environment..., which results or is likely to result in such deleterious effects as harm to living resources" (United Nations Convention on the Law of the Sea, 1982) The Marine Strategies Framework Directive has also incorporated anthropogenic noise as a pollutant and should be managed and regulated like any other transboundary pollutant(Tasker, Amundin, Andre, Hawkins, Lang, Merck, et al., 2010).

Humpback whales are large, highly migratory mysticetes that forage in high latitudes and breed in low latitudes. Since they feed only part of the year, humpback whales must maximize their energetic gains while in the foraging grounds to have enough fat reserves to endure their long migration (Curtice et al., 2015). Most of their breeding grounds are nutrient poor, therefore, it is critical to their survival to build

up enough fat reserves to sustain them until the next austral summer. An increase in vessel-based tourism could affect their foraging which could potentially disrupt reproductive success in the future.

The major objectives of this study were to analyze the signal to noise ratio of humpback whale social calls in reference to the ambient noise levels along the Western Antarctic Peninsula (WAP). This is done by establishing a difference in the signal to noise ratio (SNR) with and without ships. The signal to noise ratio illustrates how much louder their vocalizing signal is over the ambient noise when there are few to no ships in the area. This allows an establishment of a baseline or reference measurement to be able to quantify changes in the ambient noise levels with high ship activity. Another analysis is to plot the locations of vessel activity and humpback whale distribution to geo-visualize the spatial, and spectral overlap to model and predict potential effects.

Results indicate that vessel-based tourism has spatial and spectral overlap with humpback whale distributions and sound use. Recommendations for future research include long-term ambient noise monitoring to establish better metrics for predictive modelling and better information about the Antarctic soundscape. Currently, there is an inadequate management framework that regulates the noise from the tourism industry in the Antarctic. To address the threats to this vulnerable ecosystem, accurate environmental impact statements need to be integrated for tourism associated activities. There needs to be an integration of an ecosystem-based management strategy to combat issues with noise and needs to be regulated as all other pollutant types (McCarthy, 2003). Marine spatial planning, specifically with ocean zoning and designation of marine protected areas (MPAs), is an important conservation tool that help to address issues with noise pollution.

Introduction

A. History and Overview of Antarctic Governance and Environmental Protection

Protection of the Antarctic environment has been a primary objective since its establishment in 1958 when twelve countries signed the Antarctic treaty. It was signed by 12 countries participating in the International Geophysical Year (IGY) of 1957-58 which was intended to coordinate scientist from around the globe in collaborating on a series of scientific observations (Foreman, 1991). The Antarctic Treaty set the foundation for environmental protection for the Antarctic. The treaty formally designated Antarctica as a "natural reserve dedicated to peace and science" (Lamus, 2013). No military presence is allowed and there is freedom of scientific investigations and collaborations, as well as exchange of scientific observations (Foreman, 1991) However, in the early 1970's there were discussions among parties to the treaty for potential mineral mining and extraction, termed the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA) (Foreman, 1991). In response, the Antarctic and Southern Ocean Coalition (ASOC) was founded in 1978, with the intent to halt mining activities through convincing governments not to ratify the CRAMRA (Foreman, 1991). They were successful in convincing France and the US not to ratify the Mineral Convention as well as propose an additional framework of environmental regulations

This framework was later known as the Protocol for Environmental Protection ratified in 1991 and put into effect in 1998. The protocol for environmental protection banned gas and mineral exploration as well as mining; required an impact statement for all activities, and designated protections against pollution (Foreman, 1991). In addition to the protocol, in 1981 the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was established with the objective of "conservation of marine life" (CCAMLR, 2017). There was increasing interest for commercial fishing in Antarctica and CCAMLR helped to promote sustainable fishing practices through an ecosystem-based management approach. Anthropogenic activities in Antarctica are regulated and managed through the Antarctic Treaty System, which conducts yearly meetings. The Antarctic Treaty Consultative Meeting (ATCM) consists of consultative parties to the treaty where they discuss management issues related to relevant environmental pressures to mitigate the anthropogenic footprint in Antarctica. Currently, there are representatives from four sectors that attend the meetings: 1) Consultative parties 2) Non-consultative parties 3) Observers: Scientific Committee of Antarctic Research (SCAR); Council of Managers of National Antarctic Programs (COMNAP); Commission for the Conservation of Antarctic Living Resources

(CCAMLR) 4) Invited experts: Antarctica and Southern Ocean Coalition (ASOC) and the International Association of Antarctic Tour Operators (IAATO) (Foreman, 1991). The consultative parties are the constituents that are responsible for making decisions, but the other sectors can contribute to the meeting discussion.

B. History and Overview of International Association for Antarctic Tour Operators

In an effort to promote environmentally conscious private-sector travel to the Antarctic, the International Association of Antarctic Tourism (IAATO) was founded in 1991 (IAATO, 2017). Originally, the organization had 7 private tour operators that at the time had been running travel expeditions to Antarctica(IAATO, 2017). Since the establishment of IAATO, the tourism industry has drastically increased. In response to the vast influx of tourists to the Antarctic region, the IAATO came up with regulations including: 1) restrictions on numbers of people allowed ashore; 2) staff-to-passenger ratios; 3) site specific and activity guidelines; 4) pre and post activity reporting; and 5) passenger, crew and staff briefings (IAATO, 2017). IAATO conduct yearly meetings to reflect on current policies, regulations and procedures in efforts to address challenges or inadequacies in the current management framework and provide solutions. Mentioned in the previous section, IAATO also has a representative to attend the Antarctic Treaty Consultative meetings to make sure that the interest of the tourism industry is involved in the decision-making process (Basberg, 2010). There is a lack of agreement among the sectors that attend the consultative meetings that there is too much involvement from member states that have large financial gains from the tourism and are profiting from a lack of regulation (Enzenbacher, 2007).

C. Controversy Surrounding Tourism and Environmental Protection Protocols

Although tourist trips to Antarctica started in the late 1950's, they remained relatively few until the 1990's, which is when the intrigue of Antarctic tourism increased drastically (Lynch, Crosbie, Fagan, & Naveen, 2010)(Figure 1). Despite the efforts of the IAATO to promote and encourage sustainable tourism, there have been controversies among Antarctic Treaty Consultative Parties (ATCP) due to impacts associated with tourism practices and the "lack of a comprehensive regulatory and management framework" (Verbitsky, 2013). These controversies continue to build from conflicting ideologies of how tourism should be regulated. IAATO claims to have policies and guidelines in place that efficiently manage and regulate tourist activities. IAATO argues that all vessels must register with the IAATO and abide by their sustainable management practices. However, it is seen among scientists, managers, and environmental advocacy groups that this type of self-compliance and management is inadequate and doesn't adhere to the goals and objectives set by the Antarctic Treaty or the Protocol

for Environmental Protection (Verbitsky, 2013). This study aims to address specific concerns pertaining to Annex I, which requires environmental impact assessments be conducted for all activities and Annex IV, which requires prevention of marine pollution. Neither of these regulations are perceived as being upheld by the tourism sector.

Figure 1- The increase in tourism activity since IAATO was founded in 1991 until present. These data are from the IAATO Overview of Antarctic Tourism:2017-18 Season and Preliminary Estimates for 2018-19 Season.

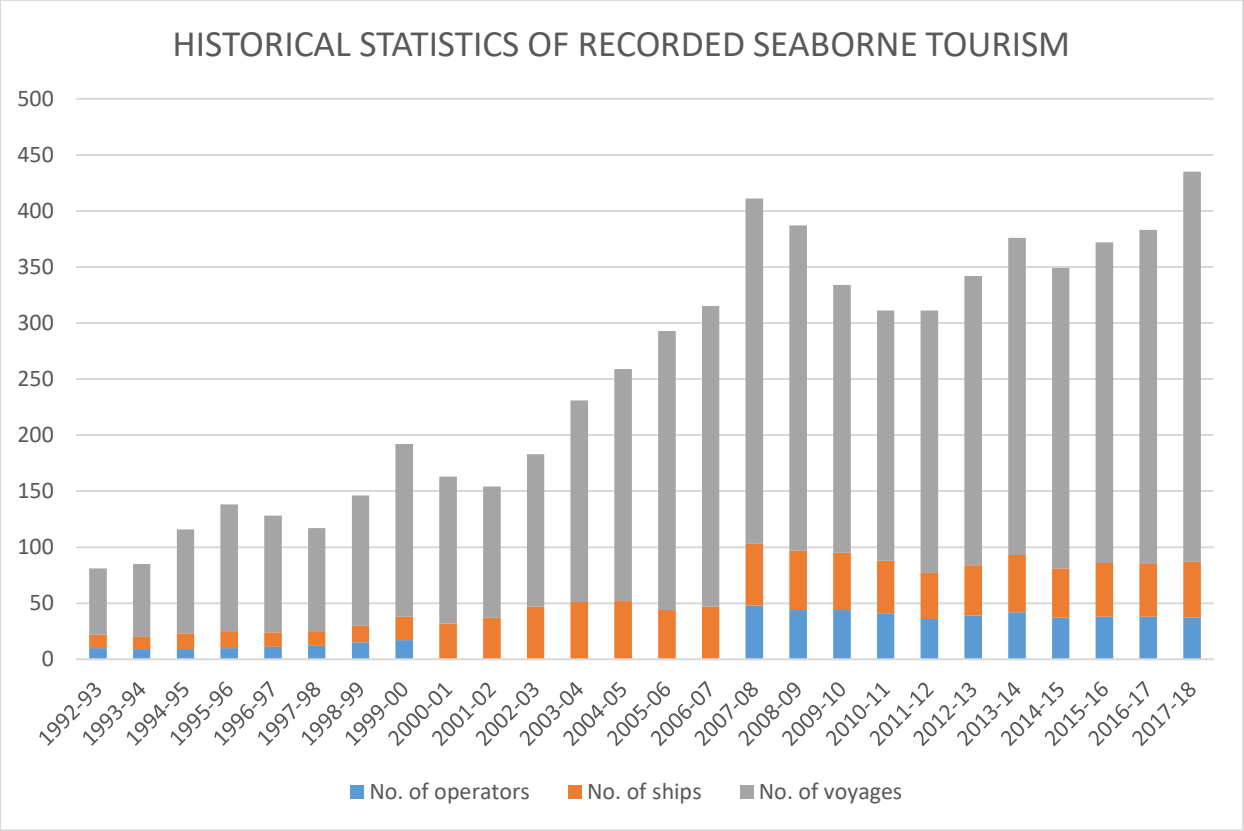


Figure 1 illustrates the increase in vessel-based tourism since the establishment of the IAATO. The majority of cruise and tour vessel operations occur between late October through March with a peak in the austral summer: December through January (IAATO, 2017). Figure 1 shows that in 2018 there were close to 450 voyages within a given season and most of the vessel tourism activity is concentrated in and around the Antarctic Peninsula (Lynch et al., 2010) . This increase in vessel activity creates an influx of acoustic energy into the Antarctic marine soundscape. This level of acoustic energy could change the acoustic characteristics of ecosystem and has the potential to cause repercussions for marine organisms that use sound as a primary sensory modality

II Sound and Ocean Noise

A. Overview and History

Contrary to popular belief, which largely stemmed from Jacques Cousteau's "A Silent World", the ocean environment is anything but silent. Even before the mechanization of human use of the ocean environment, there are many other natural sources that contribute to the acoustic soundscape (Scott, 2004). Natural sources can be biological, which are produced by a variety of marine organisms, or geological, produced from wind, waves, ice and tectonic activity. Water is an excellent medium for sound to travel, in that it can travel faster and further than it does in air. Because of this, marine animals have capitalized on the physics of the ocean as they have evolved the use of sound as a primary sensory modality. Marine animals use sound to forage, find mates, communicate, navigate, and avoid predators all of which are vital for survival. Disrupting these behaviors with the anthropogenic noise has been shown to cause significant impacts (Scott, 2004).

The nature of sound in the ocean environment is extremely dynamic and intricate with complicating parameters that affect how it propagates and how it effects marine organisms. How sound propagates can depend on a multitude of variables including but not limited to the: sound speed profile; frequency or bandwidth of the sound; depth of the sources of sound and the receiver; seafloor properties (slope, substrate properties; sea surface state (wave height); and transmission loss (spreading and absorption) (Urick, 1983)

The sound speed profile is predominately determined by temperature and pressure with salinity having a small impact. The frequency of sound can affect how it propagates. Low frequency sounds have longer wavelengths and can travel further than high frequency sounds with shorter wavelengths that attenuate more rapidly (Urick, 1983). When sounds interact with the seafloor and sea surface, it can alter how the sound propagates. The sea state of the surface as well as the seafloor rugosity can change whether a sound is reflected or absorbed (Urick, 1983). The depth of where the source of the sound is emitted also affects how sounds propagate due to spreading loss and absorption. In deeper waters the sound spreads out over a spherical area which causes a different loss in the intensity of the sound when compared to shallow water environments. In shallow water environments, the spreading is compressed by the sea surface and seafloor causing it to spread cylindrically. All these complicating factors can make assessing disturbance from noise difficult (Urick, 1983).

Anthropogenic noise can affect marine animals physiologically, behaviorally, as well as acoustically (Nowacek, Thorne, Johnston, & Tyack, 2007). To determine and quantify impacts from anthropogenic noise, a baseline of how marine organisms adapt to and interact with their surrounding acoustic environment is imperative(L. T. Hatch et al., 2016). Noise source characteristics (frequency, intensity, duration) can greatly influence the level and type of impact they can have on the marine organisms.

Acoustic impact assessments for anthropogenic activity are still relatively new and poorly understood (Scott, 2004). Previously, impacts from anthropogenic sources assessed mainly impacts of acute, isolated events that caused physical harm with a primary focus on cetaceans and marine mammals (Vol, Wednesday, & Ferguson, 2007). However, now assessments have expanded to determine behavioral disturbance from anthropogenic noise as well as determining impacts on different trophic levels in the ecosystem including fish and invertebrates (Williams, Erbe, Ashe, & Clark, 2015).

Anthropogenic noise has become ubiquitous throughout the world's oceans elevating the acoustic energy and creating noise characteristically different than that of natural sound sources. Sound energy is measured in dB which is ratio of the energy being measured to a reference pressure or intensity of that energy over an area. The dB is on a logarithmic scale relative to hearing and sound perception of the mammalian ear (Scholik-Schlomer, 2015). Therefore, an increase in 10 dB re at 1 µPa is equivalent to 10 times the sound intensity. Studies have also suggested that the reference ambient noise levels have risen over 10dB in the last 50 years which has led to a global concern to address ocean noise (McDonald, Hildebrand, Wiggins, & Ross, 2008).

B. International Concern of Ocean Noise

Globally there have been multiple international initiatives to address this burgeoning problem with ocean noise. The United Nations Conventions of the Law of the Sea defines defined "pollution" as "the introduction by man, directly or indirectly, of substances or energy into the marine environment..., which results or is likely to result in such deleterious effects as harm to living resources" (United Nations Convention on the Law of the Sea, 1982)(Art. 1(1) (4)). With the expansion of the definition to incorporate noise as a pollutant by the EU, requires noise to be managed and regulated like any other transboundary pollutant. There has been a specific initiative to target low frequency noise specifically from vessel activities. The International Maritime Organization (IMO) has recognized ship generated noise as a global threat to the marine ecosystem and has made "reducing the harmful effects of ship noise" a priority through incorporating quieter shipping technologies(Simmonds et al., 2014).

In 2008, the European Union Marine Strategies Framework Directive categorized noise as a pollutant in Article 8(4) as well as "identified low and mid-frequency impulsive sound and continuous low frequency sound as potentially impactful on marine mammals and other marine life"(Tasker, Amundin, Andre, Hawkins, Lang, & Merck, 2010). Low frequency noise from vessel activity has become an increasing international concern due to the chronic and cumulative nature from the production of the sound from vessels. Low frequency vessel noise has long wavelengths allowing the sound to travel large distances causing an acoustic fog which disrupts the communication channels and impedes vital acoustic cues required for survival (Tasker, Amundin, Andre, Hawkins, Lang, Merck, et al., 2010).

III Case Study: Role of Vessel Noise and Masking on Antarctic Humpback Whales

A. Antarctic Humpback Whales

Humpback whales are a highly migratory species that forage in high latitude areas and mate and breed in low latitudes. Different populations of humpback whales will migrate to the Antarctic Peninsula in the austral summer to forage on Antarctic krill (Curtice et al., 2015). Since they feed only part of the year, humpback whales must maximize their energetic gains while in the foraging grounds to have enough fat reserves to endure their long fasting periods (Curtice et al., 2015). Since most of their breeding grounds are nutrient poor, it is critical to their survival to build up enough fat reserves to sustain them until the next austral summer. Humpback whales are large, ~15 meters in length and weigh around 40 tons. They have large energetic demands that must be met while on the foraging grounds (Curtis et al 2015). They are in the rorqual family, meaning they have ventral pleats that expand to engulf large amounts of their prey in a single lunge and then use their baleen plates to filter out the sea water. Antarctic krill are their dominant prey species, and previous studies have shown that their abundance and distributions are influenced by large krill aggregations (Curtis et al 2015). During the austral summer the main aggregations of krill can be found in waters in and around the continental shelf as well as in and around the border of the ice sheets.

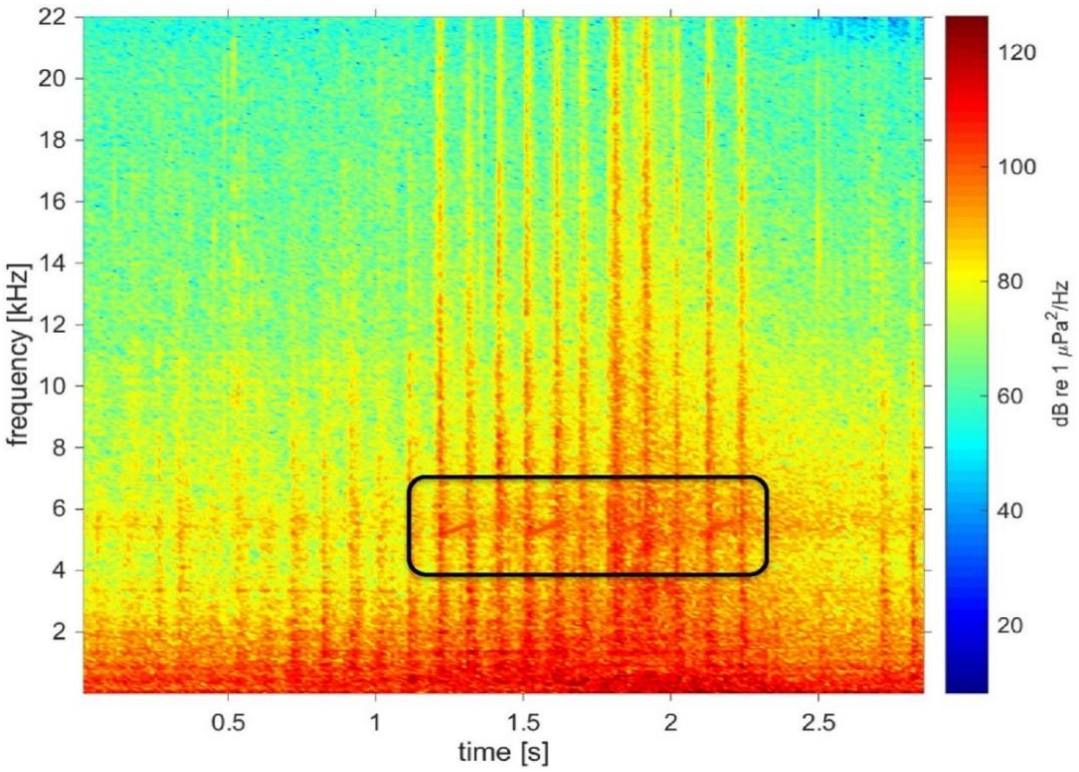
Antarctic krill lay their eggs in deeper waters and tend to be further away from the ice shelf in the summer. In the austral fall the krill move further in and around the ice sheets (NICOL, 2006). Courtice et al. (2015) report humpback whales that were tagged with satellite tags off the WAP during the austral summer of 2012 had movement patterns similar to the distribution to the Antarctic krill. In efforts to optimize their energy uptake with low expenditure they will feed cooperatively with other conspecifics. A common cooperative feeding strategy performed by humpback whales is known as bubble net

feeding. Bubble net feeding uses foraging vocalizations to coordinate this type of feeding in which one whale will dive down blowing a bubble patterns around the krill aggregations which causes them to move closer together into a large bait ball and then the conspecifics will lunge up through the bait ball (Wiley et al., 2011). This requires humpback whales to be able to communicate throughout their foraging range (Curtis et al 2015). The increase in vessel-based tourism emits sound in the same frequency band as their vocalizations potentially causing a disruption in their communication pathways. This has the potential to create masking causing population and ecosystem level effects.

B. Masking

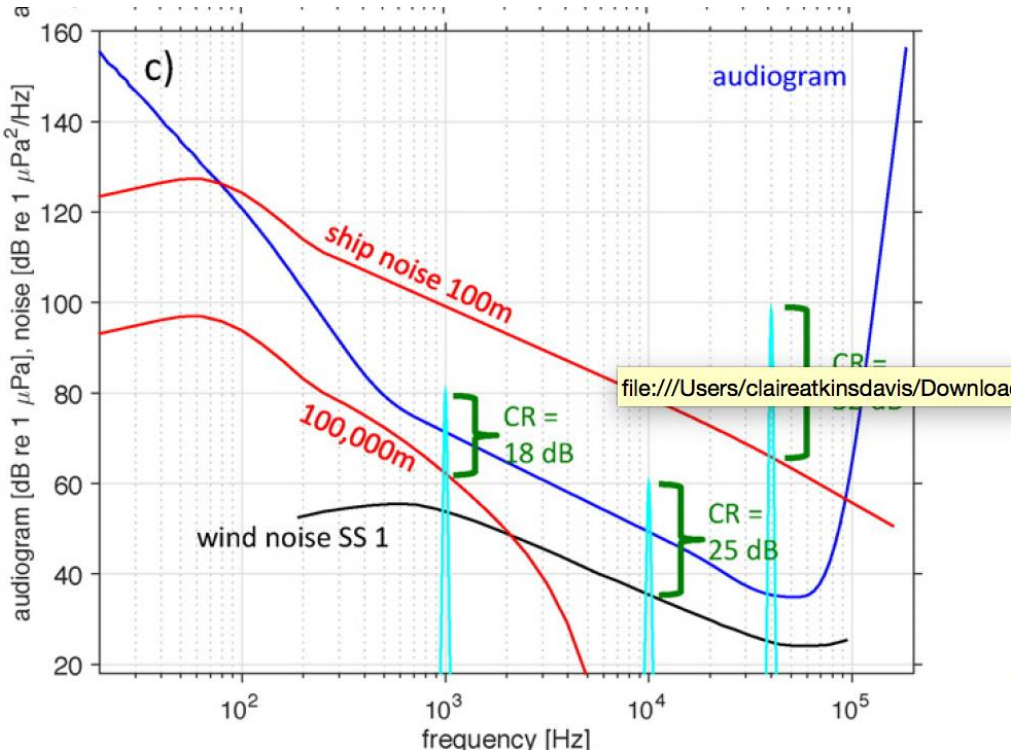
Vessels generate noise through three mechanisms. The first being the cavitation caused by the propeller blade from changes in pressure as the propeller blade rotates. The second is caused by machinery mounted to the hull of the ship which reverberates through the hull of the ship, and the third is the flow noise of water past the hull causing it to flex and bend (("Discovery of Sound in the Sea," n.d.). Many of these low frequency sound sources are in the same frequency bands as vocalizing animals, leading to potential masking and loss of communication space (Clark et al., 2009b). Masking refers to the acoustic interference when both the signal and noise are of similar frequencies and have spatial and temporal overlap (Erbe, Reichmuth, Cunningham, Lucke, & Dooling, 2016) (Figure 2).

Figure2: illustrates how propeller cavitation can cause partial masking of this upsweep call of a fin whale. On the spectrogram portions of the signal that will not be detected or distinguished by a conspecific due to the overlap of frequency bands of their vocalizations and the spectral characteristic of vessel noise (Source: Erbe et al. 2016: Creative Commons Attribution License)



Masking can be a complicated and difficult to quantify in assessing disturbance or impact. To accurately model and predict masking, certain parameters are necessary: 1) Audiogram data 2) Critical Bandwidth and 3) Critical Ratio(Erbe et al., 2016). In the case of baleen whales, there are no actual audiograms. Audiograms for baleen whales are extrapolated from the frequency bands of their recorded vocalizations, modeling of the inner ear, and combined with audiogram results from captive odontocetes. This can lead to some uncertainty when deciphering the level of masking for baleen whale vocalizations in the presence of low frequency vessel noise. The critical bandwidth can be defined as "the bandwidth of a pure tone that is just audible in the presence of white noise" (Erbe et al., 2016)with the critical ratio can being "the difference between a Sound Pressure Level (SPL) of a pure tone just audible in the presence of continuous noise"(Erbe et al., 2016). Figure 3 below illustrates the relationship between the audiogram, critical band, critical ratio that are important parameters to determine masking.

Figure 3 illustrates how the results of an audiogram help to illustrate the hearing sensitivity to determine the critical band and critical ratio. The blue line is the audiogram which is a graphical representation indicates that detection threshold of their hearing capabilities to quantify the level of masking occurs within a certain bandwidth (Source Erbe et al. 2016: Creative Commons Attribute License)



To determine masking, one approach is to measure the Power Spectral Density of the noise in a band encompassing the signal of interest and then combine the critical ratio to reach the predicted level where the signal would be identified (Erbe et al., 2016). Previous studies have determined the masking index of a conspecifics signal in the presence of anthropogenic noise (Erbe et al., 2016; Gabriele, Ponirakis, Clark, Womble, & Vanselow, 2018). However, marine organisms use acoustic cues other than communicating with conspecifics. These acoustic cues aid in navigation, predator avoidance, as well as prey detection which may have vastly different source levels than vocalizing conspecifics and could have drastically different masking repercussions (Williams et al., 2015). Although the objective of this study has a focal interest around impacts to marine mammals, there is a considerable documentation that fish as well as invertebrates are acoustically sensitive to chronic low frequency vessel noise (Normandeau Associates, 2012). This suggests that sustained levels of elevated noise from ships can have population and ecosystem level impacts. Antarctic krill are a keystone species for they are the base of the food chain in the Antarctic ecosystem (Boopendranath, 2014). There have been previous studies to suggest that elevated ambient noise can increase the metabolic rate of certain crustacean species, which was shown to result in a reduction in growth and reproduction (Kunc, McLaughlin, & Schmidt, 2016). This illustrates the levels of impact chronic low frequency ocean noise can cause by disrupting trophic linkages potentially leading to ecosystem-level impacts.

Elevated levels of vessel induced noise not only mask vocalizations of conspecifics and vital acoustic cues but can lead to behavioral disruption of biologically critical functions. In response to an elevated presence of chronic noise, some species have been documented to alter their vocalizations(Nowacek et al., 2007). Some documented cases of vocalization adaptation include a study done on beluga whales that shifted their vocalizations to a higher peak frequency in response to boat traffic (Lesage & Barrette, 1999). In a study described in (Dahlheim, 1987), gray whales increased the amplitude of their vocalizations, changed the timing of their vocalizations and used more frequency modulated signals. (Miller, 2000) concluded that humpback whales changed the duration of their song when exposed to Low Frequency Active (LFA) sonar. Unfortunately, there are major gaps in data that conclusively illustrate the consequences for altering vocalizations. However, certain predictions include the increase in their energy expenditure, as well as induce stress which will decrease their immune systems and ability to fight off aquatic pathogens.

The major objectives of this study are to determine underwater acoustic ecology metrics for the Western Antarctic Peninsula and to characterize the acoustic habitat and predict the potential impact of tourism vessel generated activities on the acoustic space in the Western Antarctic Peninsula (WAP). This is done by establishing a difference in the signal to noise ratio (SNR) with and without ships. The signal to noise ratio is the level of the signal of interest compared to the current noise level, in this case how much louder their vocalizing signal is over the ambient noise when there are few to no ships in the area. This allows an establishment of a baseline or reference measurement to be able to quantify changes in the ambient noise levels with high ship activity. Vessel noise overlaps in frequency, space and time with humpback whale social sounds that can hinder effective communication (Clark et al., 2009a). This study aims to determine this overlap though mapping the spatial distribution of tour vessels and humpback whales.

IV Methods

Fieldwork

Twenty humpback whales were tagged with non-invasive suction cup acoustic tags in waters off the Western Antarctic Peninsula in the Austral fall beginning in May through June in 2009 and 2010 (Stimpert et al. 2012). Once the tags were attached, acoustic data were recorded with a sampling rate of 96 kHz continuously until detachment, the recordings of each tag ranged from 5 – 30 hrs. The study area for the acoustic analysis was done where humpbacks were tagged in the Gerlache Strait,

Wilhemina Bay, and Andvord Bay of the Western Antarctic Peninsula (Stimpert, Peavey, Friedlaender, & Nowacek, 2012).

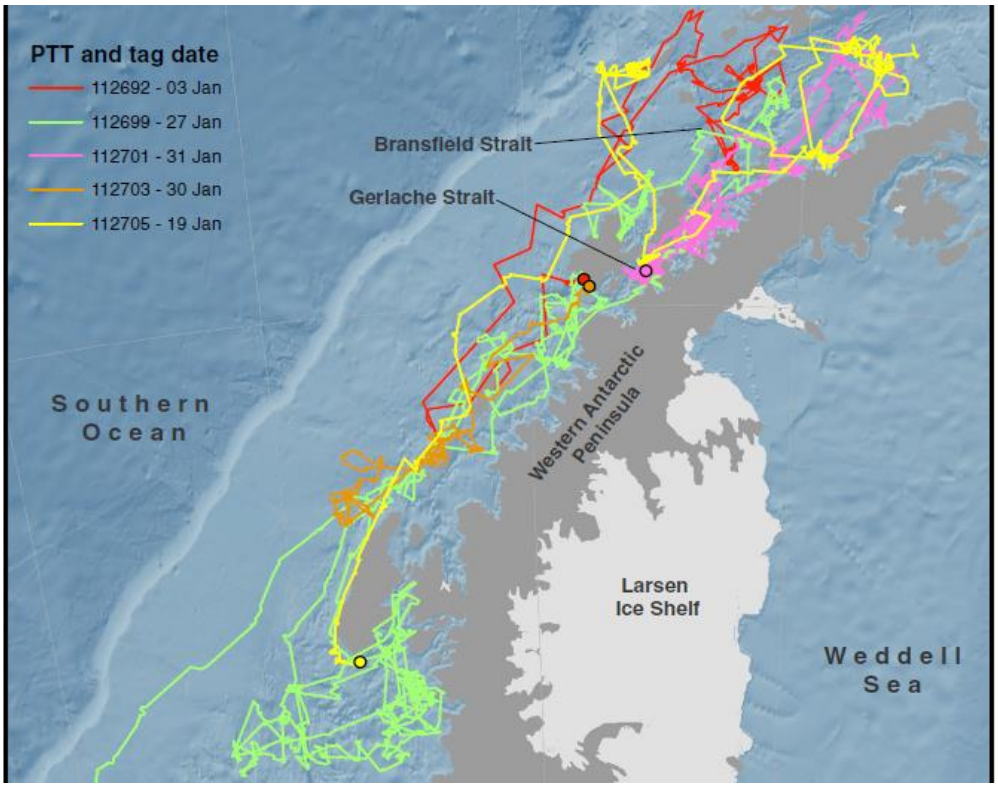
Acoustic Analysis

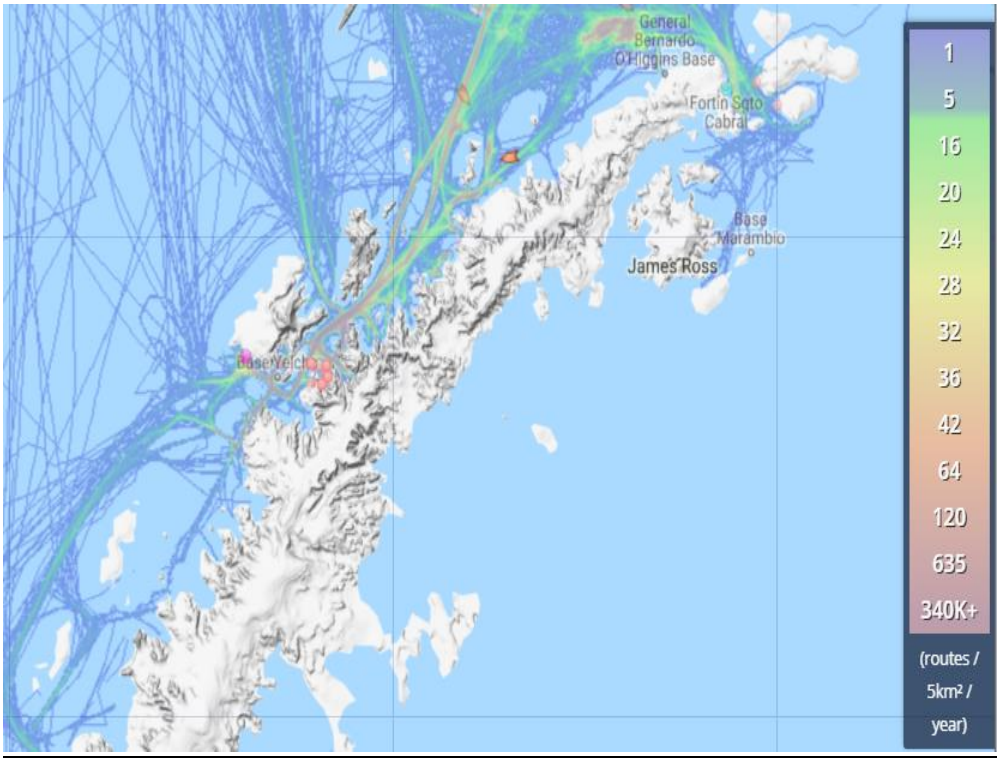
Acoustic records were visually and aurally examined for social and foraging sounds in Raven Pro 1.5. Spectrogram parameters were set using a Hann window with FFT of 1689 and a time grid set with 50% overlap and hop size of 845; Frequency grid set to a DFT size of 2048 and grid spacing of 46.9. Humpback whale vocalizations were selected as well as adjacent ambient noise measurements of the same frequency band to calculate how much louder the vocalization is over the ambient noise level, which can be described as the signal to noise ratio. Once these selections are made in the spectrogram, Raven creates a selection table that gives you a power measurement of the signal as well as the adjacent ambient noise power level. Because sound is measured in dBs, to calculate the SNR, the dB is in logarithmic units and must be converted to linear units. All tags were analyzed, and an average SNR was computed for each animals' vocalization. In addition to the SNR parameters. The signal duration was also recorded, and a regression analysis was performed to determine if a signal with a longer duration allowed for a higher SNR.

Mapping

In Arc GIS Pro, AIS (Automatic Identification System) was used to be able to determine vessel movement patterns and density estimates of the ships transiting through the Gerlache Strait in and around the WAP. This is to illustrate the spatial, and spectral overlap of vessel and humpback whale density resulting in loss of acoustic space from increased vessel activity through geo-visualizing noise density from AIS vessel locations and density maps obtained from the marine traffic website (Figure 4). The tag data is temporally disparate from the shipping data. The tags were put on in the austral fall of 2009 and 2010, and the vessel data is from 2017-2019. However due to previous studies, there can be inferences made from the spatial and spectral overlap of distribution in efforts to model and predict effects.

Figure 4: (top) is from the satellite tagging study (Curtis et al. 2012, Creative Commons Attributions License) of humpback whales from 2012 that illustrates their movement patterns in and around where the vessel traffic density is the highest. (Bottom) is a density map from marine traffic.com that shows the vessel density from AIS data within the year of 2017. When comparing these two images, the spatial overlap is evident (Source: marinetraffic.com).

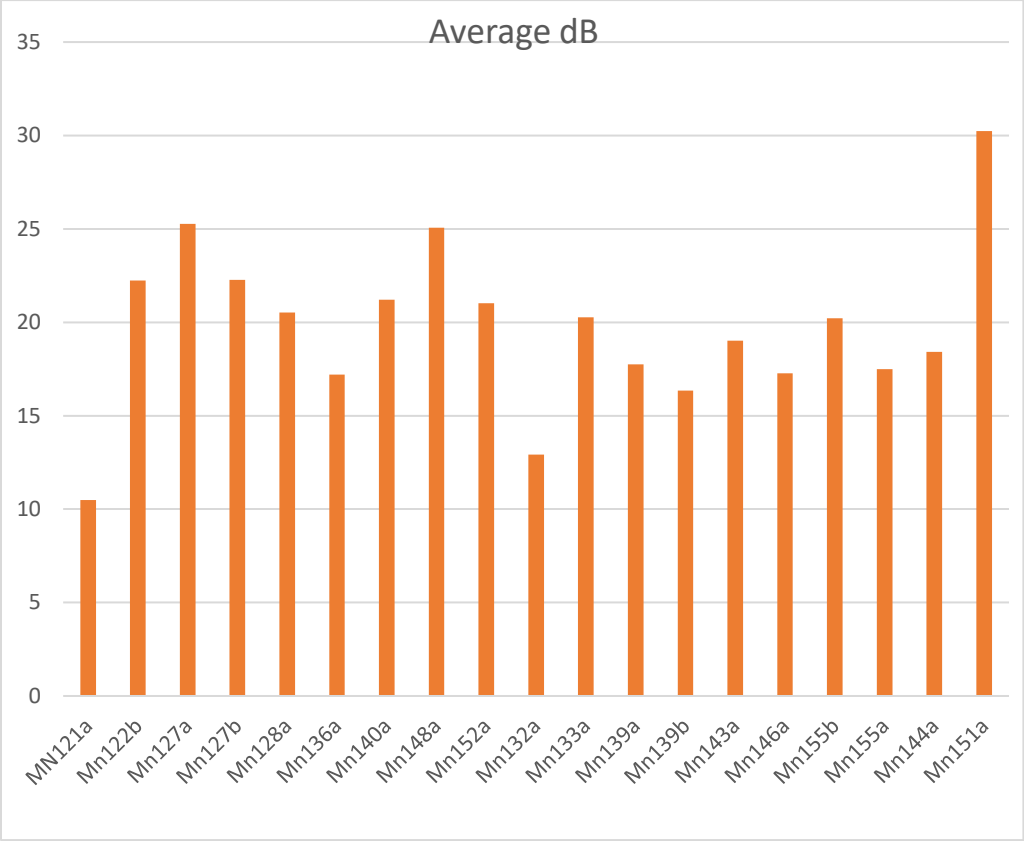

PTT and tag date
112692 - 03 Jan
112699 - 27 Jan
112701 - 31 Jan
112703 - 30 Jan
112705 - 19 Jan
Bransfield Strait
Gerlache Strait
Southern Ocean
Western Antarctic Peninsula
Larsen Ice Shelf
Weddell Sea


General Bernardo O'Higgins Base
Fortín Sgto Cabral
Base Marambio
James Ross
1
5
16
20
24
28
32
36
42
64
120
635
340K+
(routes / 5km² / year)

Results

From the acoustical analysis, the signal to noise ratio was calculated for the humpback whale vocalizations for each digital acoustic recording tag. To be able to calculate the average SNR, the dB had to be converted to the linear unit which represents the intensity level of the signal and the average SNR of the intensity of all tags was 123.6 W/m2. This measurement needs to be converted to a decibel logarithmic scale with a mean SNR of ~20dB re at 1 µPa.

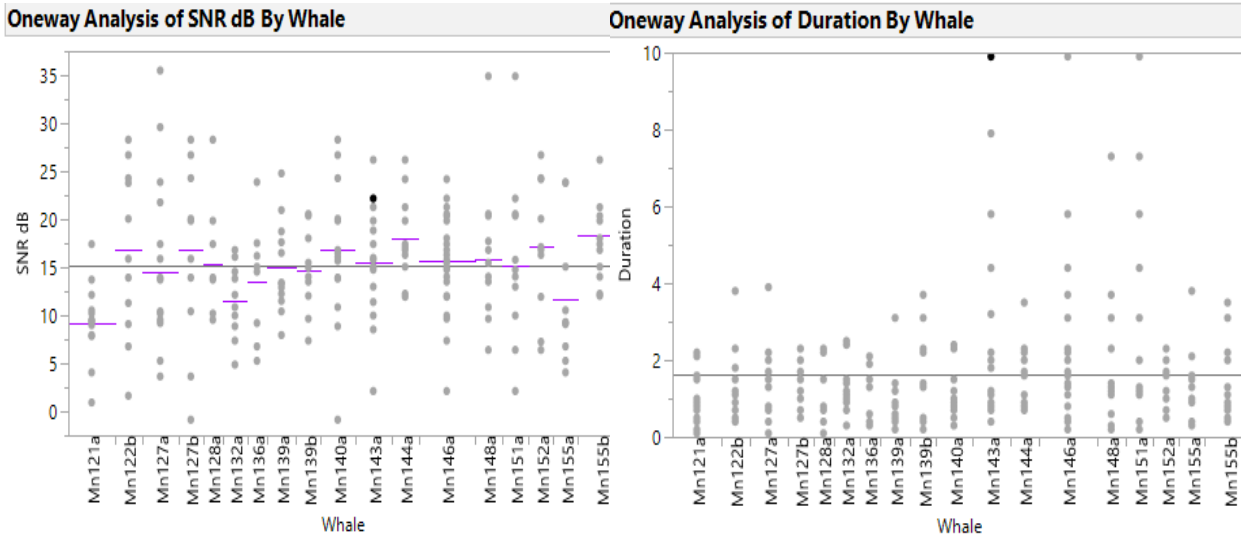
Figure 5: Calculations of the SNR from the acoustic analysis showing values from each tag.



In Figure 5, the results of the acoustic analysis demonstrate a large range in SNR values among tags. Mn121a has a SNR level around 10dB re at 1µPa and Mn151a has a SNR of 30dB re at 1 µPa. Since sound is measured on a logarithmic scale, a difference of 20dB re at 1 µPa is immensely different in terms of intensity and pressure of their vocalizations. When you have this large of a discrepancy in vocalization intensity above the ambient noise without the presence of ships gives an indication of how complicated it is to quantify the level of masking. From the aural and visual measurements recorded in Raven 1.5, statistical analysis tests were performed in JMP software. The first statistical test was the

Kruskall Wilcox test to determine if the variation of the SNR was statistically significant between the tags as well as the duration of signals between tags. The results are below (Figure 6):

Figure 6: (Left) is the results from the Kruskall Wilcox test to determine if the difference in SNR between tags was statistically different and (Right) are the results to see if the duration of signals was statistically different



Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Mn121a	19	915.000	2156.50	48.158	-4.551
Mn122b	11	1376.00	1248.50	125.091	0.601
Mn127a	15	1596.00	1702.50	106.400	-0.433
Mn127b	10	1289.00	1135.00	128.900	0.760
Mn128a	8	889.000	908.000	111.125	-0.102
Mn132a	10	752.000	1135.00	75.200	-1.893
Mn136a	8	788.000	908.000	98.500	-0.658
Mn139a	12	1362.00	1362.00	113.500	0.000
Mn139b	10	1108.50	1135.00	110.850	-0.129
Mn140a	14	1821.00	1589.00	130.071	0.977
Mn143a	15	1817.00	1702.50	121.133	0.466
Mn144a	11	1626.50	1248.50	147.864	1.785
Mn146a	23	2850.00	2610.50	123.913	0.804
Mn148a	11	1345.50	1248.50	122.318	0.456
Mn151a	11	1290.50	1248.50	117.318	0.196
Mn152a	10	1340.50	1135.00	134.050	1.014
Mn155a	10	743.000	1135.00	74.300	-1.937
Mn155b	18	2741.50	2043.00	152.306	2.623

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
39.8314	17	0.0014*

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Mn121a	19	1653.50	2156.50	87.026	-1.845
Mn122b	11	1183.50	1248.50	107.591	-0.305
Mn127a	15	1526.00	1702.50	101.733	-0.720
Mn127b	10	1159.50	1135.00	115.950	0.119
Mn128a	8	809.500	908.000	101.188	-0.540
Mn132a	10	1141.00	1135.00	114.100	0.027
Mn136a	8	707.000	908.000	88.375	-1.105
Mn139a	12	880.000	1362.00	73.333	-2.187
Mn139b	10	1235.00	1135.00	123.500	0.493
Mn140a	14	1326.00	1589.00	94.714	-1.109
Mn143a	15	2129.50	1702.50	141.967	1.745
Mn144a	11	1432.00	1248.50	130.182	0.866
Mn146a	23	3239.50	2610.50	140.848	2.117
Mn148a	11	1365.50	1248.50	124.136	0.551
Mn151a	11	1626.50	1248.50	147.864	1.787
Mn152a	10	1184.50	1135.00	118.450	0.243
Mn155a	10	1047.00	1135.00	104.700	-0.433
Mn155b	18	2005.50	2043.00	111.417	-0.139

1-Way Test, ChiSquare Approximation

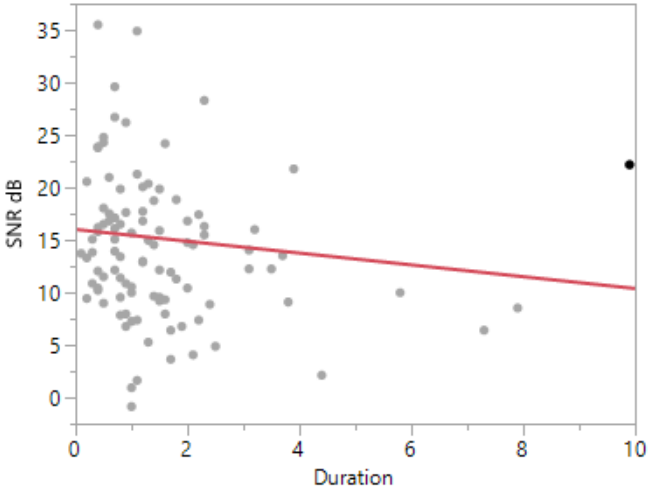
ChiSquare	DF	Prob>ChiSq
22.3132	17	0.1730

Results from previous masking studies indicated that the level of masking from humpback vocalizations varied based on the function of their vocalization (Cholewiak et al., 2018; Clark et al., 2009a; Gabriele et

al., 2018) and indicate that the social sounds had higher masking probability than song . The hypothesis is that song is more repetitive and longer in duration which could indicate that duration of the signal influenced how much louder the vocalization would be over the ambient noise levels. To test this, a linear regression was calculated to determine if there was a correlation between signal duration and SNR. The results of the linear regression indicate that there is a relationship between signal duration and SNR (Figure 7), however these results reflect that the SNR is negatively correlated with the duration. During the acoustical analysis, there were broadband pulse vocalizations that were very short in duration but had a much greater power energy measurement. Most of these broadband pulses were between 0.2 and 0.4 seconds and had SNR levels that ranged from 20 to ~30 dB re at 1 µPa. Compared to song vocalizations that ranged between 2-10 seconds and had SNR levels that ranged from 12-17 dB re at 1 µPa. From the acoustic analysis, the broadband pulses could have potentially caused the negative correlation between the signal duration and the SNR.

Figure 7: The correlation between the duration of the signal and the signal to noise ratio. The results of the Linear Regression Test which was ran using JMP software indicate there is a negative correlation between the signal duration and the signal to noise ratio.

Bivariate Fit of SNR dB By Duration



Linear Fit

Linear Fit

SNR dB = 16.007305 - 0.5630733*Duration

Summary of Fit

RSquare	0.017838
RSquare Adj	0.013454
Root Mean Square Error	6.604626
Mean of Response	15.1034
Observations (or Sum Wgts)	226

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	177.4644	177.464	4.0683
Error	224	9771.1215	43.621	Prob > F
C. Total	225	9948.5859		0.0449*

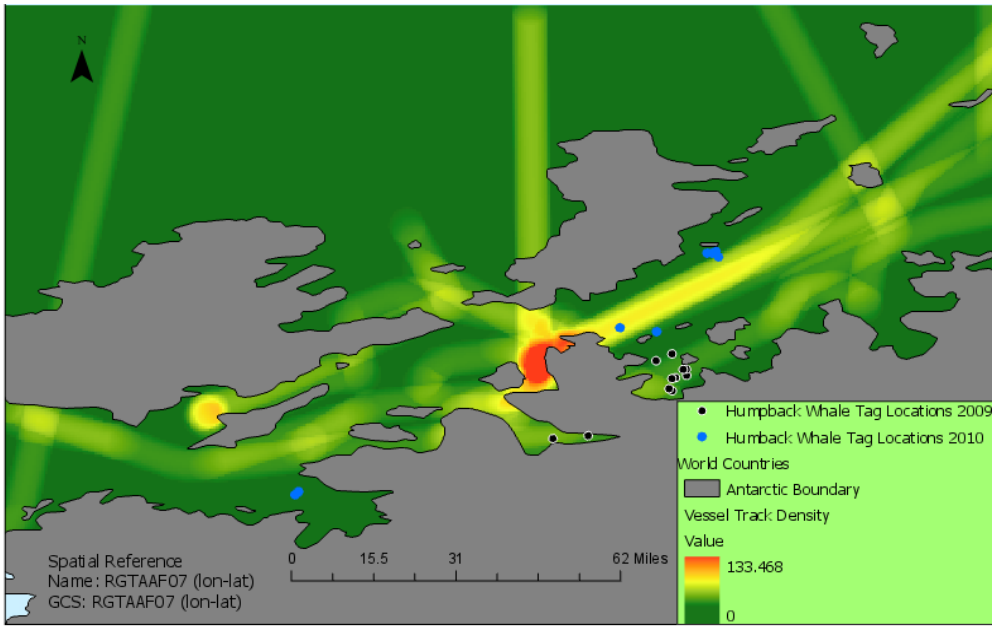
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	16.007305	0.627571	25.51	<.0001*
Duration	-0.563073	0.279163	-2.02	0.0449*

The level of masking and loss of communication space is variable and dependent on the location of the signaler, and the location of the receiver in reference to the location of the ship. Other variables that can affect the masking level of ships is their speed, the number of vessels within a given area as well as the duration the ships are transiting an area (Frankel & Gabriele, 2017). In efforts to emphasize the spatial overlap, ArcGIS Pro was used to plot the locations of the tagged whales in 2009 and 2010 relative to the locations of the vessels. However, Figure 8 demonstrates an analysis that looked at a finer time scale than the shipping density within an entire year.

From the AIS data, geographic coordinates of vessels were obtained from marinetraffic.com that were transiting the study area from February 28th -March 3rd, 2019. The ship coordinates and timestamps were taken from the passenger vessels and plotted in ArcGIS Pro software in order to determine the vessel density within a 5-day period. Figure 8 helps to visualize the amount of vessel traffic that was extrapolated from AIS data to represent only the passenger tourism vessels transiting the study area and the overlap with humpback whale tag locations.

Figure 8: A geo-visualization of the vessel density over a 5-day period which illustrates how much vessels transit an area during in critical foraging habitat to identify areas of overlap for humpback whale locations and vessel density.

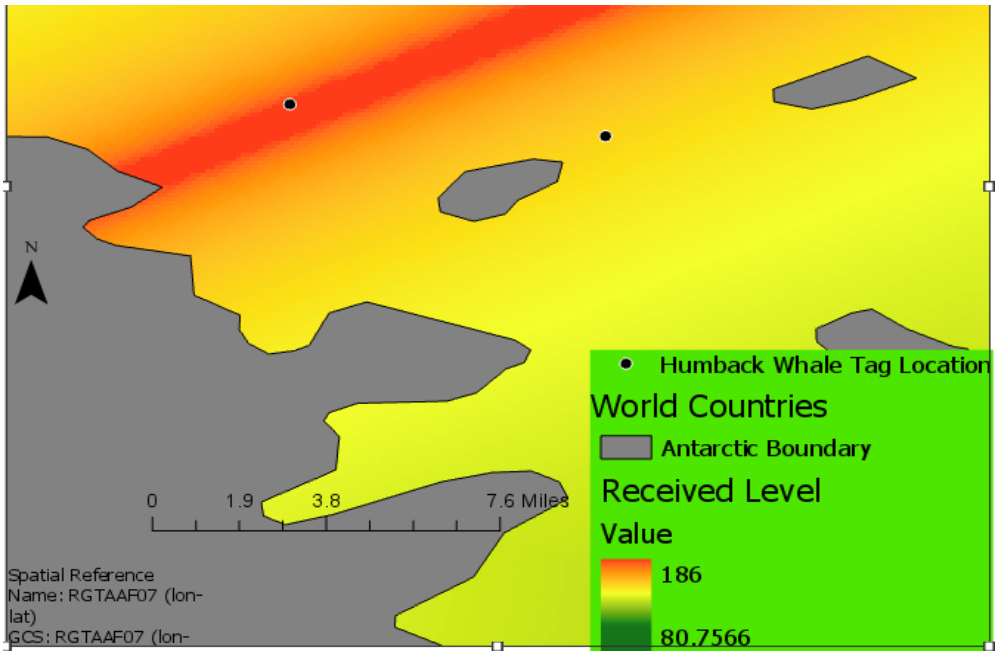


Due to the fact the data is temporally disparate can potentially indicate there is less overlap. The tag locations were put on in the austral fall which is when the humpback whales aggregate closer to shore following the krill seek refuge in large aggregation on the boundary of ice sheets (Johnston, Friedlaender, Read, & Nowacek, 2012). When vessel activity is at its peak, the distribution of whales has been documented with higher density levels and are more distributed throughout the continental shelf and don't aggregate in the bays as often (Curtice et al., 2015).

In order to determine levels of masking, track locations of a single ship transiting through the Gerlache Strait was used along with tag location of two whales to represent a static screenshot of a typical scenario of the location of the signaler, receiver, and ship (Figure 9). The sonar equation, which is an underwater propagation formula, was used to determine the transmission loss of the source level of noise from the ship. I used the spherical spreading formula that is 20 * log 10(range). The range is the

distance from the ship to the humpback whale receiver. The source level used in the sonar equation came from previous literature (L. Hatch et al., 2008a). Figure 9 demonstrates how the vocalizations of the two humpback whales would be completely masked in this static example. However, the movement of the ships and whales are dynamic, and the level of masking will change based on vessel speed, density, and size as well as duration of ship(s) transiting through the area and the relative distance of the signaler and receiver to the ship (L. Hatch et al., 2008b). Recent distribution data of humpback whales would have produced more conclusive results.

Figure 9: A geo-visualization of what happens to the communication space from one ship. When there are multiple large ships, could contribute to a large influx of low frequency energy into the humpbacks active acoustic space



Discussion

A. Potential Consequences

The amount of vessel-based tourism has grown drastically over the last couple of decades without mitigation strategies and spatial planning around the WAP (Verbitsky, 2013). The chronic and cumulative effects of vessel noise is difficult to quantify without future research. However, the results of this study suggest potential consequences that have been a result to elevated vessel noise within the area. Since humpback whales are foraging during the same time of year as tourism or expeditions, the noise could disrupt their abilities to feed cooperatively which allows them to maximize their energy uptake. Previous studies have indicated that some animals will avoid critical foraging habitat all together if there is high-

density vessel activity (Vol et al., 2007) This could have population level effects due to their inabilities to gain enough weight to survive the journey to the breeding grounds and back. For pregnant or lactating females, this would directly impact their abilities to provide enough milk for long enough or have enough nutrition to deliver a healthy calf (Braithwaite, Meeuwig, & Hipsey, 2015). Calves that have been birthed that year will accompany its mother on her migration to the feeding ground.

While on the Antarctic feeding grounds, lactating mothers will continue to nurse until the calf is weaned. The nursing calf needs to stay within proximity to the mother for protection from predators which requires effective communication (Parks, 2012). However, the communication between mother and calf can be relatively much quieter based on previous literature finding in order to avoid being detected by the killer whale (*Orcinus Orca*) (Parks, 2012). Since the communication signals between mother and calf are quieter, the increase in energy in their vocalization frequency from vessel activity can potentially have a higher masking effect (Parks, 2012).

B. Management Implications

Acoustic habitat characterization is important in creating accurate models that will quantify and reflect the changes in communication space due to vessel induced noise (Cholewiak et al., 2018). The quantification of anthropogenic input can aid in proper impact assessment, delineation of areas of high impact, areas of low impact, areas with acoustically sensitive species as well as provide insight on mitigating strategies (Gedamke et al., 2016). Collaboration among nations is required for the development of an efficient international monitoring network. This network must encompass cost-effective and contemporary technologies with the ability to collect measurements on spatial and temporal scales that will aid in effective management strategies (Tasker, Amundin, Andre, Hawkins, Lang, Merck, et al., 2010). Currently, there is an inadequate management framework that regulates noise pollution associated with the tourism industry in the Antarctic. To address the threats to this vulnerable ecosystem, accurate environmental impact statements need to be mandated and followed by IAATO for tourism related activities. There needs to be an integration of an ecosystem-based management strategy to combat issues with noise and needs to be regulated as all other pollutant types (McCarthy, 2003). Marine spatial planning, specifically with ocean zoning and designation of marine protected areas (MPAs), are important conservation tools that help to address issues with noise pollution (McCarthy, 2003). Certain restrictions on cruise ship activity need to be incorporated into management plans to regulate and mitigate impacts from vessel-based tourism. Recommendations include: time area closures during increased foraging activity, track restrictions away from shallow bays

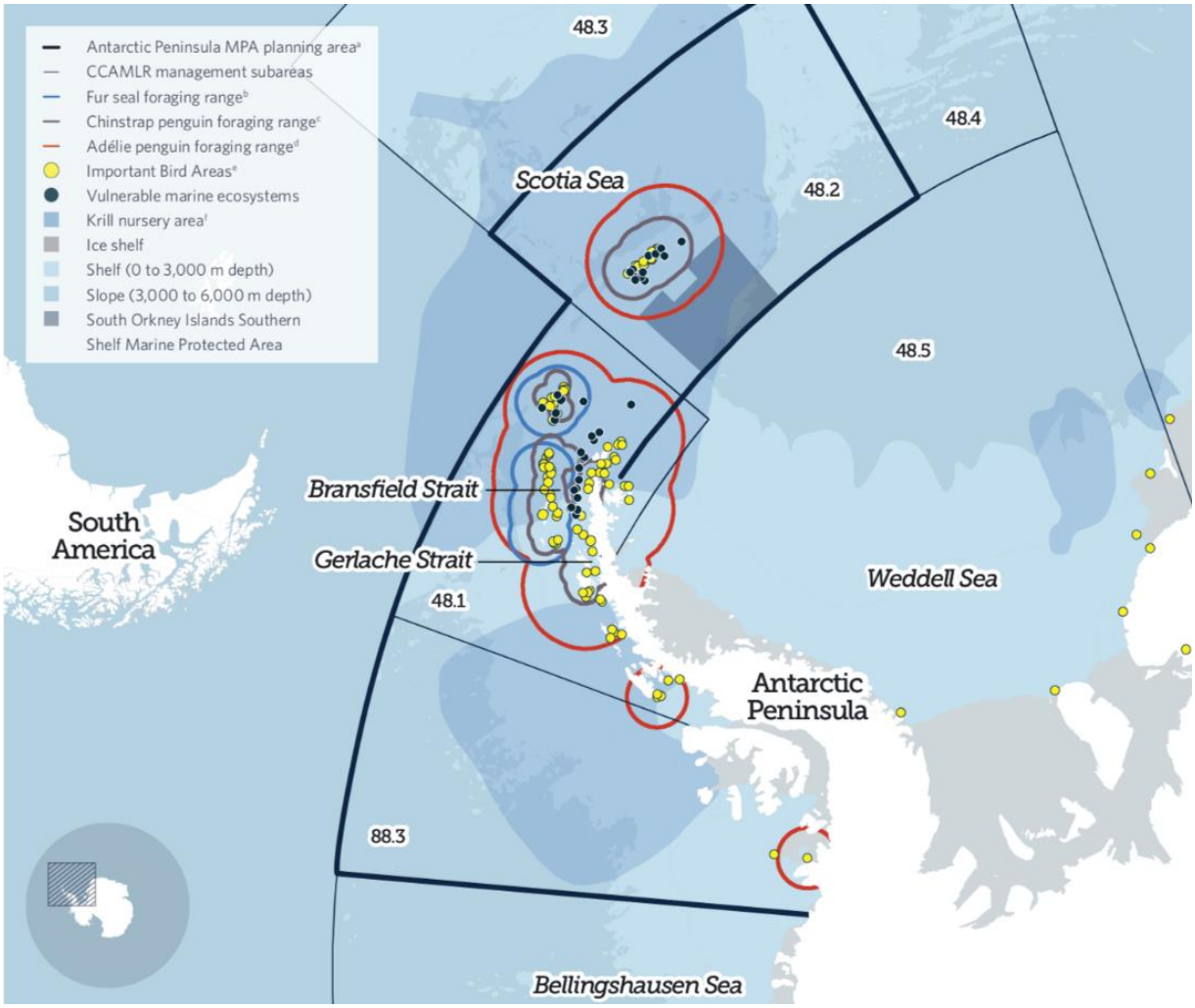
and areas with high foraging aggregations, caps on the number and size of vessels and voyages, speed restrictions as well as environmental impact assessments.

The process of designating and implementing an MPA in the Antarctic has a very distinctive process compared to MPAs elsewhere (Brooks, 2013). The South Orkney's Island Southern shelf encompassing 94,000 km^2 was the first Antarctic MPA proposed by the UK in 2009 in which commercial fishing is prohibited and the major conservation goal is permitted research activities for baseline comparison for unprotected areas. The second designated MPA was originally purposed by the United States and New Zealand in 2012. The proposal was later revised followed by a period of scientific and diplomatic review and came into force in December 2017 (Brooks, 2013). It is considered a large scale MPA encompassing 1.55 million km^2 with the conservation objectives to "protect large-scale ecosystem processes, conserve biodiversity, establish and protect biologically important areas, and promote scientific research" (Brooks, 2013).

The WAP is an area currently being proposed by Chile and Argentina as a marine protected area geared toward the assessing the impact of climate change (CCAMLR, 2017)(Figure 9). The major conservation objectives are focused on climate change because it is one of the fastest warming regions in the world with an average temperature increase of 7°C since 1950 (Ducklow et al., 2013). The recommendations for this proposal include: 1) year-round no fishing covering coastal foraging ranges in Bransfield and Gerlache Straits; 2) contained scientific research areas to use as baselines in establishing impact outside of the MPA boundaries; 3) protect sensitive spawning nursery habitat; 4) provide robust research and monitoring plans; and 5) permanency (CCAMLR, 2017). The purpose of this paper is to lay out the potential effects of vessel-based tourism to the Western Antarctic soundscape and suggest different regulations and mitigation measures specifically targeting the tourism industry.

Figure 9: The current area that is being proposed for MPA status around the Antarctic Peninsula by Chile and Argentina. The primary objectives are surrounded toward climate change and this map highlights biologically important species that have high site fidelity around the Antarctic Peninsula (Source: ("Pew Charitable Trust:

Protection for the Antarctic Peninsula Region," n.d.)



The increase in tourism-based ship traffic can cause synergistic impacts including the emission of carbon into the atmosphere and an emission of sound into the soundscape (Eijgelaar, Thaper, & Peeters, 2010). Tourism companies are encouraging travelling to see this iconic destination before it disappears. This sales pitch manifests a paradoxical situation where it is supposedly the intent to raise awareness about climate change and a disappearing polar ecosystem while at the same time significantly exacerbating this problem (Eijgelaar et al., 2010). Just like climate change, ocean noise is a very dynamic threat that is difficult to address in terms of specific boundaries.

C. Conclusion

Marine ecosystems have become ensonified by anthropogenic vessel pollution at an international scale which requires a multi-disciplinary approach to mitigate, monitor and manage impacts through

research, technological advances, effective policy creation, and cooperation among sectors that contribute to ocean noise. Future research is required to establish more conclusive evidence of the acoustic characteristics of the Antarctic soundscape. Recommendations include having a moored hydrophone that will better accurately capture the reference ambient noise levels as well having recordings of vessel noise during the peak season as well as current humpback whale distribution data. Once these measurements are obtained, better information will determine how the sound propagates in this Antarctic environment and help accurately quantify the level of noise emitted into the acoustic space and the potential impacts it could cause. Ecosystem-based management strategies need to incorporate noise as a pollutant to be properly regulated and enforced within the management plan.

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