Australian Government
Department of Defence
Defence Science and
Technology Organisation

Mitigation Modelling of the Leeuwin Class Hydrographic Sonars in Jervis Bay

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DSTO-TR-2120

ABSTRACT

Jervis Bay is an important training area for the Royal Australian Navy. To conduct operations in Jervis Bay in an environmentally sensitive manner Navy use mitigation strategies during any training exercises. One such mitigation strategy is to have established stand-off ranges, and to cease sonar operations when a marine mammal is within these ranges. This document describes an improved determination of these stand-off ranges based on the effect of acoustic energy emanating from the Leeuwin class hydrographic ship sonars. Modelling methods used and the mitigation ranges calculated are shown.

Published by

Maritime Operations Division
DSTO Defence Science and Technology Organisation
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 8259 5555
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AR-014-170
December 2009

APPROVED FOR PUBLIC RELEASE

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Executive Summary

The ability to conduct training exercises in Jervis Bay is an important requirement for the Royal Australian Navy, but Jervis Bay is also a highly valued Marine Park. To enable the Navy to conduct exercises in Jervis Bay in an environmentally sensitive manner, a number of mitigation strategies have been implemented. One strategy in relation to sonars on Leeuwin class hydrographic vessels is to use a stand-off range and to cease sonar transmissions when a marine mammal is within this mitigation range. The RAN Environment Manager requested DSTO to conduct acoustic modelling of the Leeuwin class hydrographic ship sonars in the Jervis Bay region to confirm suitable mitigation ranges. This document shows the results from the acoustic modelling.

The Leeuwin class hydrographic ships have a number of different sonars designed for specific operations. The welfare of dolphins is the main concern in Jervis Bay in reference to hydrographic sonar frequencies, with a resident population of around 60 Indo-Pacific bottlenose dolphins (*Tursiops aduncus).* Modelling therefore concentrated in the auditory frequency range of dolphins, 1 to 150 kHz. Sonar operations at frequencies above 200 kHz were not considered since their effects on dolphins were considered inconsequential.

The acoustic modelling was done using a gaussian beam model called SCAT-RD. This modelling included a number of different environments typical of the Jervis Bay region throughout the year. Seafloor roughness and seagrasses were ignored during the modelling, as these would have reduced the sound levels propagated. All modelling was then carried out on a worse-case basis.

This modelling showed that the required mitigation range was dependent on season, sea state, and location, but these dependencies were specific to sonar type and frequency. To avoid overly complicating the mitigation strategies a single worse-case range was recommended for each type of sonar on the Leeuwin class hydrographic ships. These sonars could be placed into three groups for the purpose of operations in the vicinity of dolphins, with recommended mitigation ranges being as follows:

1. 1700 yards for the CMAS forward looking sonar.
2. 700 yards for the Fansweep 20 Multibeam Echo Sounder and Klein 2000 Towed Light Weight Side Scan Sonar.
3. 200 yards for the EDO Model 3060 Doppler Velocity Log and Atlas DESO 25 Single Beam Echo Sounder.

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Contents

Acronyms

AGSO	Australian Geological Survey Organisation (now Geoscience Australia)
AODC	Australian Oceanographic Data Centre (now Defence Oceanographic Data Centre)
CMDR	Commander, RAN
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DOM	Directorate of Oceanography and Meteorology
DSTO	Defence Science & Technology Organisation
FEOHSCO	Fleet Environmental and OHS Coordinating Officer
kyds	kilo yards
METOC	Directorate of Oceanography & Meteorology
OH&S	Occupational Health & Safety
RAN	Royal Australian Navy
SCAT-RD	Sonar Capability Analysis Tool-Range Dependent
SL	Source Level
SSP	Sound Speed Profile
TL	Transmission Loss
WOA	World Ocean Atlas

1. Introduction

DSTO was requested by the RAN Environment Manager to perform acoustic modelling of the Leeuwin class hydrographic ship sonars in the area of Jervis Bay. The work was performed under NAV 05/043, "Impact of environment on operations".

Jervis Bay is an important exercise area for the Navy, but also part of a highly valued Marine Park. A population of around 60 Indo-Pacific bottlenose dolphins (*Tursiops aduncus)* reside within Jervis Bay. A closely related species, *Tursiops truncatus* has a hearing sensitivity in the frequency range 1 to 150 kHz [Au *et al* 2000]. The received acoustic levels from the Leeuwin class hydrographic ships operating near this frequency range were modelled over various environmental conditions.

The acoustic modelling was done using a gaussian beam ray model, SCAT-RD[1], to show the expected maximum ranges receiving a sound pressure level over 182 dB and 160 dB throughout Jervis Bay. These sound pressure levels of 160 dB and 182 dB were used since they are currently recognised throughout Australia as the threshold for noise disturbance and the threshold for harassment [Polglaze 2003], respectfully.

2. Location

Jervis Bay is situated in NSW, Australia, 35° 5' S 150° 45'E. It is a shallow well sheltered bay with no major fresh water inflows from rivers [Vogelaar *et al* 2006]. The SCAT-RD modelling used climatological databases for sound speed as a function of depth and bathymetry. Other parameters including time of year and wind speed were varied over expected ranges to show how these affected the mitigation ranges required.

2.1 Bathymetry

The maximum depth is slightly over 20 m in the bay adjoining the continental shelf past the heads (see figure 1). The bathymetry was obtained using a one minute[2] AGSO database [AGSO 2005].

[1] SCAT-RD is an in-house front end graphical interface for a gaussian beam model. Enabling a number of transmission loss runs to be automated, thus reducing operator work load.
[2] One minute is equivalent to 1 nautical mile in the north south direction.

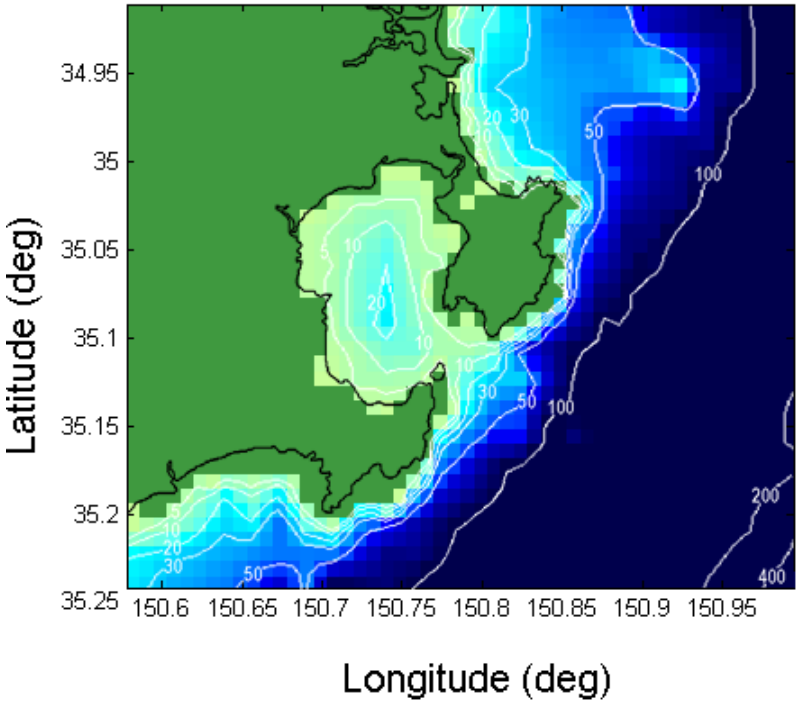

Figure 1: Bathymetry of Jervis Bay in metres

2.2 Sediment

The sediment in the bay varies from very fine sand near some of the shore line regions to coarse sand north of Bowen Island, figure 2. The continental shelf region near Jervis Bay is medium sand changing to coarse sand near the 400 m depth contour [Davies 1979].

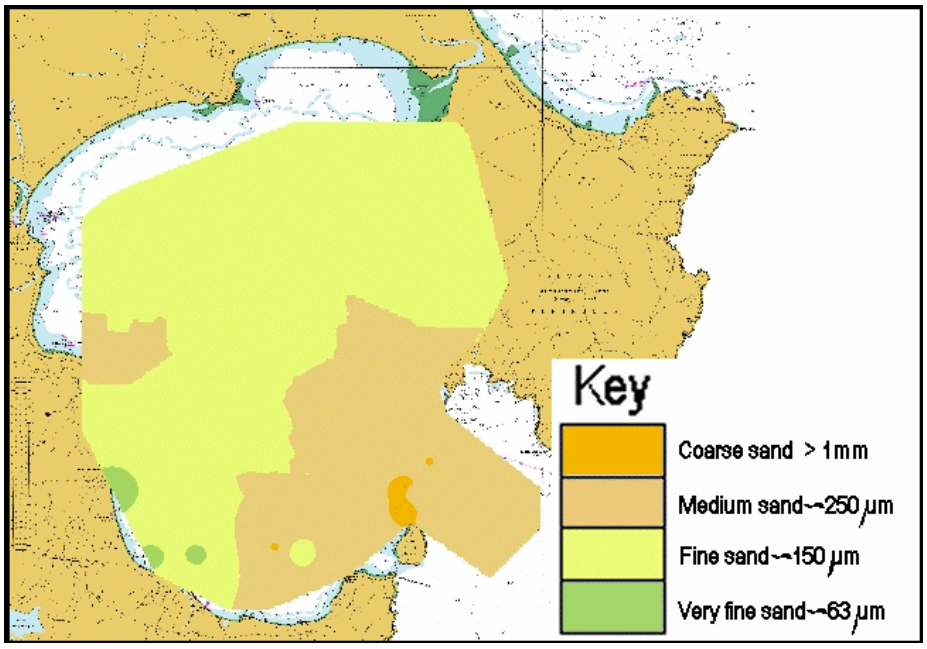

Figure 2: Bottom sediments in Jervis Bay [AODC, 2002]

Jervis Bay contains a few seagrass beds, figure 3. Acoustic modelling of seagrass beds at hydrographic frequencies can be difficult due to the high scattering from seagrass at these frequencies. This scattering would normally reduce the coherent signal produced from hydrographic sonars, thus reducing the required mitigation range. Since the purpose of this study is to establish a worst-case mitigation range, the effects of scattering from sea grass was not included in the acoustic modelling.

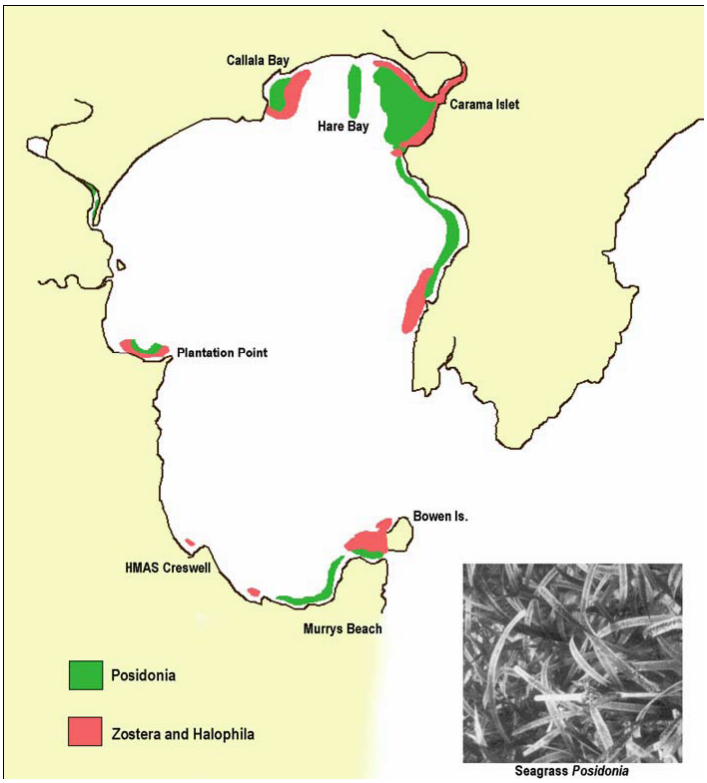

Figure 3: Seagrass beds around Jervis Bay [Jodie Vogelaar 2006]

2.3 Sound Speed Profiles

The sound speed in the ocean is a function of the temperature, salinity, and pressure [Urick 1983]. Since temperature and salinity change with time of year and location around the bay, the sound speed profiles in the Jervis Bay region will also vary. The spatial variation was modelled using sound speed profiles taken from the world ocean atlas (WOA) 15 min grid. Four different months during the year were modelled (see figures 4 to 7).

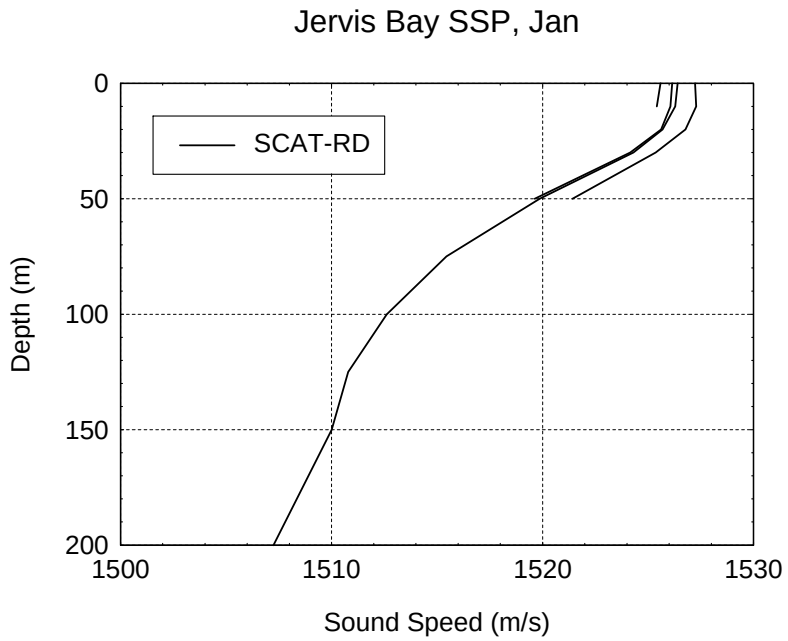

Figure 4: Sound speed profile for January in the Jervis Bay region

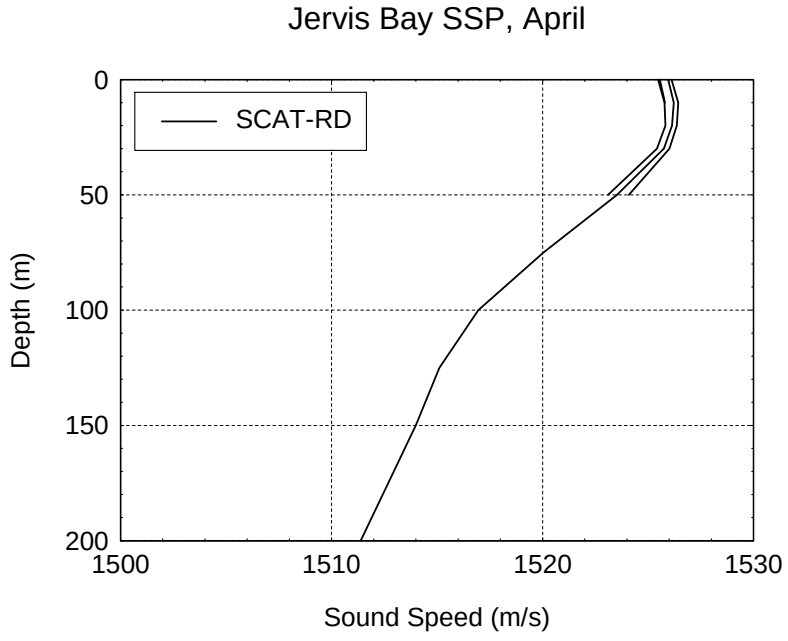

Figure 5: Sound speed profile for April in the Jervis Bay region

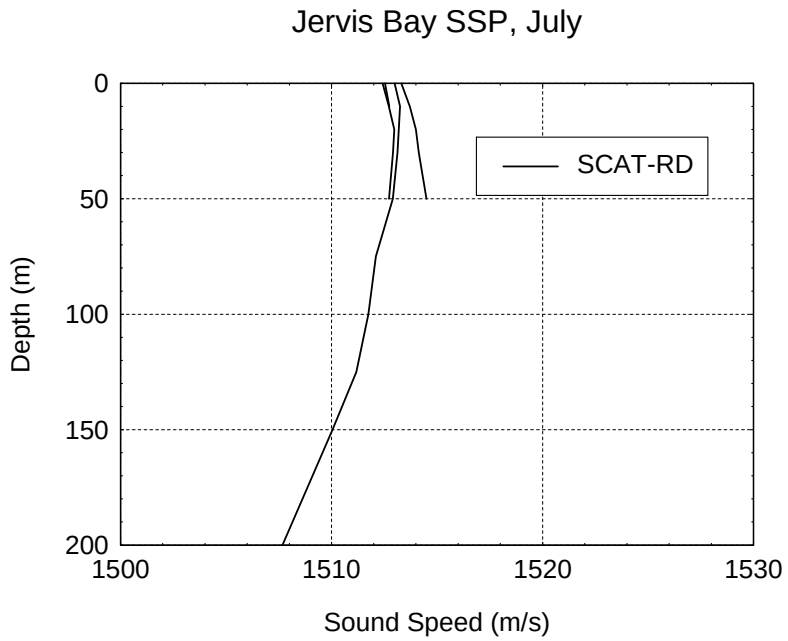

Figure 6: Sound speed profile for July in the Jervis Bay region

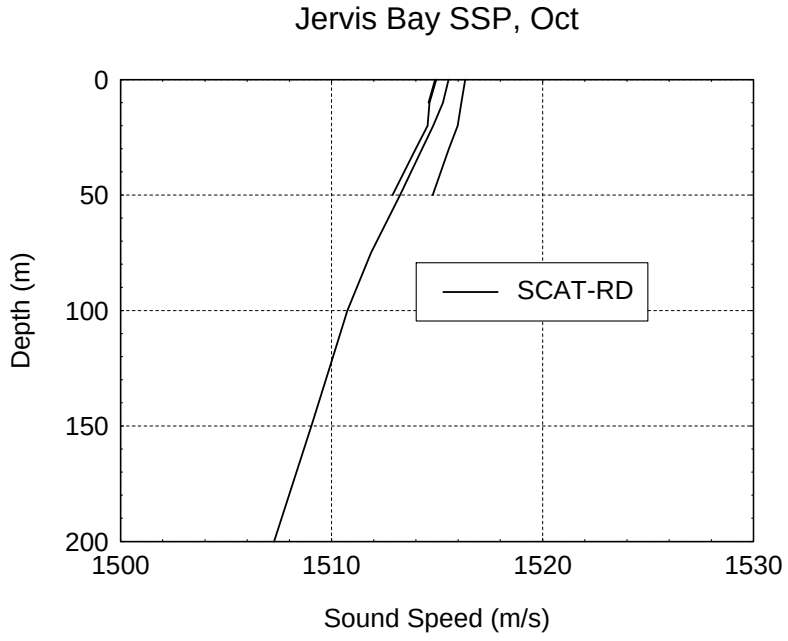

Figure 7: Sound speed profile for October in the Jervis Bay region

3. Hydrographic Sonar Parameters used for Modelling

There is a number of different sonar systems used on the Leeuwin class hydrographic ships with different source levels, pulse lengths, frequencies, and beam patterns. The different sonars are listed in tables 1 and 2. These parameters are not all the available operating options, but were chosen as they give rise to the highest received sound levels.

Table 1: Leeuwin class hydrographic sonar parameters

Sonar	Frequency (kHz)	Pulse length	Source Level[3]
Fansweep 20 Multibeam Echo Sounder	100	120 µs	227 dB
Klein 2000 Towed Light Weight Side Scan Sonar	140	107.5 ms	228 dB
	500	71.5 ms	228 dB
EDO Model 3060 Doppler Velocity Log (DSVL)	171	100 ms	210 dB
Atlas DESO 25 Single Beam Echo Sounder	210	2.3 ms	203 dB
	33	15.5 ms	235 dB
	12	15.5 ms	224 dB
CMAS Forward Looking Sonar 36/39	36	150 ms	219 dB
	39	150 ms	219 dB

Table 2: Leeuwin class hydrographic sonar beam patterns (see figure 9 for explanation of angles)

Sonar	Frequency (kHz)	Beamwidth (deg)			
		Combined	Each	Horizontal	Vertical
Fansweep 20 Multibeam Echo Sounder	100	161 x 1.3	3.3 x 1.3		Down
Klein 2000 Towed Light Weight Side Scan Sonar	140			1	95° to 135°
	500			0.2	95° to 135°
EDO Model 3060 Doppler Velocity Log (DSVL)	171		4 separate beams at 3.5°	3.5	148° to 152°
Atlas DESO 25 Single Beam Echo Sounder	210		9		Down
	33		6 x 8		Down
	12		15		Down
CMAS Forward Looking Sonar 36/39	36			180	87° to 93°
	39			180	87° to 93°

[3] The source levels in this table are for a reference range of 1 m, ie. the acoustic sound pressure level received at 1 m from the centre of the transmitter.

The beam pattern and sonar combinations in Table 2 are complex, so some are explained in more detail below:

- The fansweep sonar has a number of beams used to survey the seafloor. Each beam is 3.3° x 1.3°, but all beams combine to give a 161° wide beam underneath the ship (see figure 8).
- The Klein 2000 towed light weight side scan sonar has two broadside beams, one either side of the tow body.
- The EDO Model 3060 doppler velocity log uses 4 beams in different directions underneath the ship. Each beam is 3.5° wide and transmits at an angle of 150° from the ship.
- In the vertical beamwidth column, "down" refers to a signal which is transmitted vertically down towards the seafloor, making a circle or ellipse on the seafloor.

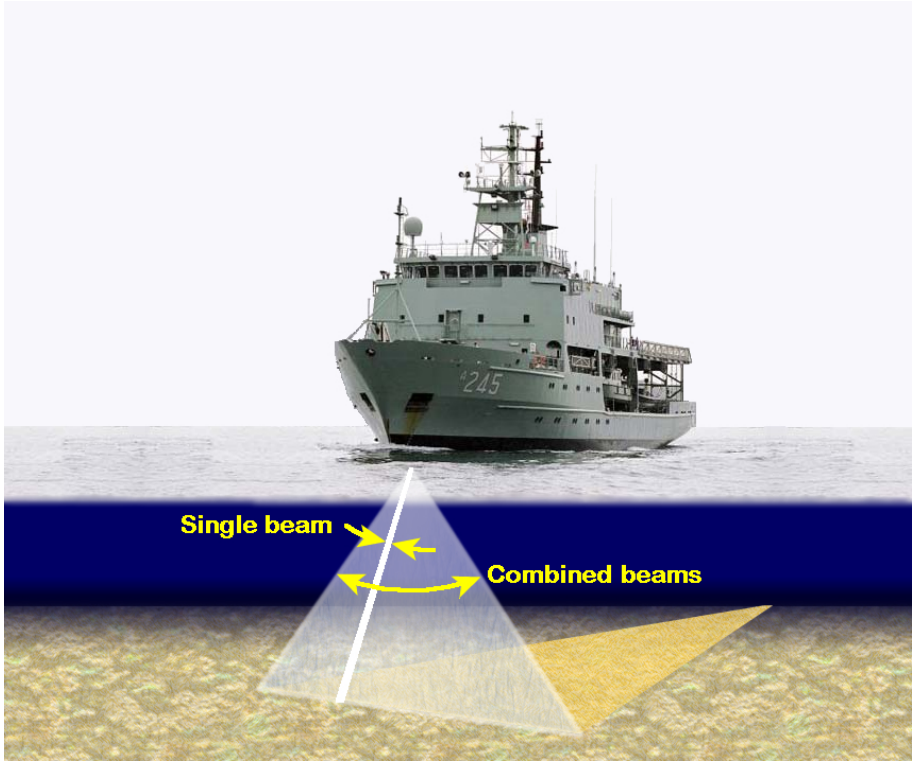

Figure 8: Fansweep multibeam echo sounder, showing the single and combined beams

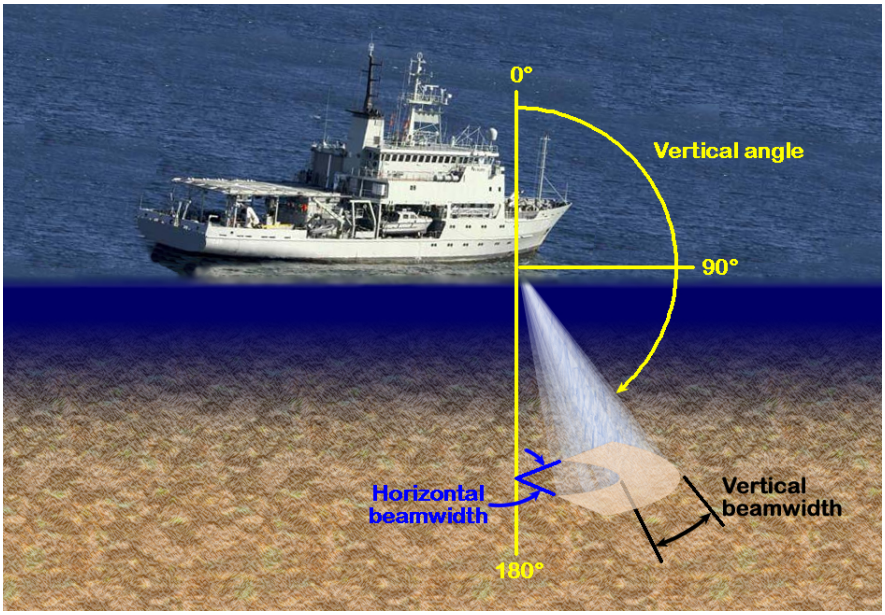

Figure 9: Beamwidth angles used in table 2 and 3. For the case shown, horizontal beamwidth is 90°, vertical beamwidth is 15°, and vertical angle is 140°. Vertical beamwidth could also be described as 140° to 155°.

Table 3 shows the parameters used in the acoustic modelling. Pulse lengths were varied from the original parameters, tables 1 and 2, due to limitations in the SCAT-RD acoustic model. Some beamwidths were also increased to compensate for pitch and roll of the ship or tow body. Any variations were chosen so as to increase the mitigation range and present a worst-case. Signals at frequencies above 200 kHz were not considered. Also, the EDO Model 3060 doppler velocity log was only modelled using hand calculations.

Table 3: Sonar parameters used during the acoustic modelling (see figure 9 for explanation of angles)

Sonar	**Frequency (kHz)**	**Pulse length**	**Beamwidth**		**Source Level**
			Horizontal	**Vertical**	
Fansweep 20 Multibeam Echo Sounder	100	100 ms	360°	90° to 180°	227dB
Klein 2000 Towed Light Weight Side Scan Sonar	100	108 ms	1°	90° to 140°	228 dB
EDO Model 3060 Doppler Velocity Log (DSVL)	171.3	100 ms	3.5°	148° to 152°	210 dB
Atlas DESO 25 Single Beam Echo Sounder	33 12	15.5 ms 15.5 ms	360° 360°	176° to 180° 172° to 180°	235 dB 224 dB
Forward Looking Sonar CMAS 36/39	36 39	150 ms 150 ms	180° 180°	87° to 93° 87° to 93°	219 dB 219 dB

4. SCAT-RD Modelling Parameters

Transmission loss calculations were carried out by repeating them at sites on a one minute grid over the bay. At each grid point the TL calculation was done in four directions (north, south, east, and west) to account for spatially dependent depth properties. The modelling used a number of acoustic sub-models, described below, to determine the acoustic attenuation caused by the surface, seafloor, and water volume.

4.1 Surface Attenuation

The surface reflection is very dependent on the surface roughness at hydrographic sonar frequencies. The model used in SCAT-RD to describe the surface attenuation per reflection at different wind speeds was created by the Applied Physics Laboratory, University of Washington [Applied Physics Laboratory 1994]. The surface attenuation curves used in SCAT-RD are shown in figures 10 to 14.

The surface attenuation model uses wind speed as the input to calculate the surface loss, but since Jervis Bay is a sheltered environment wind speed is not a good variable to estimate surface roughness[4]. Instead this document uses sea state, which correlates well to surface roughness and surface attenuation in a sheltered environment.

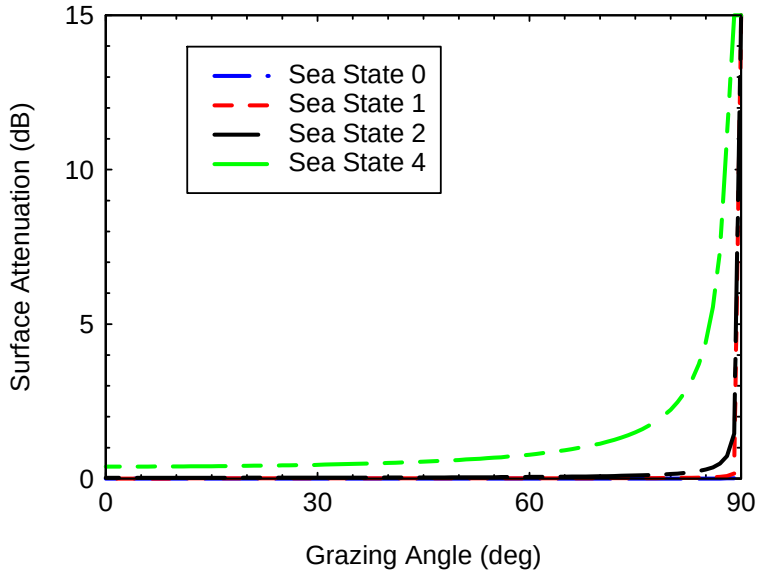

Figure 10: Surface Attenuation vs Grazing Angle for 12 kHz

[4] The correlation between wind speed and surface roughness in SCAT-RD assumes a fully developed sea (ie. the sea will not get any rougher at the current wind speed). To obtain a fully developed sea the wind speed must be constant for a minimum time and flow over a large area of sea surface, called fetch.

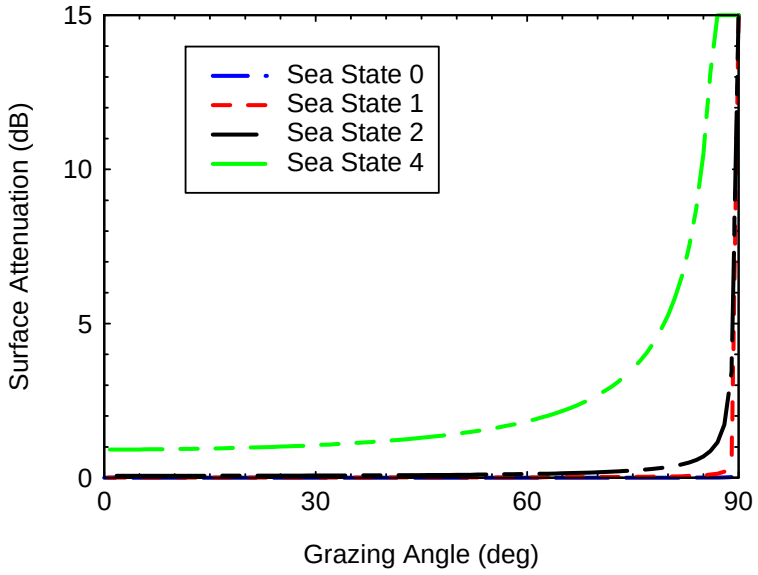

Figure 11: Surface Attenuation vs Grazing Angle for 33 kHz

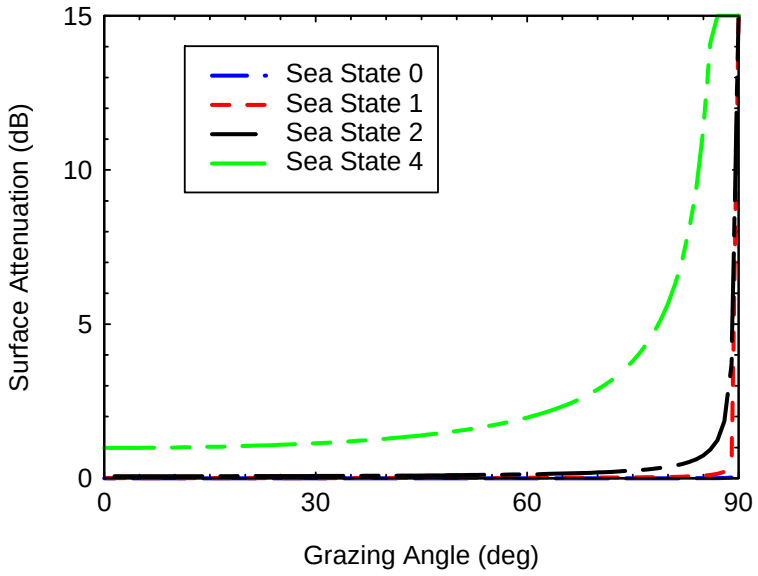

Figure 12: Surface Attenuation vs Grazing Angle for 36 kHz

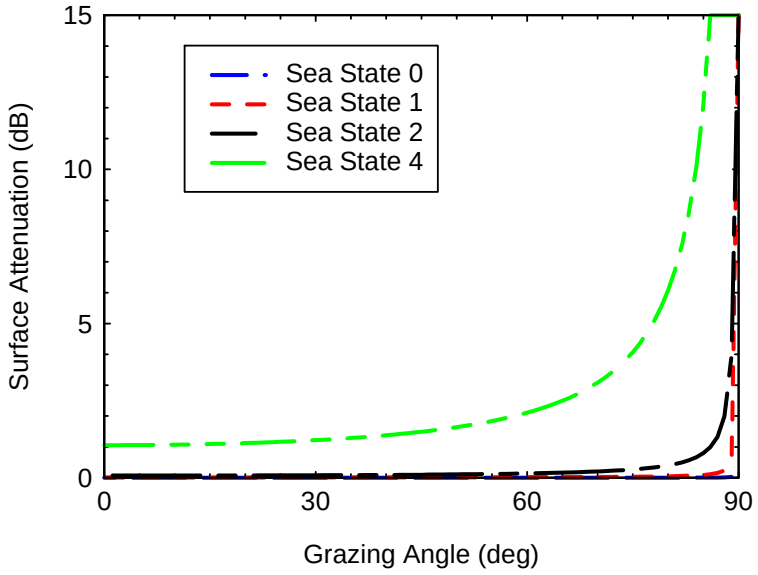

Figure 13: Surface Attenuation vs Grazing Angle for 39 kHz

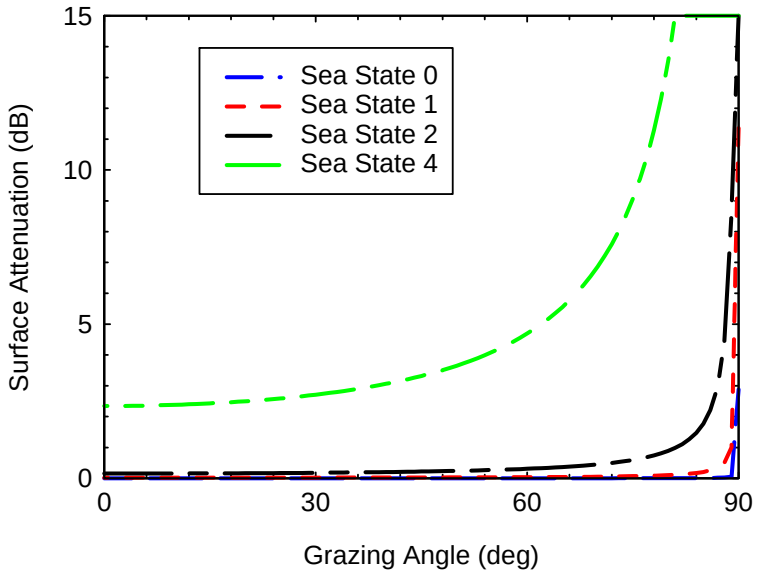

Figure 14: Surface Attenuation vs Grazing Angle for 100 kHz

4.2 Seafloor Attenuation

The seafloor sediment in Jervis Bay varied from fine sand to coarse sand [AODC 2002] in the regions of interest. The seafloor was modelled using the parameters for the most reflective sediment, thus giving the longest mitigation ranges. SCAT-RD used the Rayleigh specular reflection model to determine the seafloor attenuation [Officer 1958]. This model does not include any reflection scattering losses so represents an over prediction of received level. The attenuation curves used in SCAT-RD are shown in figure 15.

As a comparison the MGS model [Yarger 1976] has also been plotted in figure 15. This plot shows that for high grazing angles (short ranges) the MGS model should give a lower TL and produce a slightly higher mitigation range. For ranges over 100 m the grazing angle is less and the MGS model should give a higher TL than the Rayleigh model, which would result in shorter mitigation ranges for MGS. Since the expected mitigation ranges are over 500 m SCAT-RD used the Rayleigh model, giving a worst-case result.

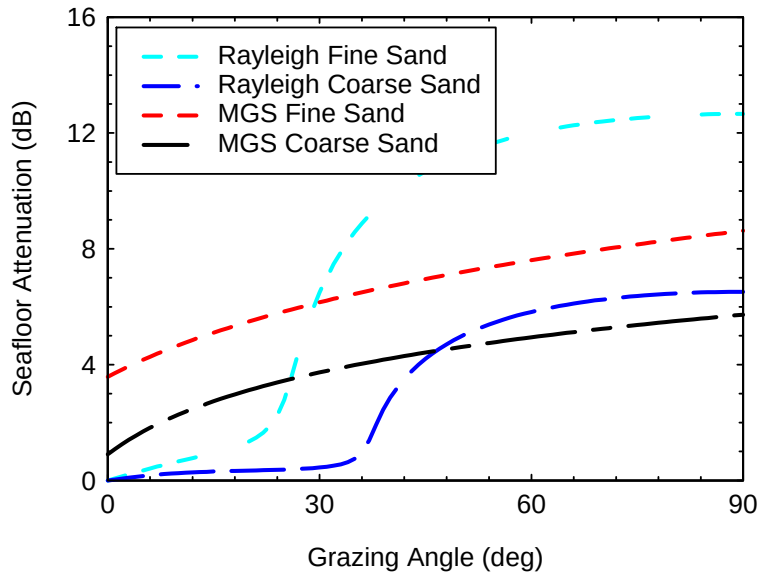

Figure 15: Seafloor Attenuation vs grazing angle for Jervis Bay. This is frequency independent at hydrographic frequencies for the Rayleigh and MGS models.

4.3 Volume Attenuation

SCAT-RD used the Francois – Garrison model to determine the attenuation of sound due to seawater absorption [Francois *et al* 1982].

5. Mitigation Range Calculation

The modelling of the acoustic signal radiated by the hydrographic sonars was done for a number of different environmental conditions including:

- Sea states 0, 1, 2, and 4.
- Typical sound speed profiles for January, April, July, and October.
- Sonar orientations north, south, east, and west.
- Water depths according to location throughout the Jervis Bay region.

The most reflective sediment type within the bay (coarse sand) was used for all the modelling, producing a worst-case transmission loss. This was done to remove any uncertainty about sediment variations through out the bay affecting the modelling results.

The mitigation ranges were obtained according to a worst-case selection process to reduce the amount of modelling data to a useable form, as follows:

1. SCAT-RD transmission loss (TL) modelling was performed for each combination of the different environmental conditions with, in turn, the sonar centred at each point over the 1 minute grid encompassing Jervis Bay (see figure 16).
2. Each output from SCAT-RD contained TL vs range and depth. These output data were reduced by finding the worst-case (minimum) TL over the depths 0 to 150m for each range step, thus producing TL vs range for the different environmental conditions for each point at which the sonar was located.
3. The TL vs range results for the four directions at each location were compared using the worst-case selection criteria, reducing the data to one set of TL vs range at each location, sea state, and season.
4. This TL data was then used to determine the maximum (worst-case) received acoustic pressure level around the sonar while transmitting using the formula below:

$$IL = SL - TL \qquad \text{(equation 1)}$$

where IL = received (incident) acoustic pressure level
SL = source level of the hydrographic sonar
TL = worst-case transmission loss

This gave the IL vs range at each location, sea state, and season.

5. Next the worst-case ranges at each location were found for received acoustic pressure levels of 160 dB and 182 dB. This produced plots of mitigation ranges required for each sea state and season, see appendix A. Since only worst-case TL was used during the previous steps, with no averaging, these plots show the maximum required ranges for different locations, sea states, and seasons to experience incident levels less than 160 or 182 dB, respectfully.
6. The mitigation range plots for different sea states and seasons were then compared using the worst-case criteria to give the maximum mitigation ranges required for any of the environmental conditions around Jervis Bay (see Chapter 7).

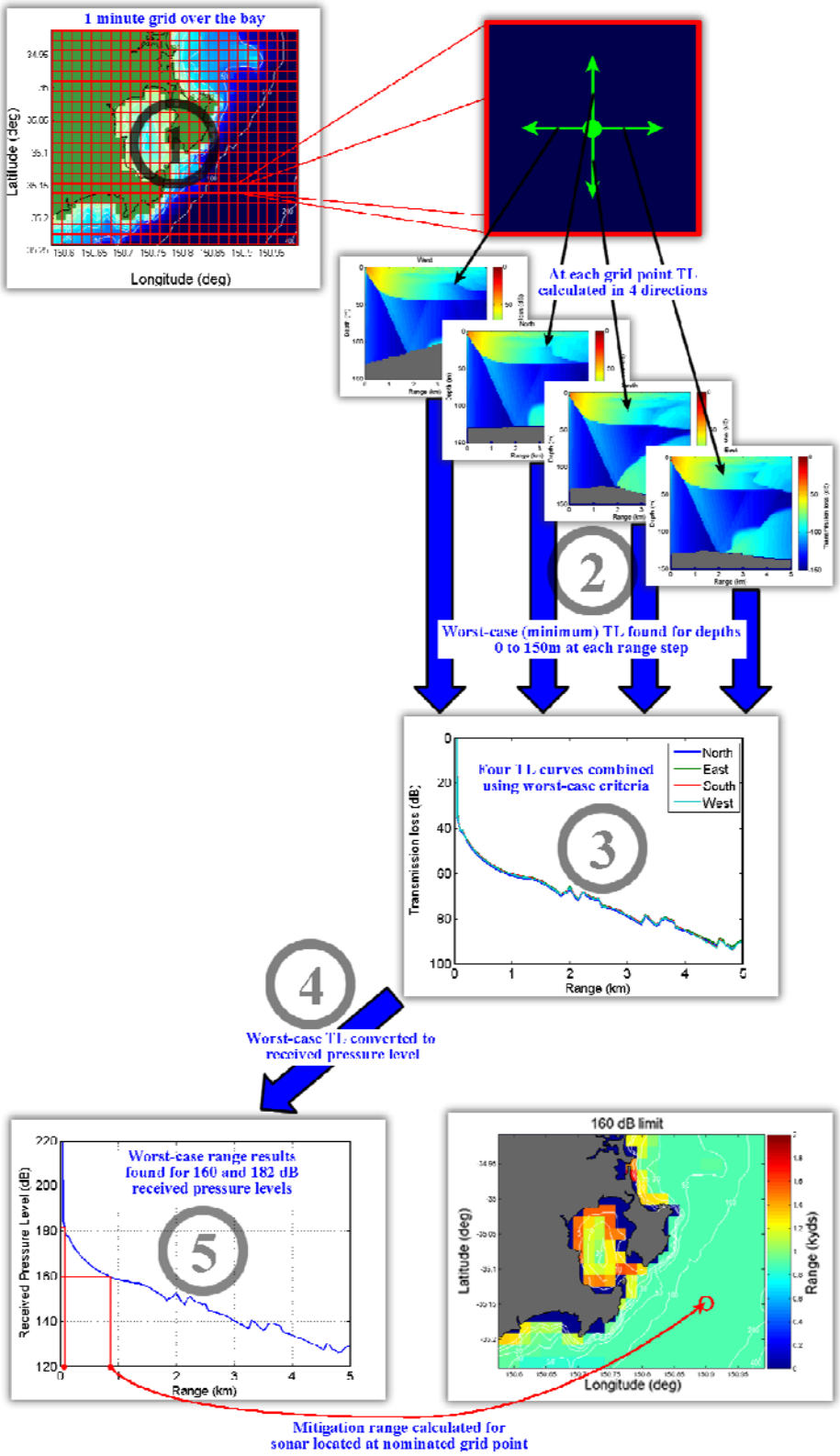

Figure 16: Mitigation range calculation procedure for one location, sea state, and season

5.1 EDO Model 3060 Doppler Velocity Log

The EDO doppler velocity log had a frequency of 171 kHz, which was above the frequency limit of SCAT-RD. Since 171 kHz was also above the expected 150 kHz hearing threshold limit of dolphins a simplified method was used to get the expected mitigation ranges.

The received acoustic levels were calculated assuming spherical spreading existed and sea water absorption (see table 4). A conservative value of 30 dB / km [Fisher *et al* 1977] was used for the sea water absorption.

Table 4: Received sonar levels for the EDO doppler velocity log with range

Range (m)	Transmission Loss (dB)			Received Level (dB)
	Spreading	Absorption	Total	
10	20	0	20	190
20	26	1	27	183
30	30	1	30	180
40	32	1	33	177
50	34	2	35	175
60	36	2	37	173
70	37	2	39	171
80	38	2	40	170
90	39	3	42	168
100	40	3	43	167
110	41	3	44	166
120	42	4	45	165
130	42	4	46	164
140	43	4	47	163
150	44	5	48	162
160	44	5	49	161
170	45	5	50	160
180	45	5	51	159
190	46	6	51	159
200	46	6	52	158

6. Environmental Dependence

6.1 Seasonal Dependence

The mitigation range plots showed a reasonable dependence on seasonal variations, mainly in deeper water outside the bay due to specific sound speed profiles deflecting energy into the seafloor. These variations were very sound speed dependent. This can be seen in figures 17 to 20, which showed how the required mitigation range changed for different seasons at sea state 0 using the Klein 2000 towed light weight side scan sonar. More plots showing the seasonal variation can be seen in Appendix A.

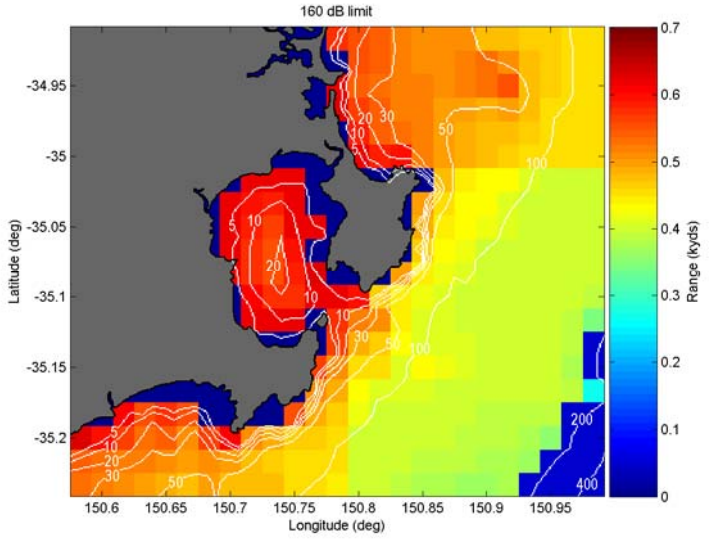

Figure 17: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

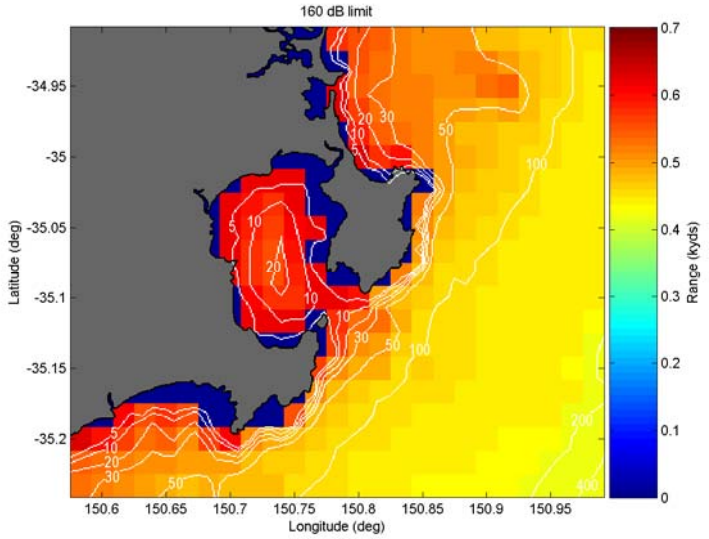

Figure 18: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

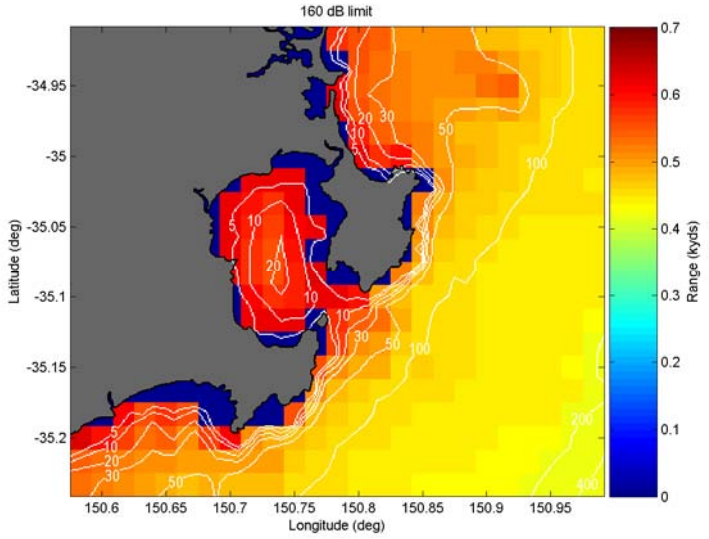

Figure 19: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

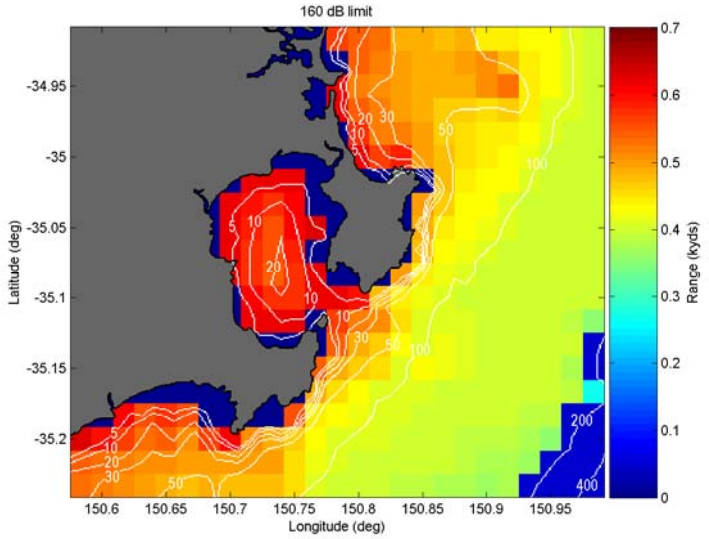

Figure 20: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

6.2 Sea State Dependence

The mitigation range dependence on sea state was as expected, with the longest mitigation ranges needed for low sea states. The effect of sea surface roughness on attenuating the sound for sea state 0 and 1 was small for all sonars. The change in mitigation range due to increased surface attenuation at sea state 2 and 4 varied depending on the sonars, but always reduced

the required mitigation ranges. This effect can be seen in figures 18, 21, 22, and 23. The effect on other sonars can be seen in Appendix A.

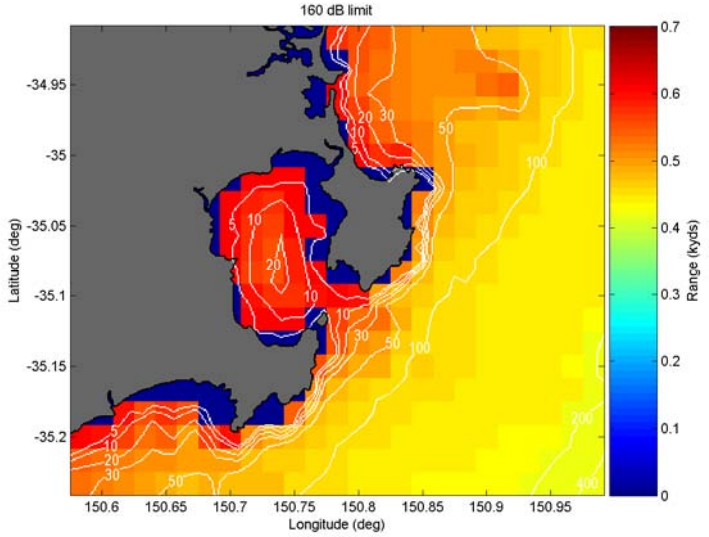

Figure 21: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

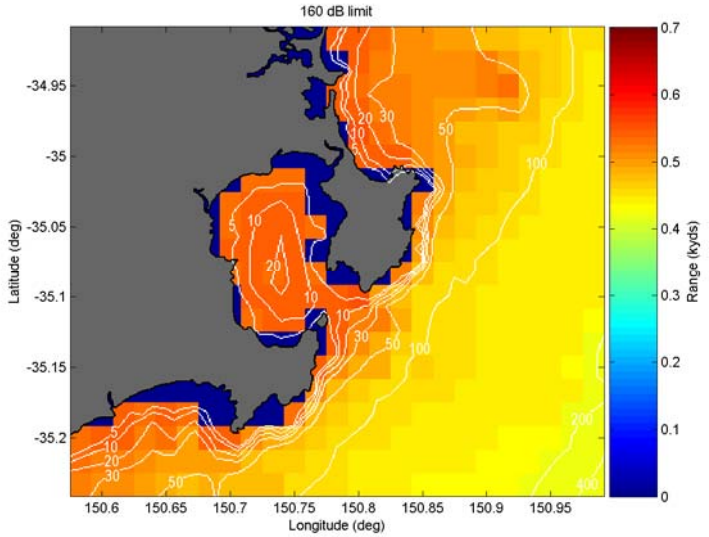

Figure 22: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

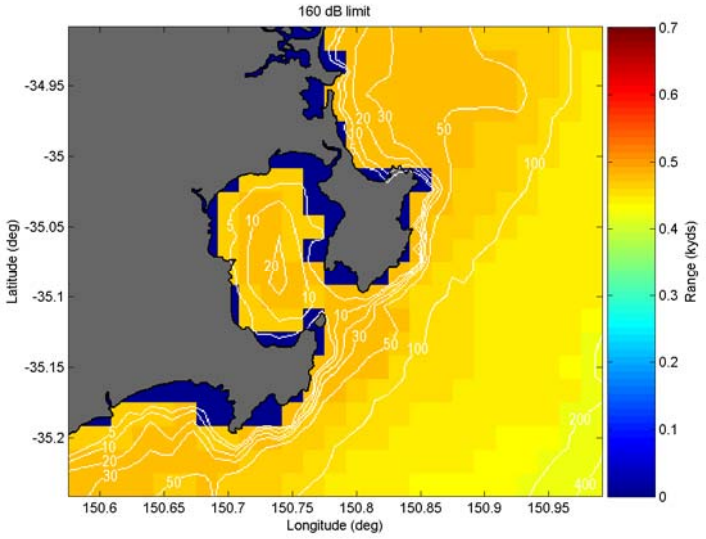

Figure 23: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay.

6.3 Ocean Depth Dependence

All the mitigation range plots for the Leeuwin Class sonars showed significant dependence upon ocean depth (see Appendix A), but due to the varying beam patterns between sonars there were no consistent trends.

7. Mitigation Range Results

The mitigation range determination for the different environmental conditions across Jervis Bay (see appendix A) have been combined using a worst-case criterion for which the maximum mitigation range is shown. These results are shown in figures 24 to 35. Table 5 shows the maximum determined ranges for each sonar type across all environmental conditions, including location.

Table 5: Maximum mitigation ranges calculated for the Leeuwin Class sonars at all locations in and around Jervis Bay

Sonar	Frequency (kHz)	Received Level (dB)	Mitigation Range Required (kyds)
Fansweep 20 Multibeam Echo Sounder	100	160	0.63
		182	0.22
Klein 2000 Towed Light Weight Side Scan Sonar	100	160	0.63
		182	0.22
EDO Model 3060 Doppler Velocity Log (DSVL)[5]	171	160	0.18
		182	0.03
Atlas DESO 25 Single Beam Echo Sounder	33	160	0.04
		182	0.01
	12	160	0.08
		182	0.011
CMAS Forward Looking Sonar 36/39	36	160	1.7
		182	0.10
	39	160	1.5
		182	0.10

[5] The EDO doppler velocity log mitigation ranges were calculated using spherical spreading and sea water absorption instead of SCAT-RD modelling.

7.1 Fansweep 20 Multibeam Echo Sounder

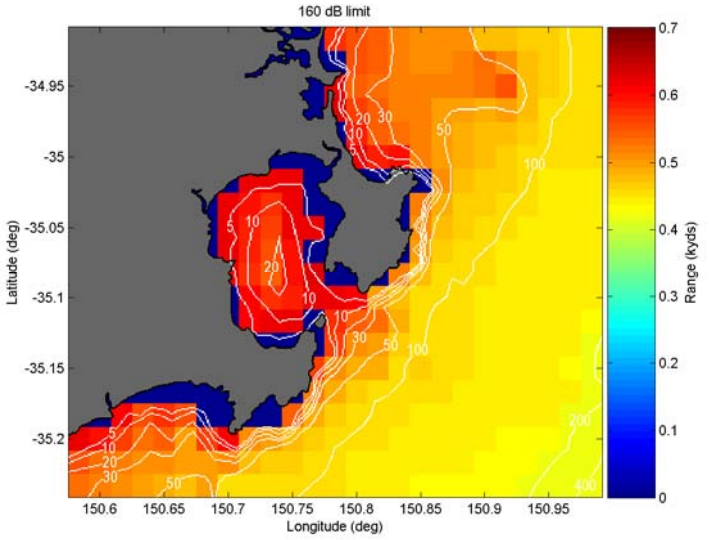

Figure 24: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the Fansweep 20 Multibeam Echo Sounder

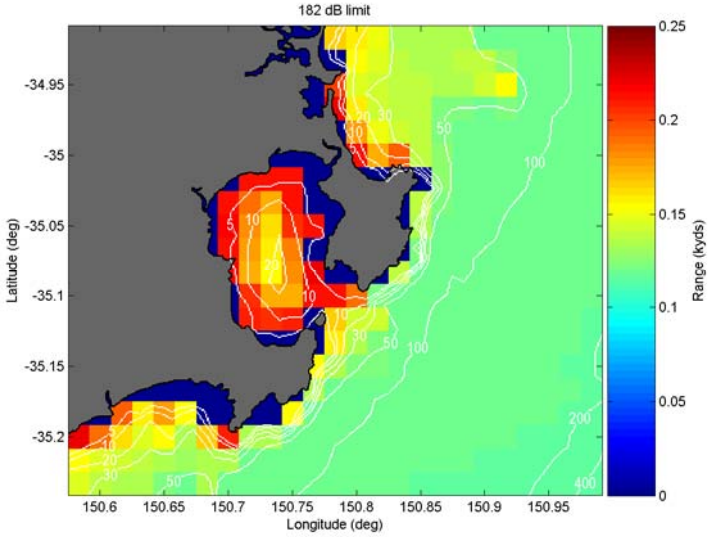

Figure 25: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the Fansweep 20 Multibeam Echo Sounder

7.2 Klein 2000 Towed Light Weight Side Scan Sonar

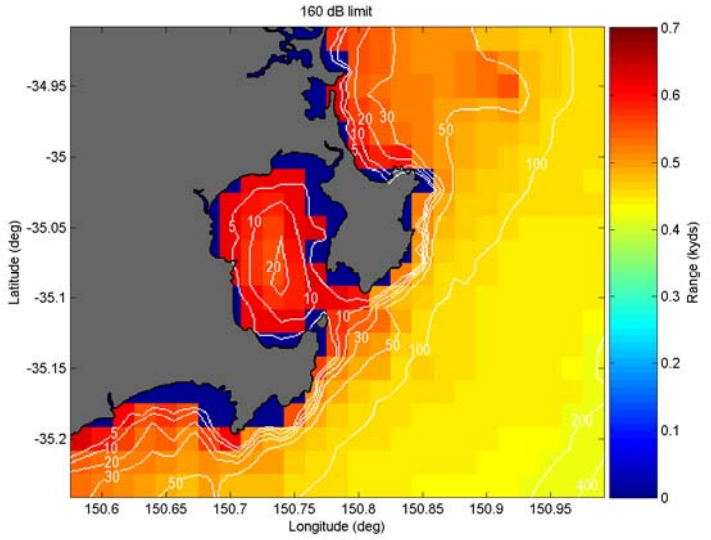

Figure 26: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the Klein 2000 Towed Light Weight Side Scan Sonar

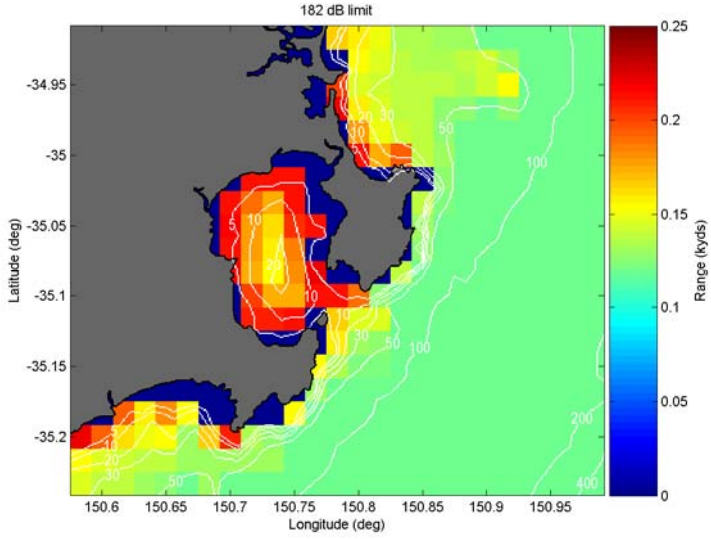

Figure 27: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the Klein 2000 Towed Light Weight Side Scan Sonar

7.3 Atlas DESO 25 Single Beam Echo Sounder

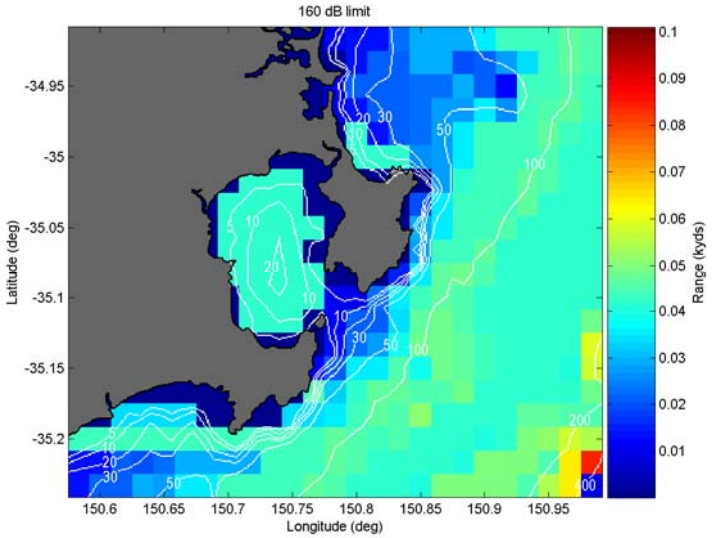

Figure 28: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz

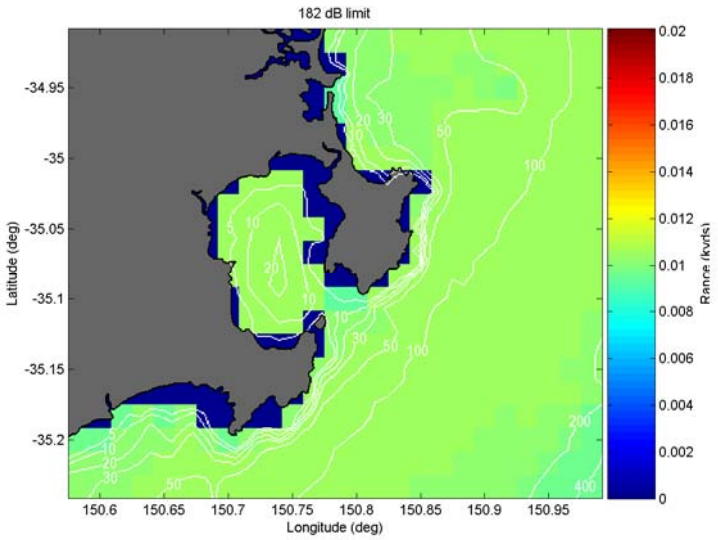

Figure 29: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz

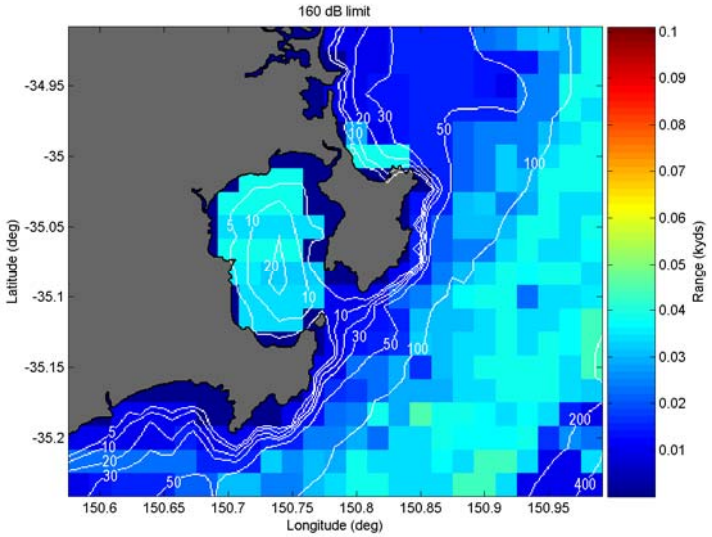

Figure 30: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz

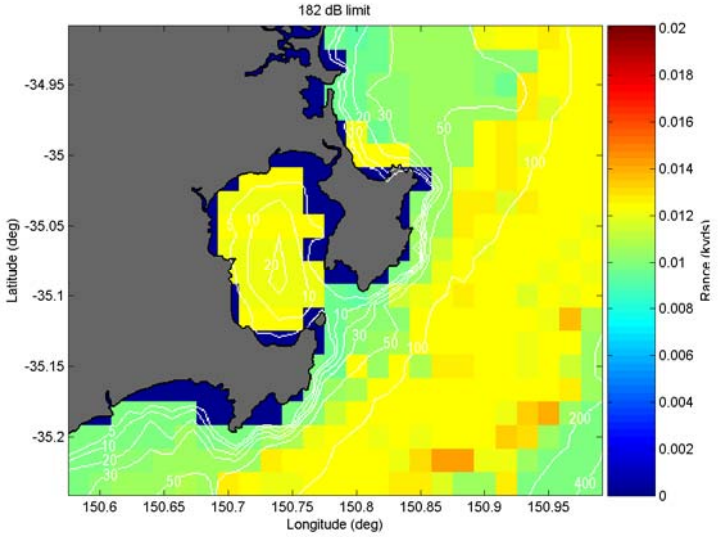

Figure 31: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz

7.4 CMAS Forward Looking Sonar

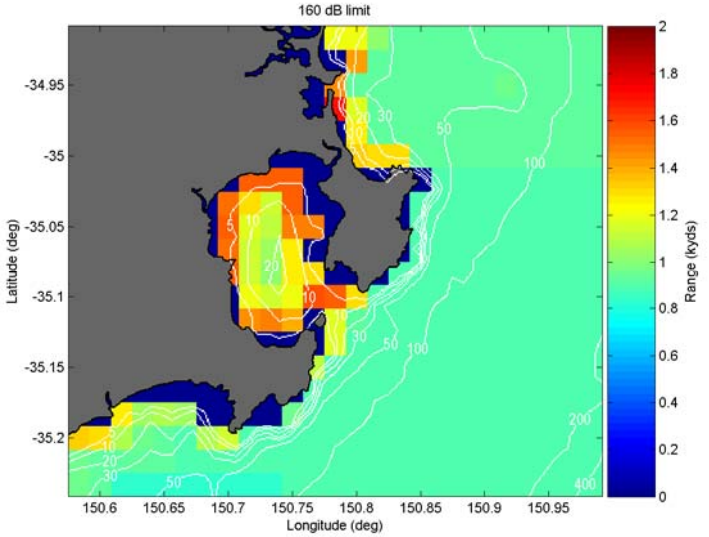

Figure 32: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the CMAS Forward Looking Sonar using 36 kHz

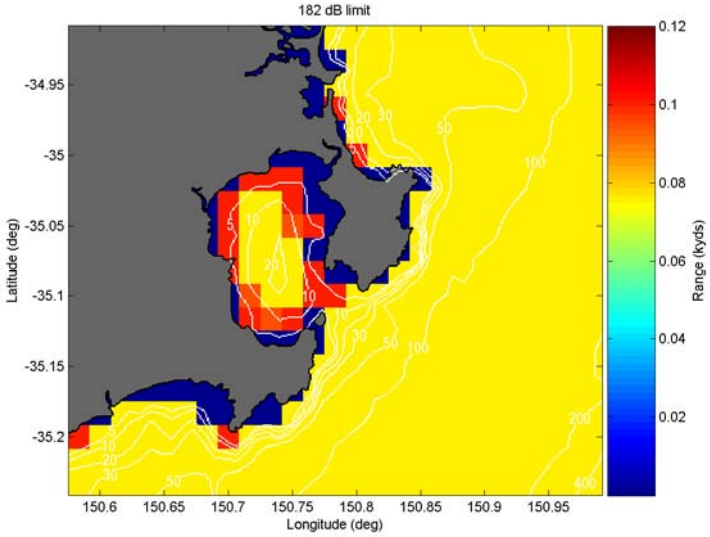

Figure 33: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the CMAS Forward Looking Sonar using 36 kHz

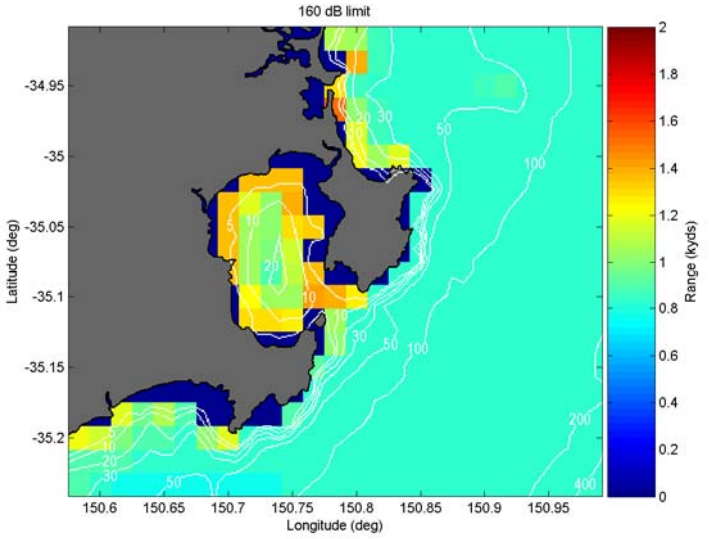

Figure 34: Maximum mitigation ranges calculated for a received acoustic pressure level of 160 dB on the CMAS Forward Looking Sonar using 39 kHz

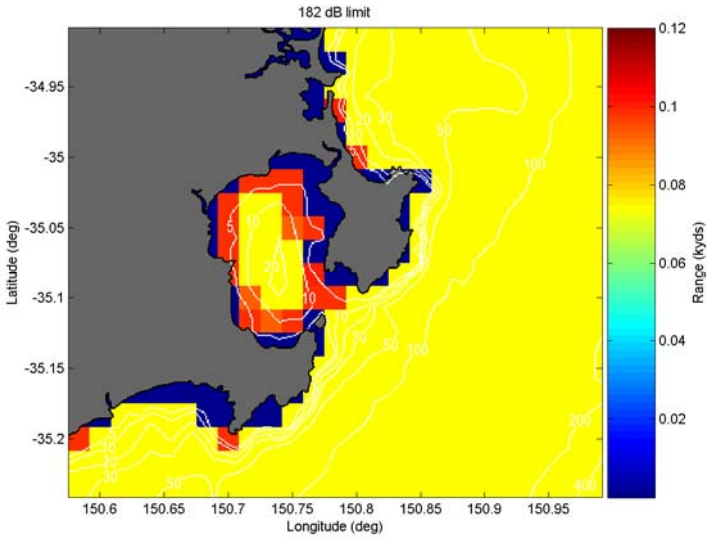

Figure 35: Maximum mitigation ranges calculated for a received acoustic pressure level of 182 dB on the CMAS Forward Looking Sonar using 39 kHz

8. Conclusion

Modelling of the received sonar signal levels for the Leeuwin class hydrographic sonars was done for a number of different environmental conditions in and around Jervis Bay. The maximum expected mitigation ranges have been determined using different environmental variations including four wind speeds, four different months during the year, and various water depths around the bay.

The modelling results show reasonable seasonal dependence on mitigation ranges resulting from seasonal changes in the sound speed profiles. However sound speed profiles vary significantly over each day and month, so it is not recommended that these monthly averages be used to reduce the mitigation range for one season compared to the other. Ocean water depth also had a significant effect on mitigation range, but due to the large variations in beam patterns of the Leeuwin class hydrographic sonars no consistent trend were seen. The only consistent trend is a reduction in mitigation range with increasing sea state. This mitigation range reduction is only significant for the sonars that have a long mitigation range at sea state 0 and when the sea state is above 2.

The modelling results show a very large difference in the recommended mitigation ranges, depending on which sonar the Leeuwin class hydrographic ship is using. The sonars could be placed into three groups with the following mitigation ranges:

1. 1700 yards for the CMAS Forward Looking Sonar.
2. 700 yards for the Fansweep 20 Multibeam Echo Sounder and Klein 2000 Towed Light Weight Side Scan Sonar.
3. 200 yards for the EDO Model 3060 Doppler Velocity Log and Atlas DESO 25 Single Beam Echo Sounder

9. Acknowledgments

The author wishes to thanks the following people for their efforts in producing this document:

- CMDR Fiona Smith, RAN, and Dr Stuart Anstee, DSTO, in obtaining the required Leeuwin class hydrographic sonar parameters used in this report.
- John Polglaze, Principal Environmental Scientist in URS Australia, when comparing the results to current mitigation procedures and advising Navy if any modifications were required to the current procedures.
- Dr Michelle Lemon, University of Sydney contracted to DSTO, for information about the dolphins resident in Jervis Bay.

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Appendix A: Mitigation Ranges for different Environmental Conditions around Jervis Bay

The hydrographic sonar modelling was done for a number of different environmental conditions. The mitigation ranges found are shown below, figures 36 to 227.

A.1. Mitigation Ranges for the Fansweep 20 Multibeam Echo Sounder at 160 dB Received Pressure Limit over Coarse Sand in Jervis Bay

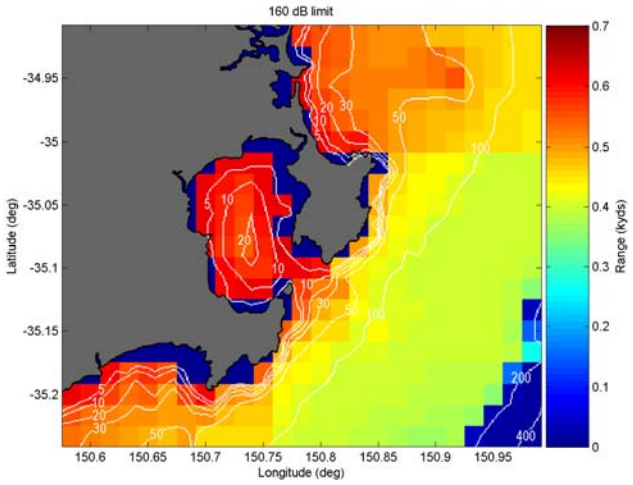

Figure 36: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

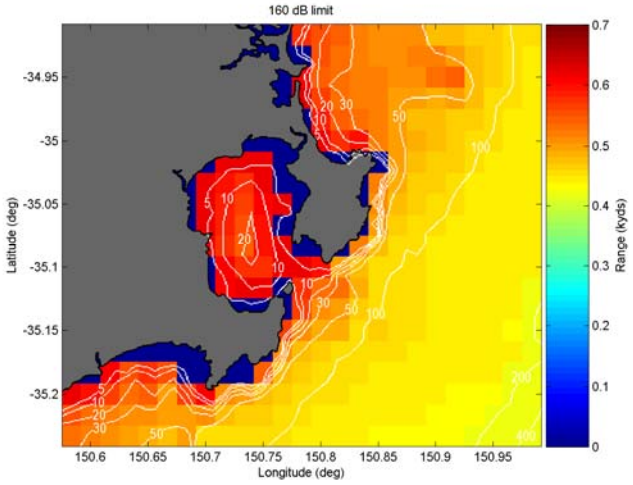

Figure 37: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

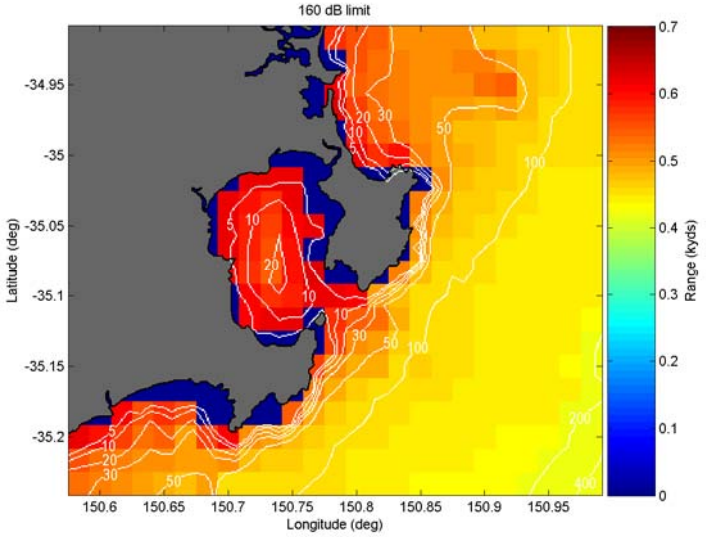

Figure 38: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

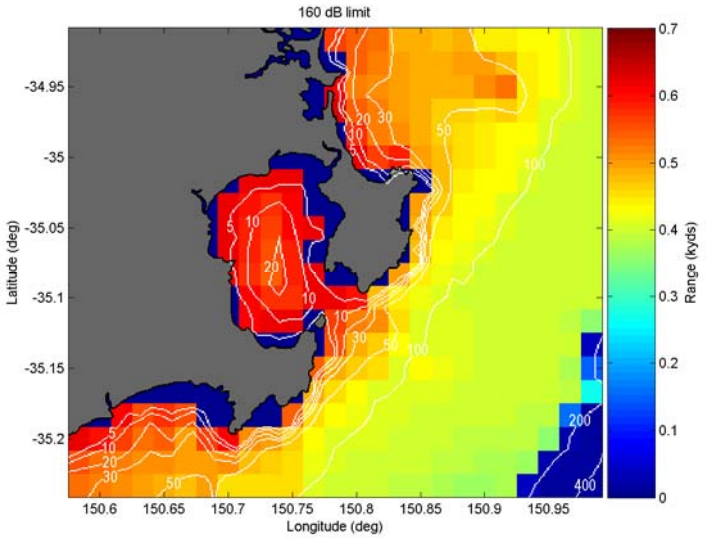

Figure 39: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

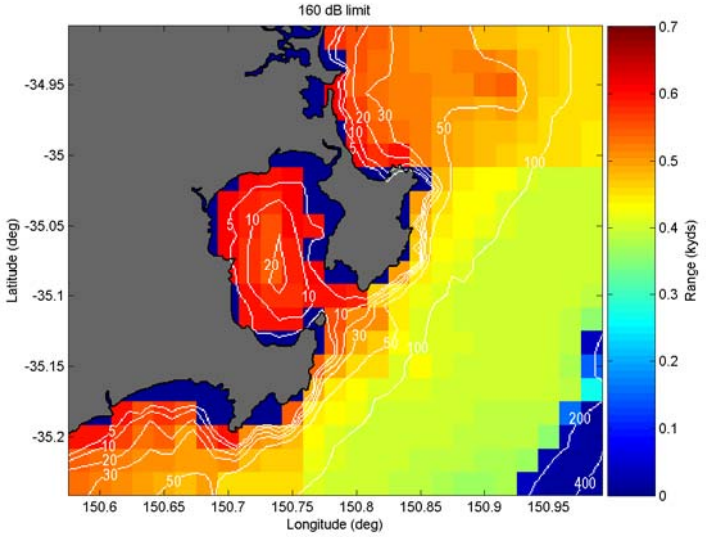

Figure 40: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

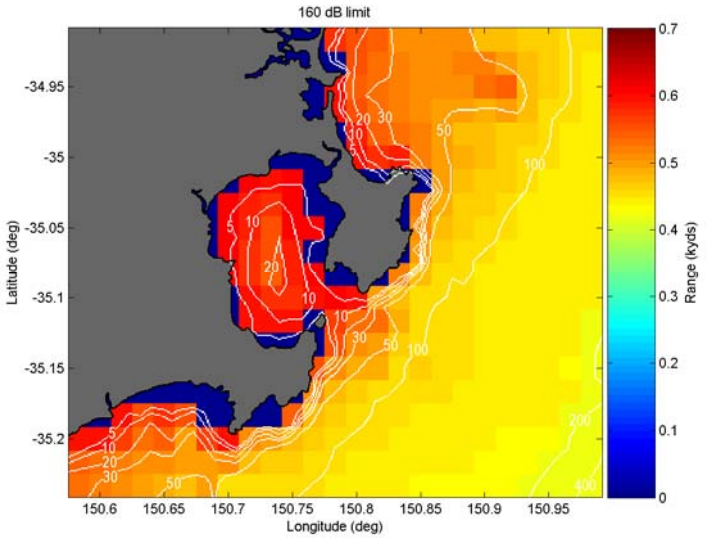

Figure 41: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

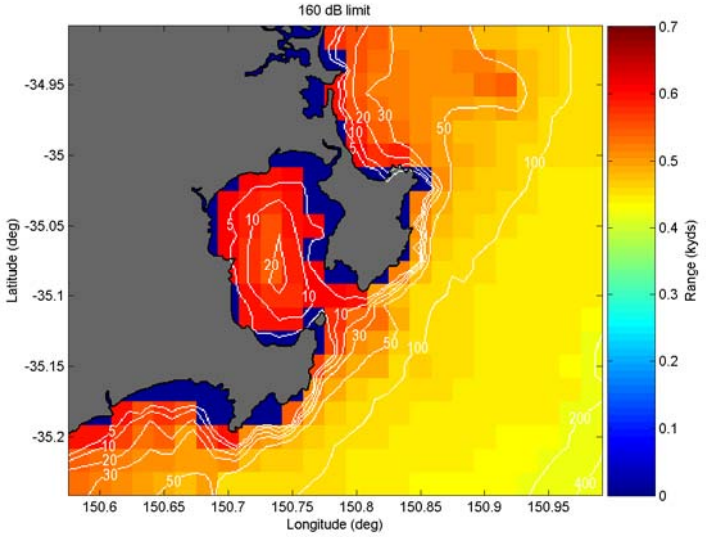

Figure 42: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

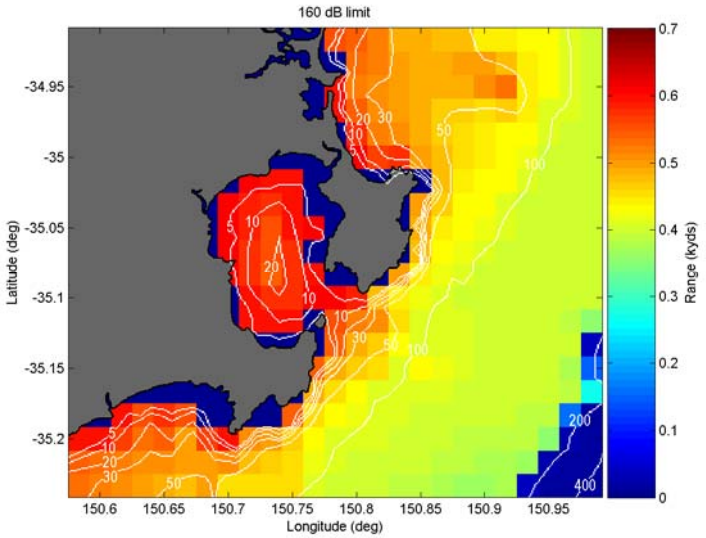

Figure 43: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

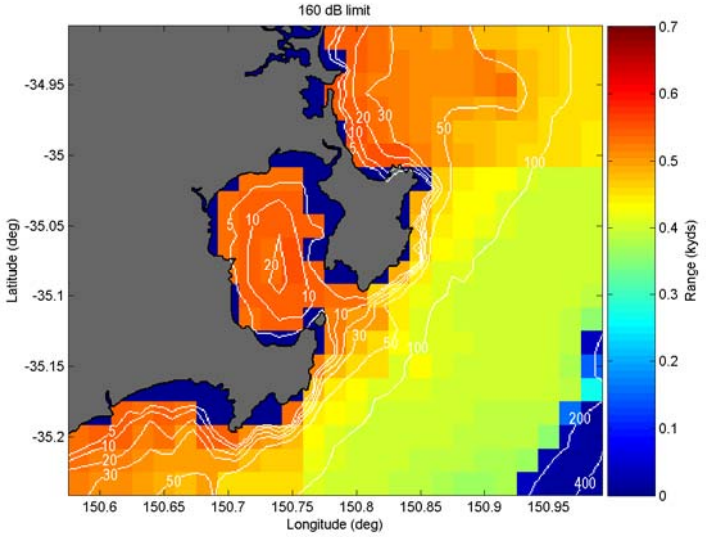

Figure 44: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

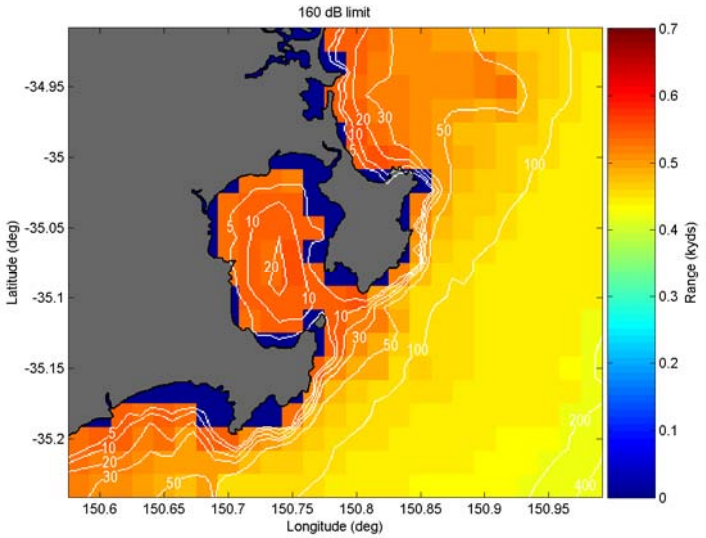

Figure 45: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

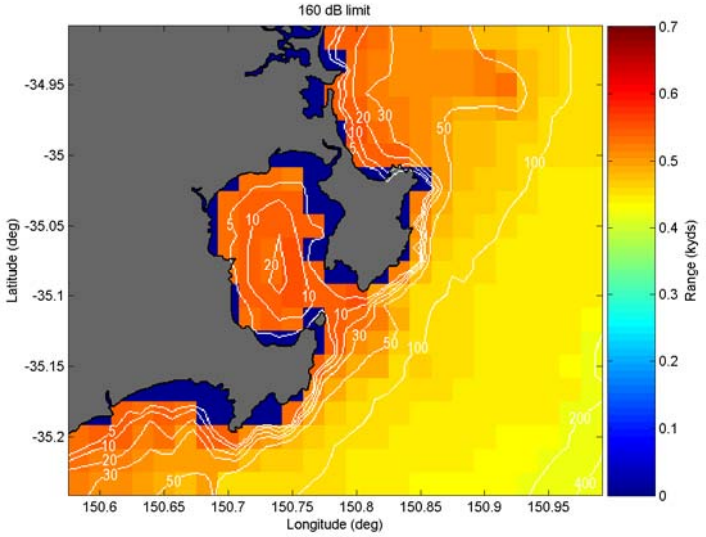

Figure 46: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

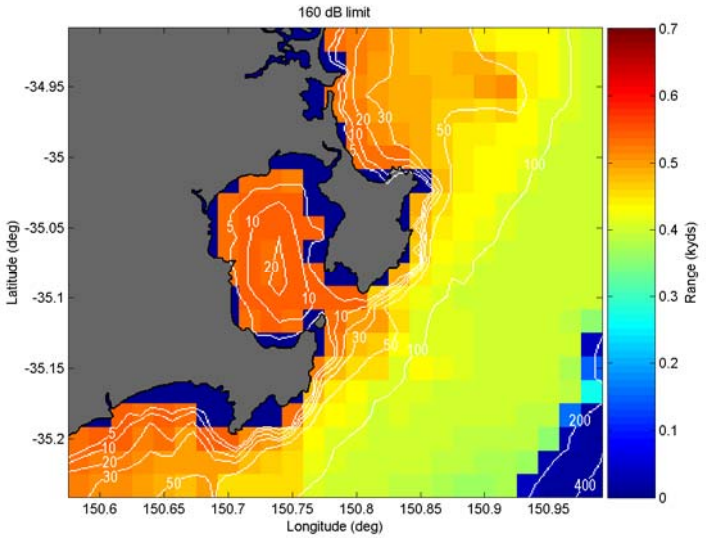

Figure 47: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

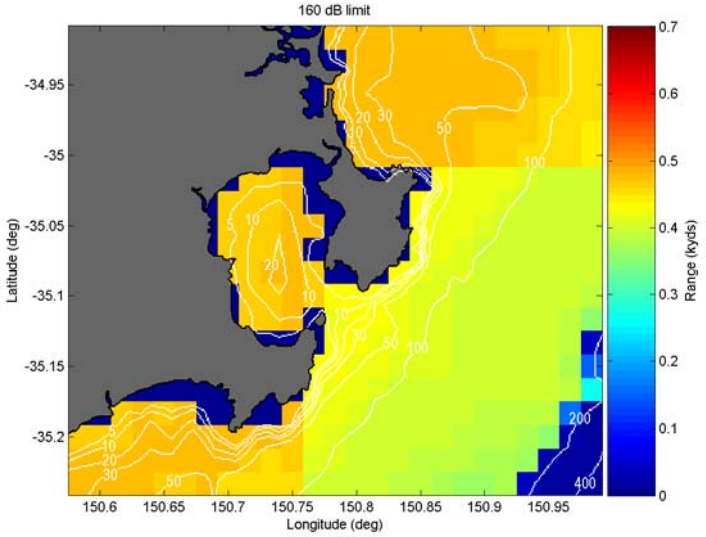

Figure 48: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

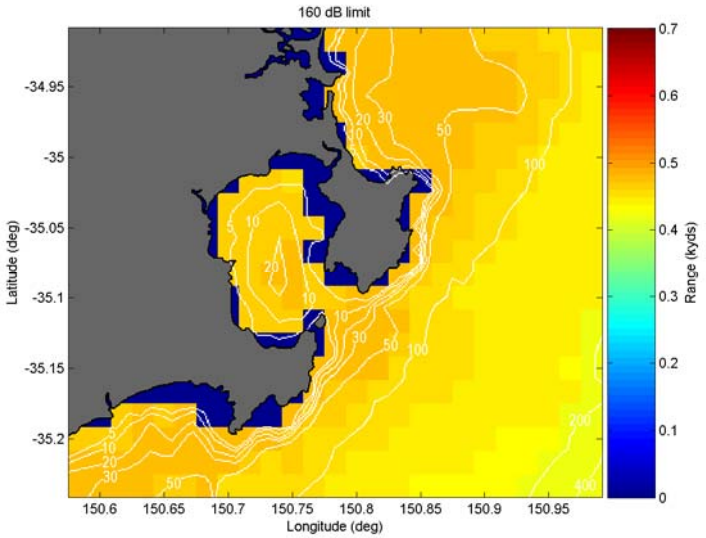

Figure 49: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

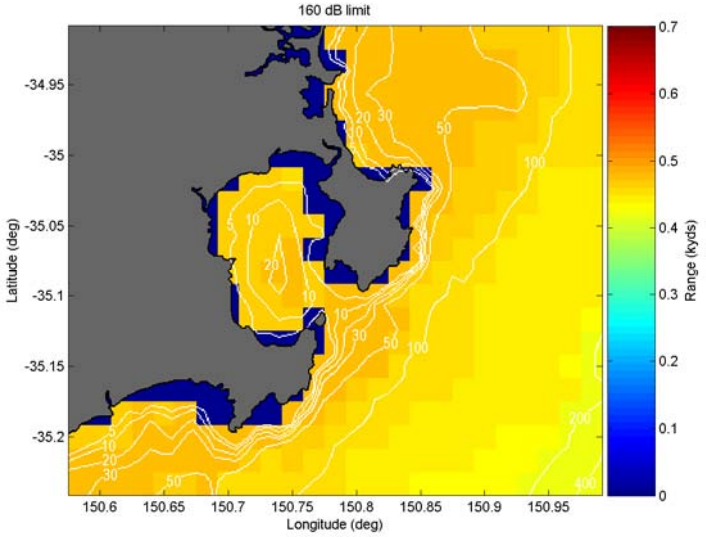

Figure 50: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

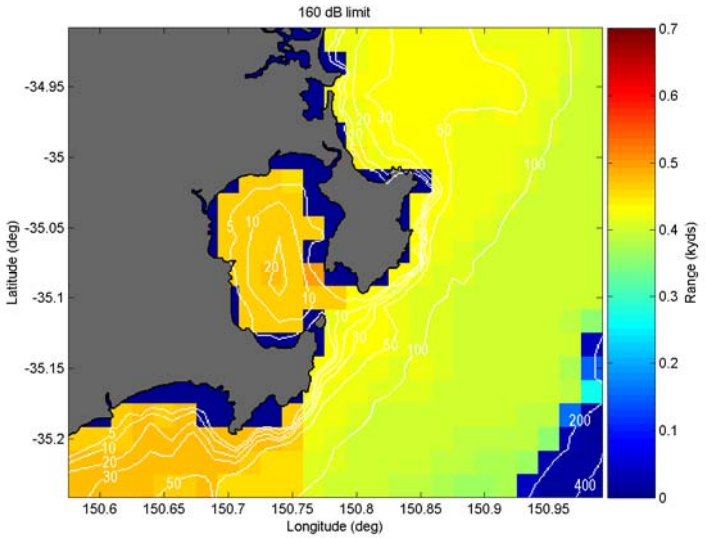

Figure 51: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

A.2. Mitigation Ranges for the Klein 2000 Towed Light Weight Side Scan Sonar at 160 dB Received Pressure Limit over Coarse Sand in Jervis Bay

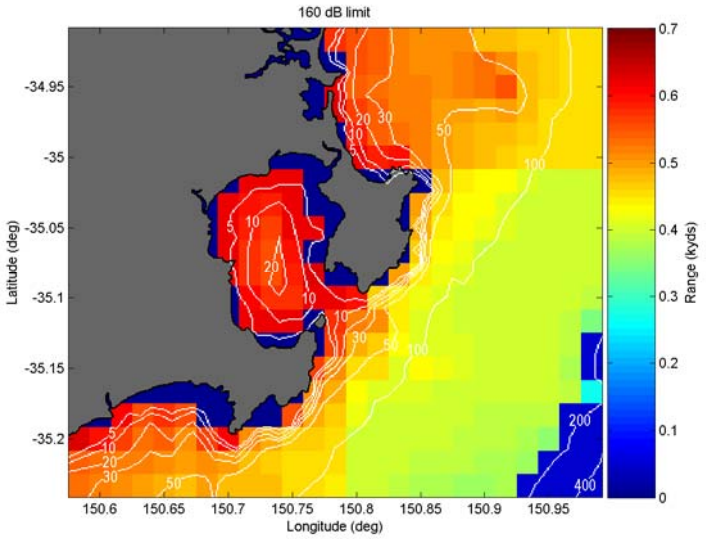

Figure 52: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

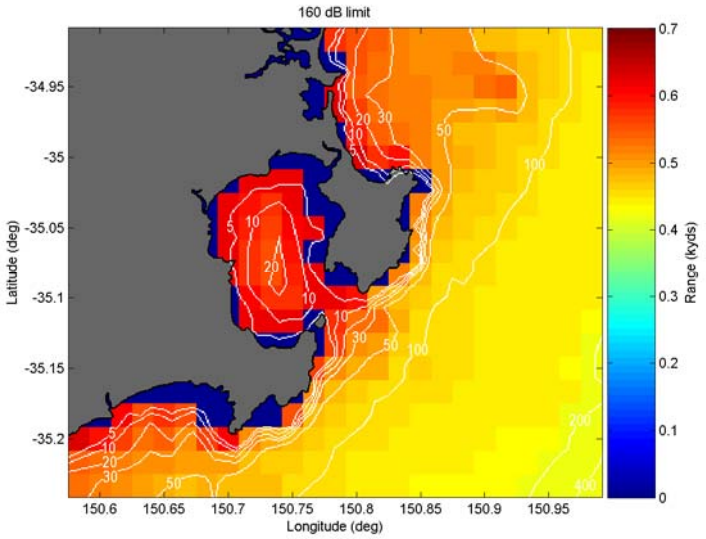

Figure 53: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

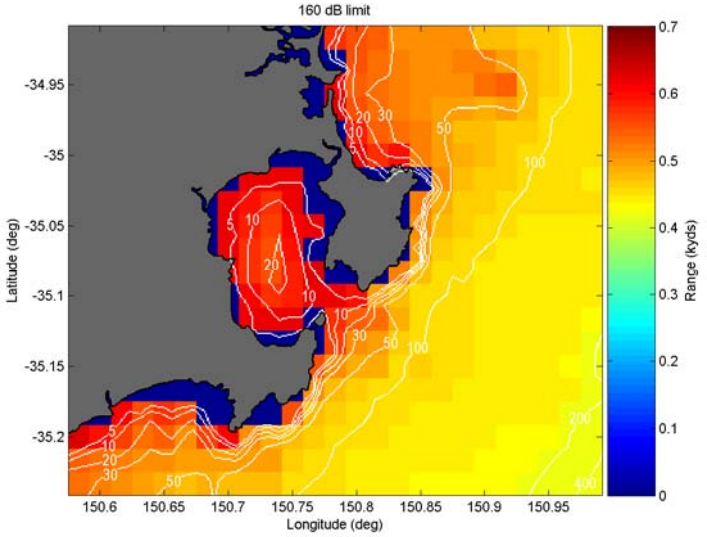

Figure 54: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

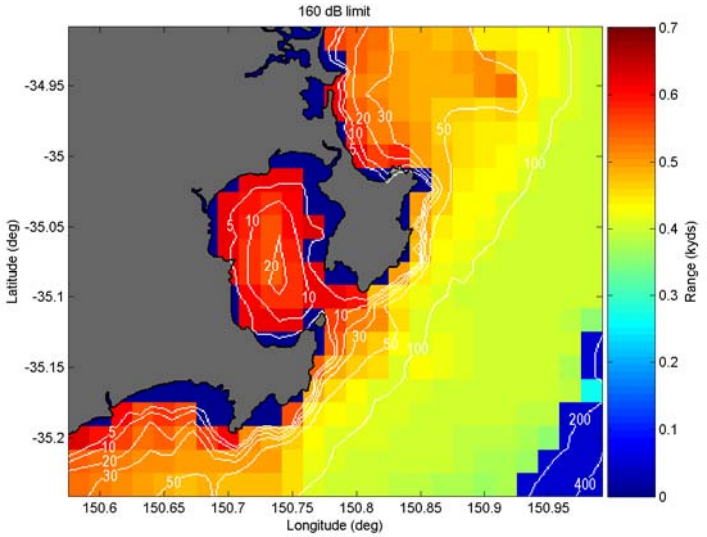

Figure 55: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

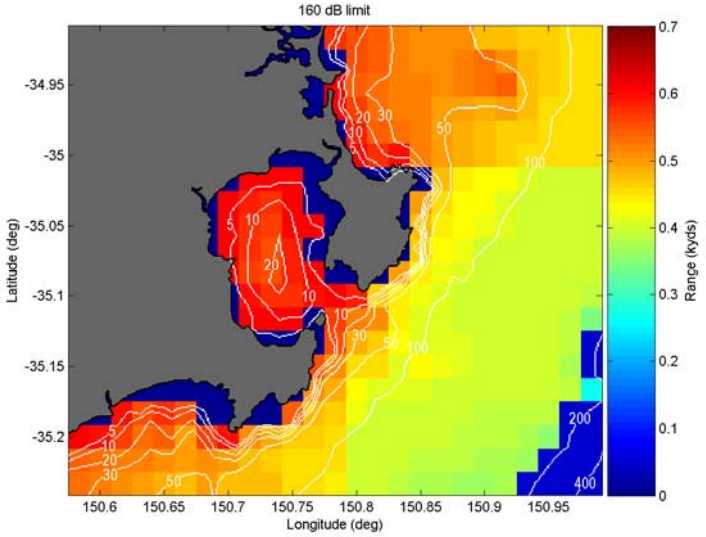

Figure 56: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

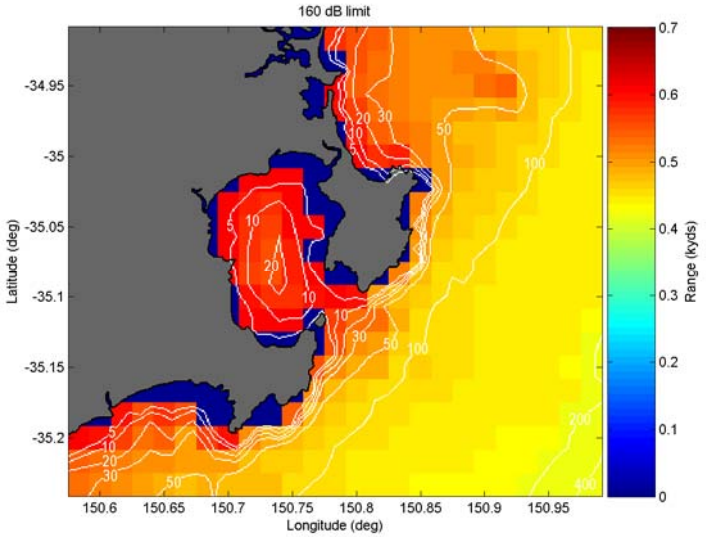

Figure 57: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

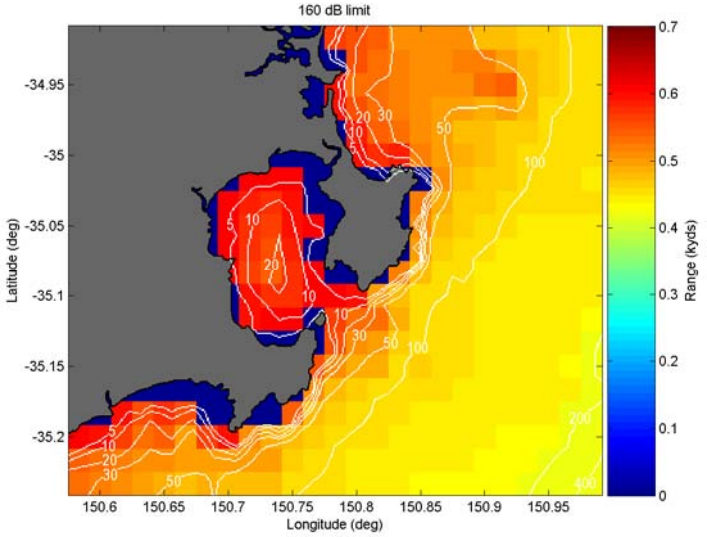

Figure 58: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

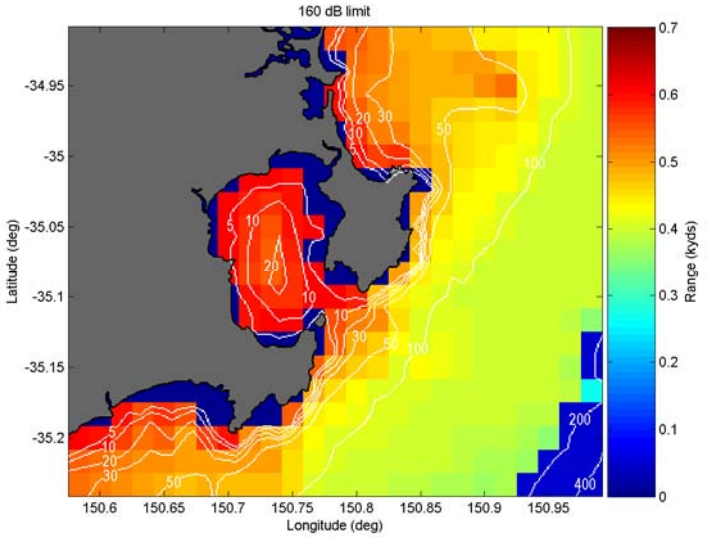

Figure 59: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

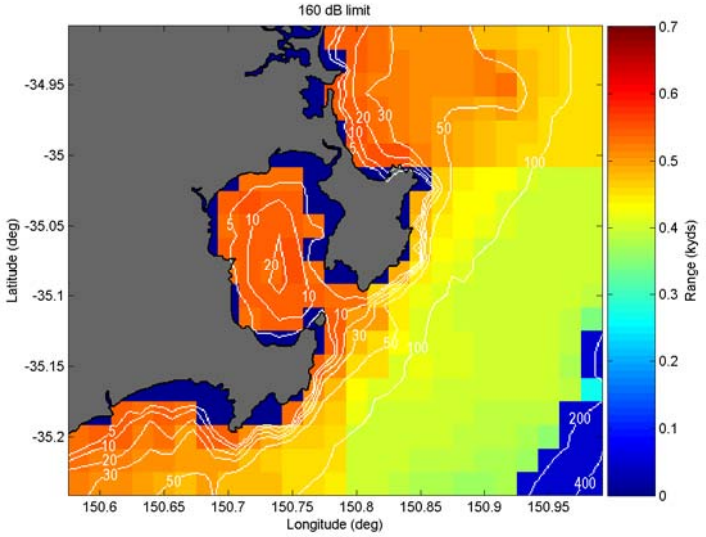

Figure 60: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

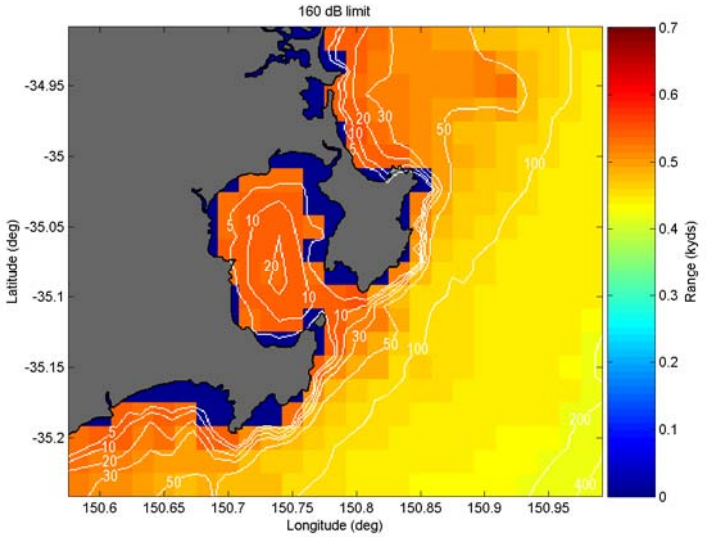

Figure 61: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

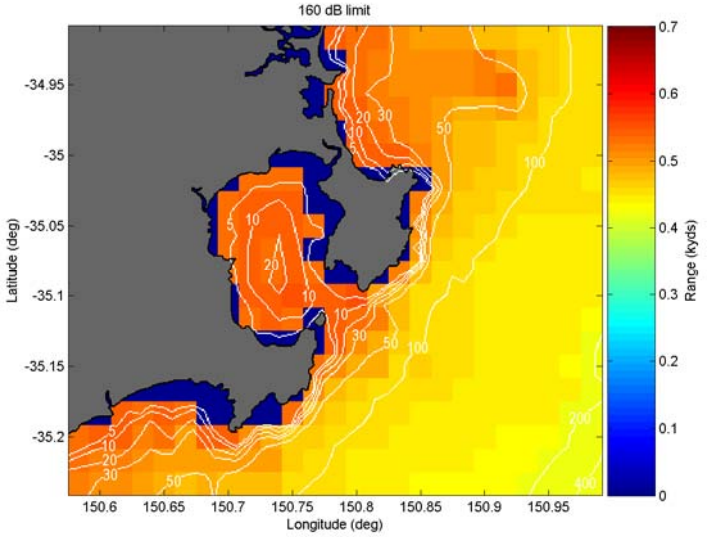

Figure 62: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

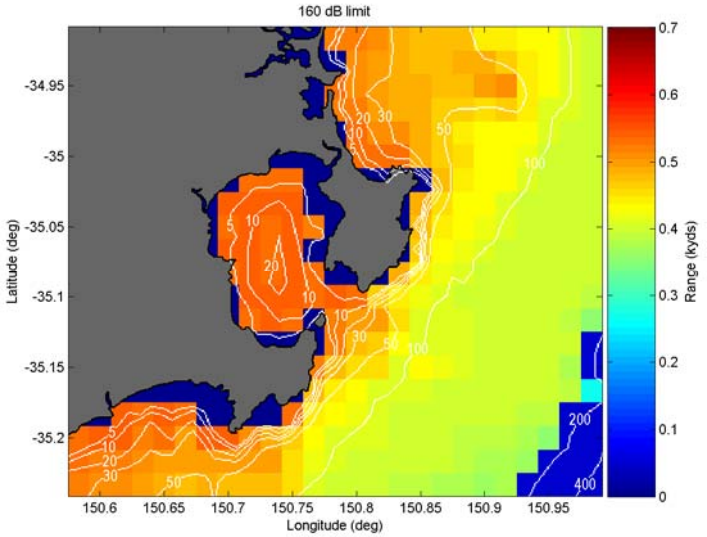

Figure 63: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

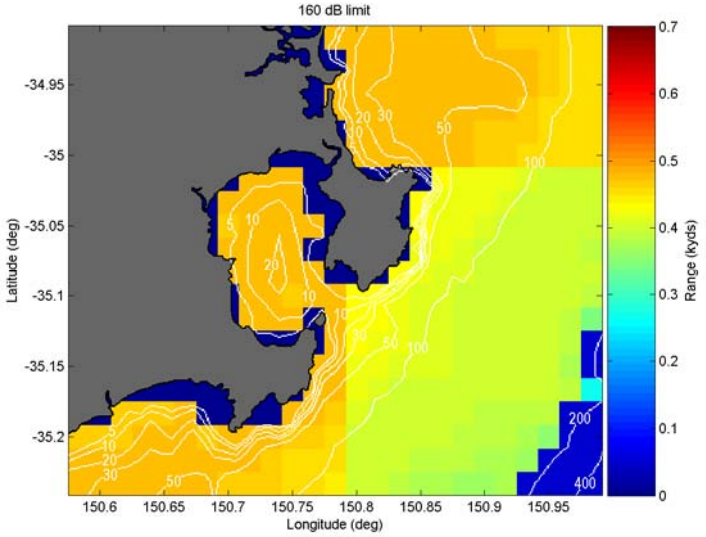

Figure 64: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

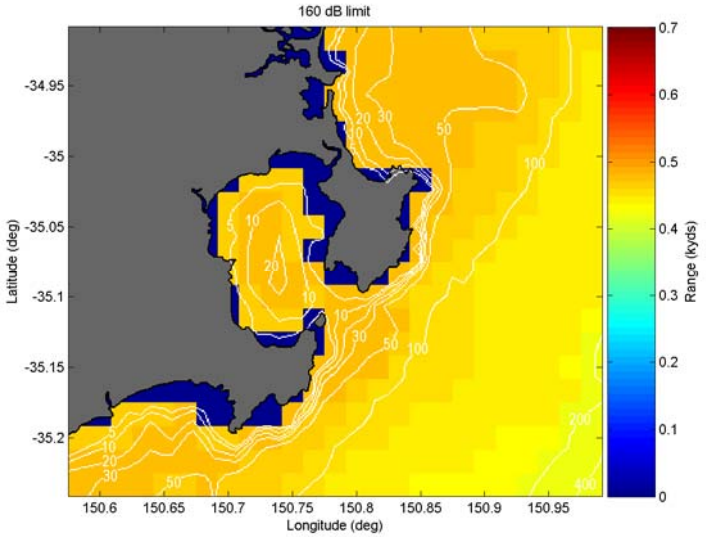

Figure 65: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

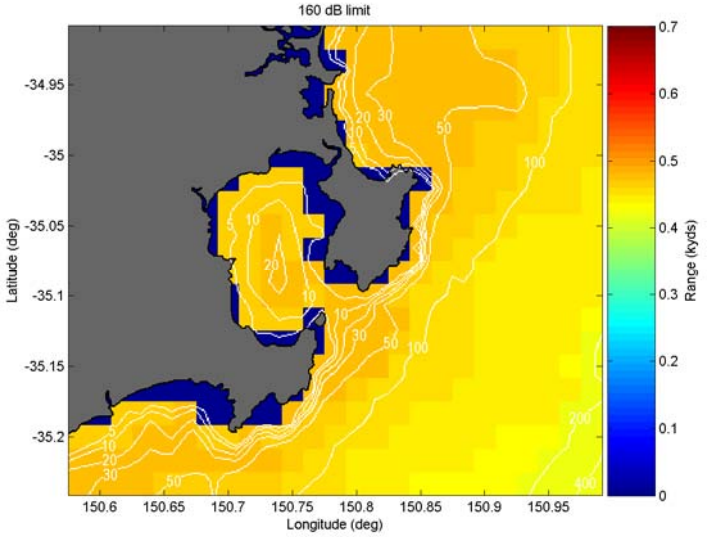

Figure 66: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

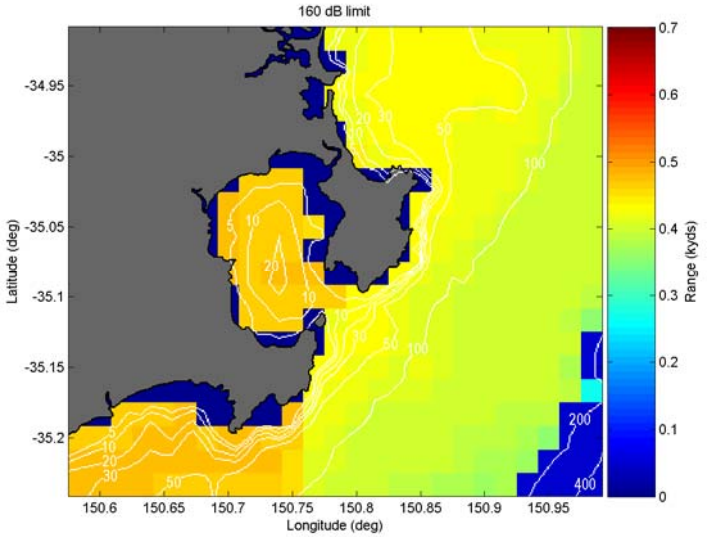

Figure 67: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

A.3. Mitigation Ranges for the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz at 160 dB Received Pressure Limit over Coarse Sand in Jervis Bay

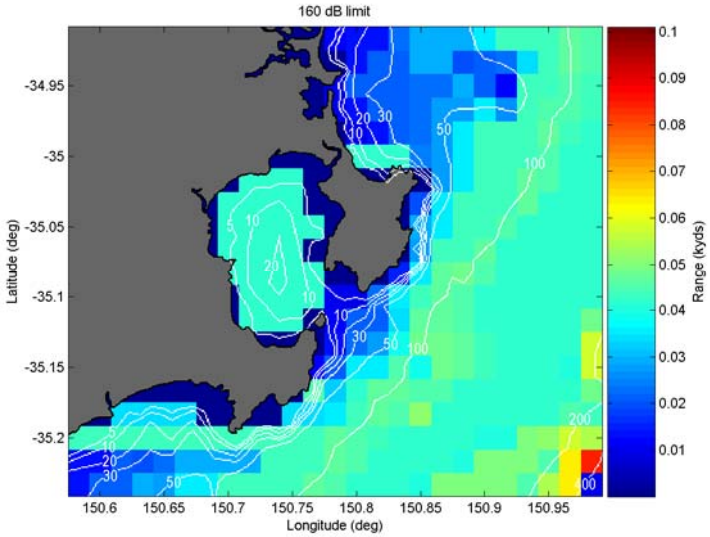

Figure 68: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

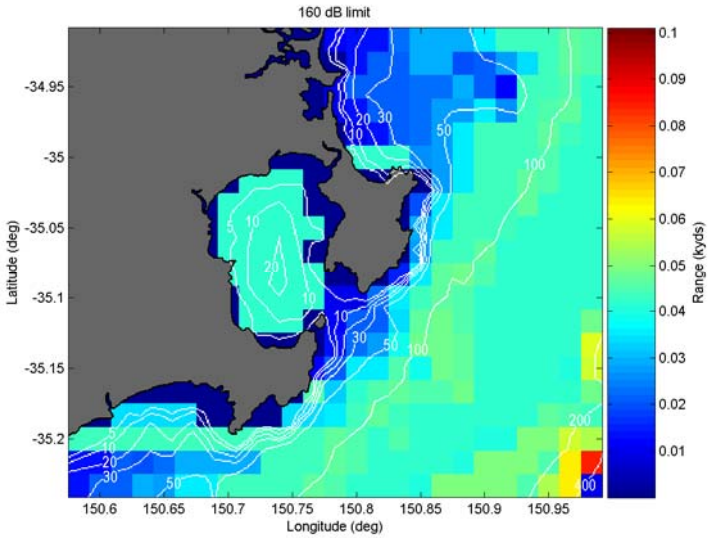

Figure 69: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

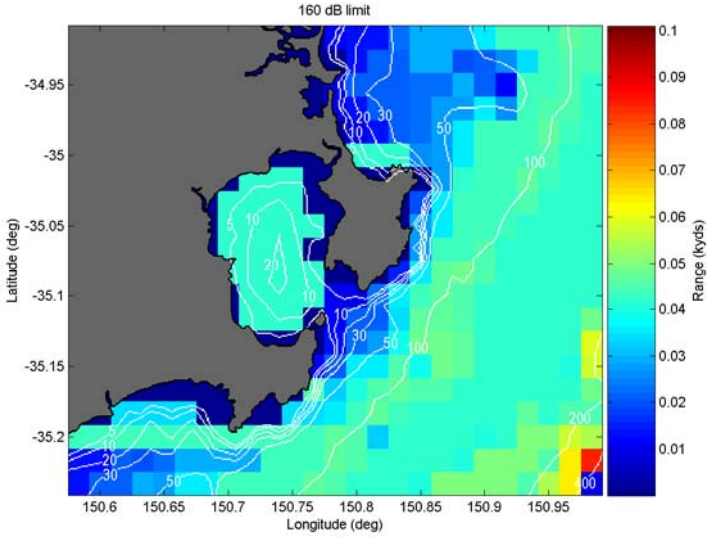

Figure 70: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

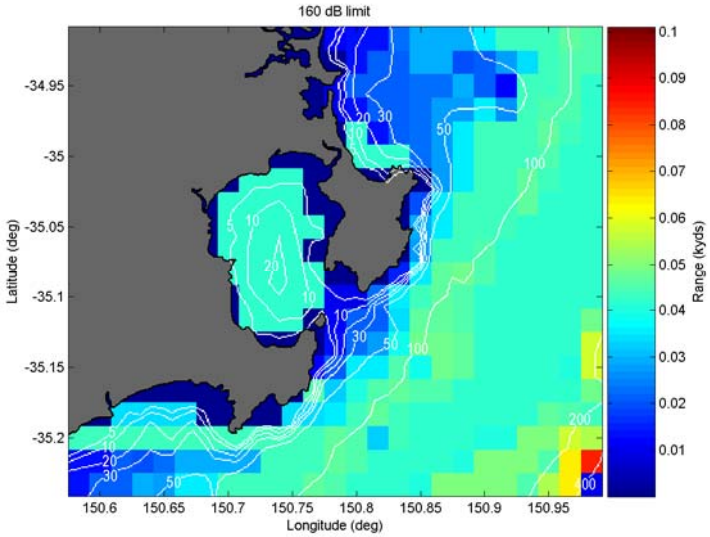

Figure 71: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

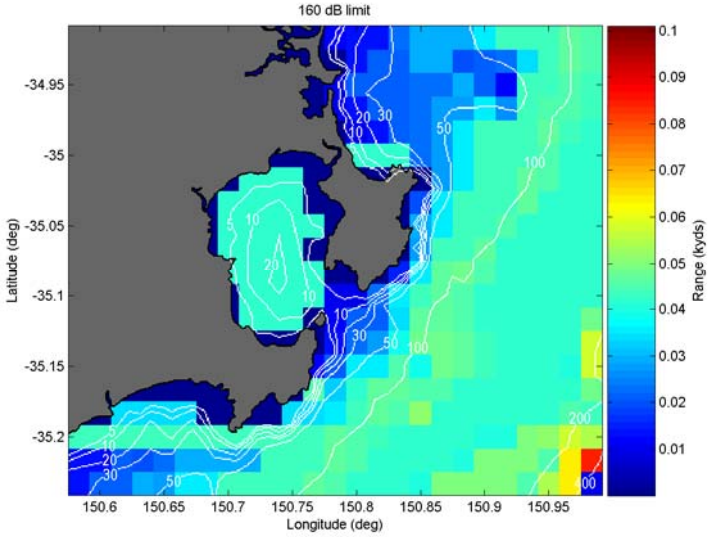

Figure 72: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

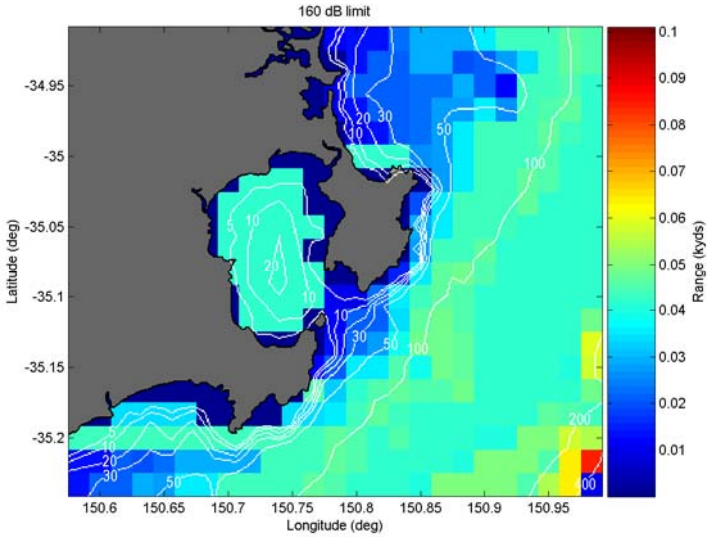

Figure 73: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

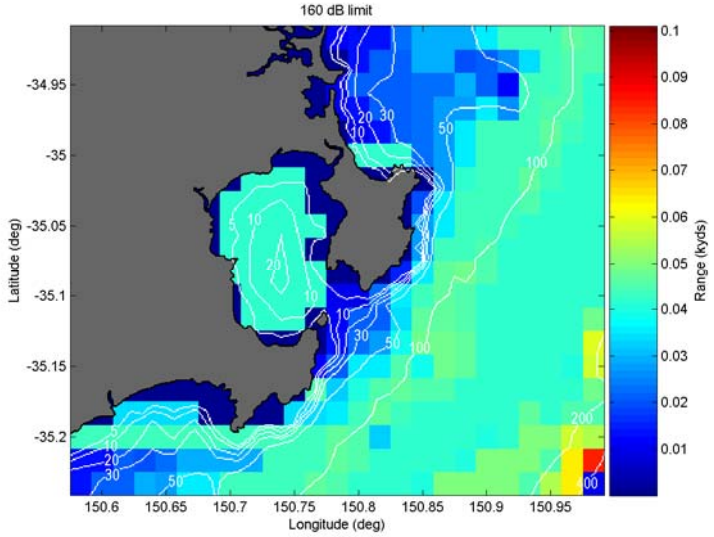

Figure 74: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

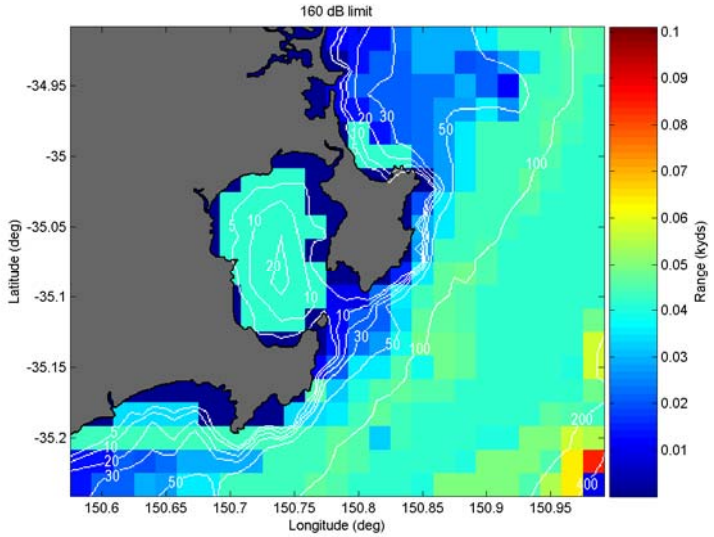

Figure 75: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

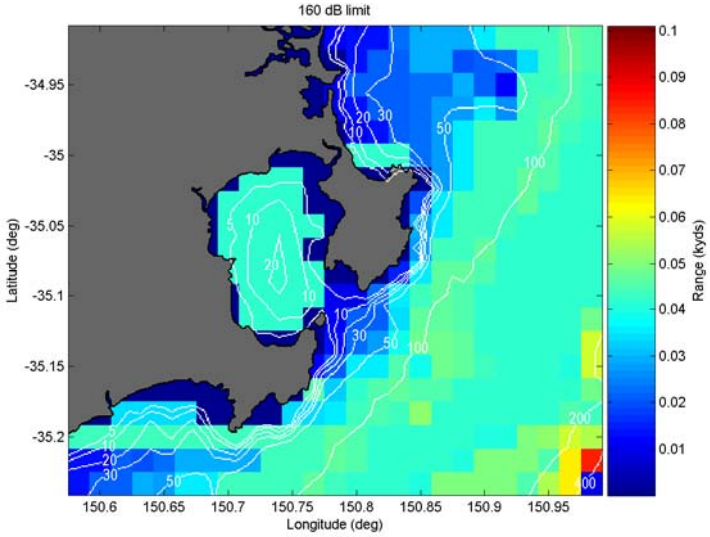

Figure 76: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

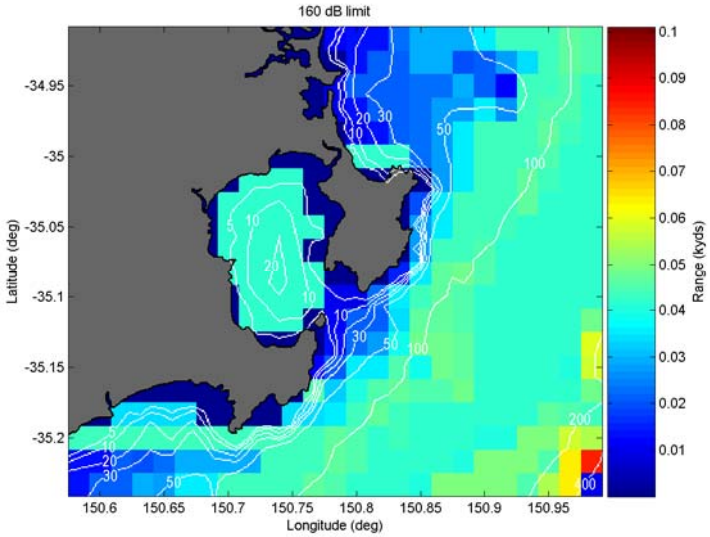

Figure 77: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

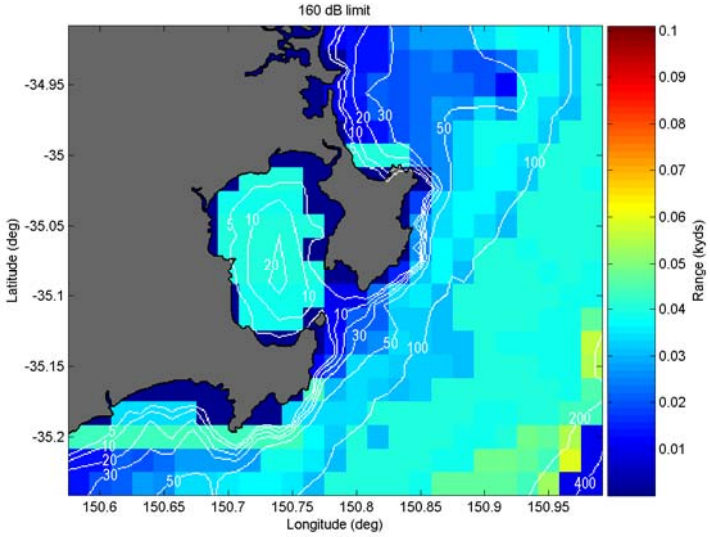

Figure 78: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

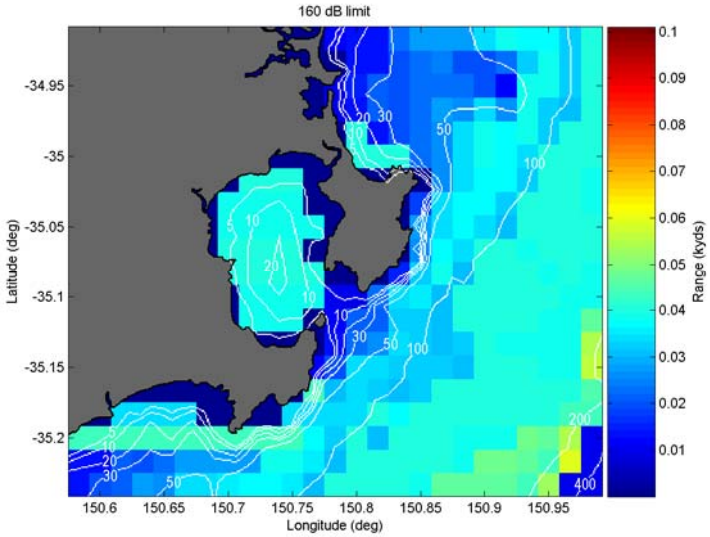

Figure 79: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

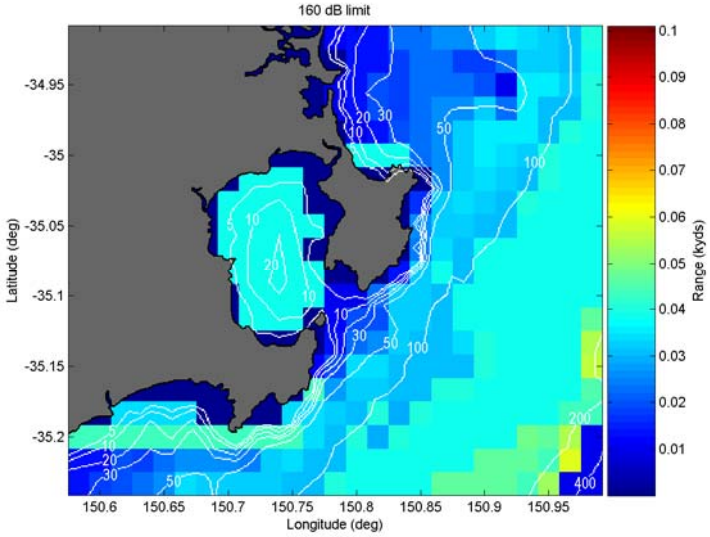

Figure 80: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

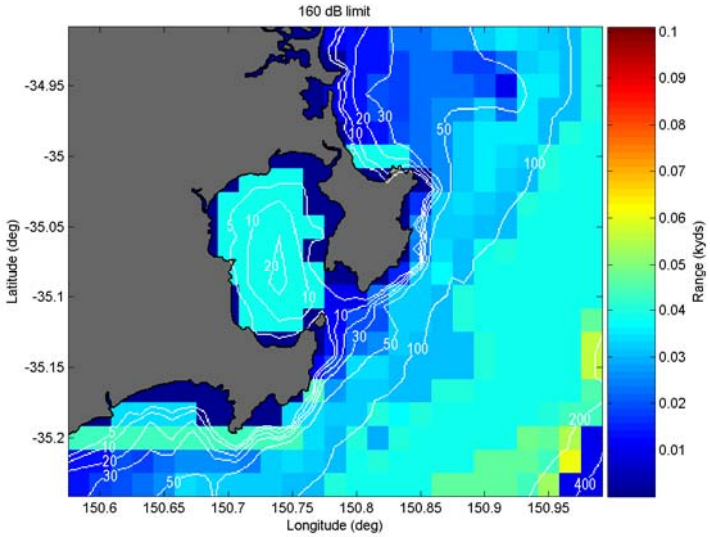

Figure 81: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

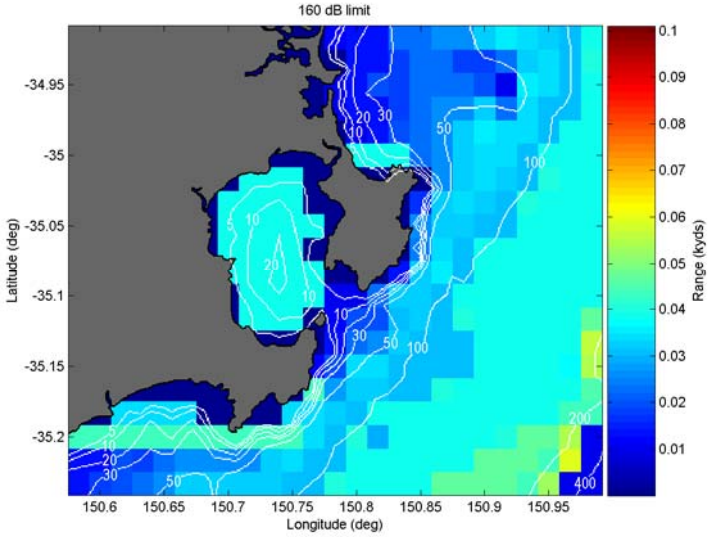

Figure 82: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

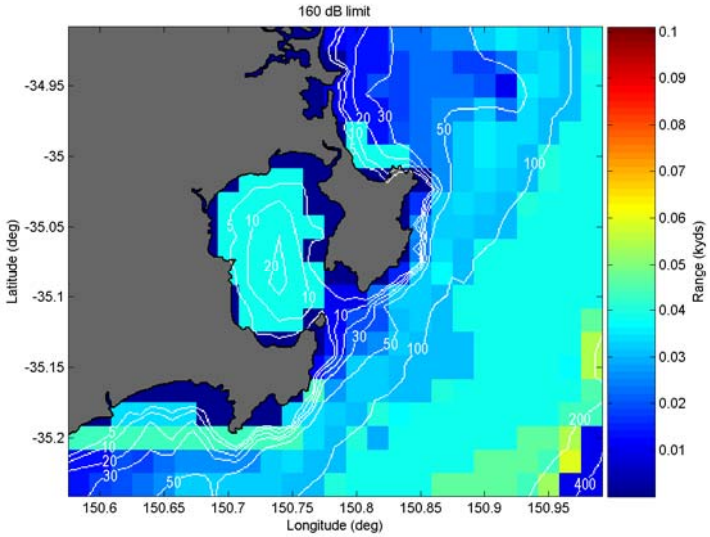

Figure 83: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

A.4. Mitigation Ranges for the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz at 160 dB Received Pressure Limit over Coarse Sand in Jervis Bay

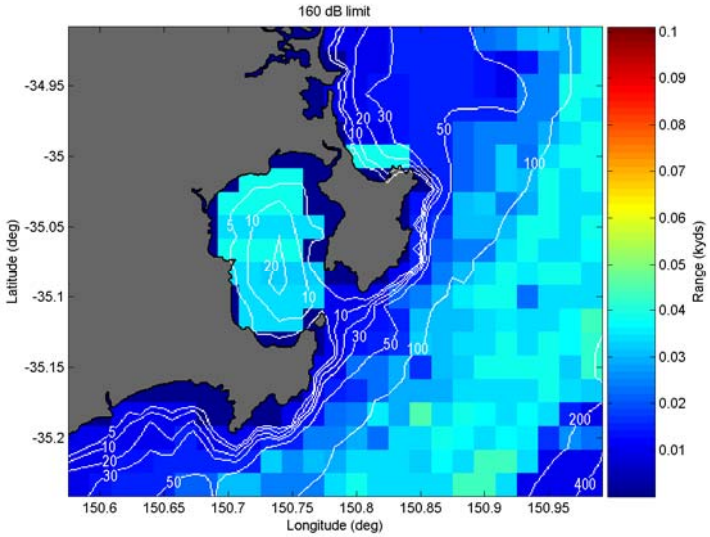

Figure 84: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

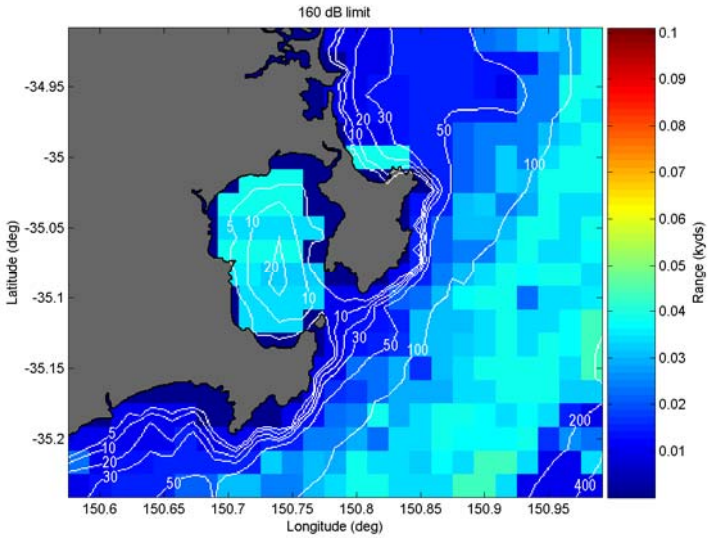

Figure 85: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

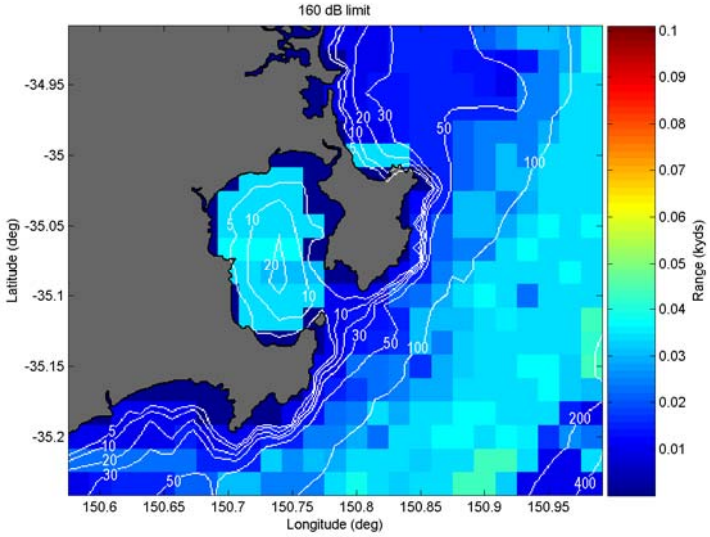

Figure 86: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

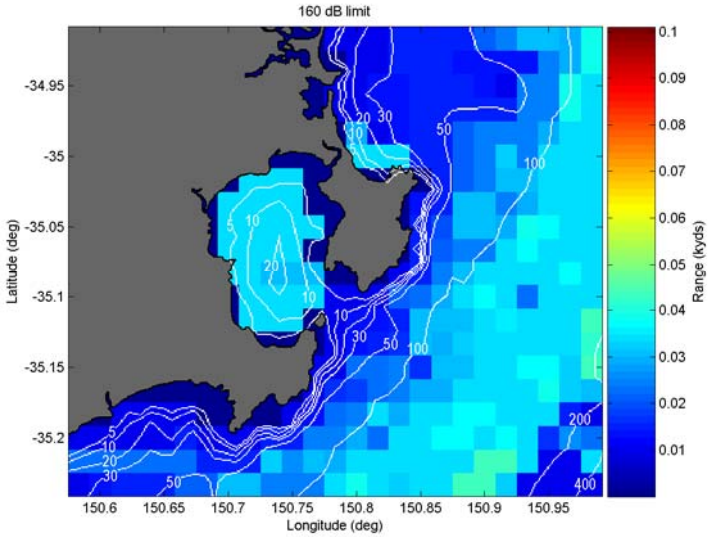

Figure 87: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

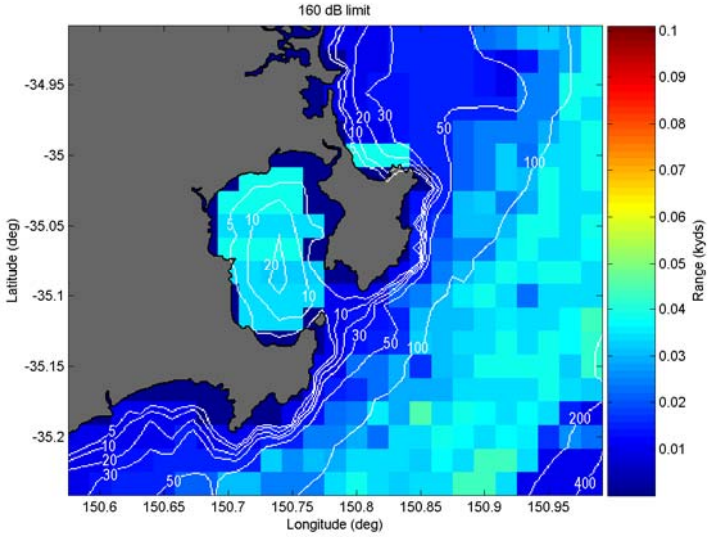

Figure 88: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

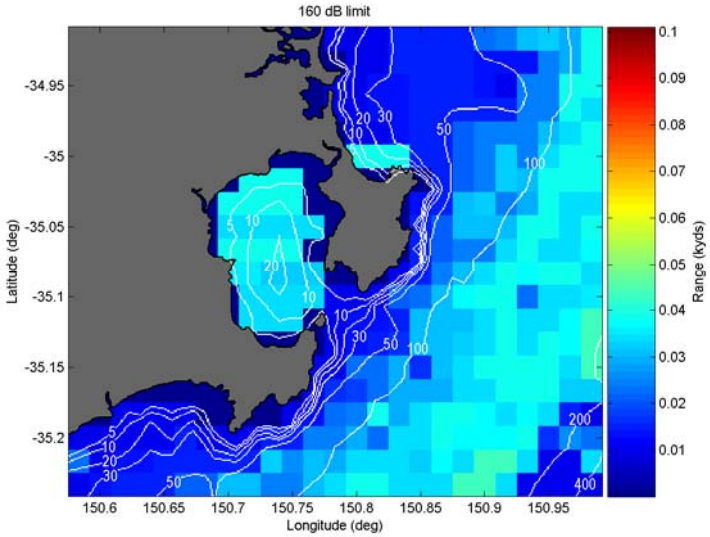

Figure 89: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

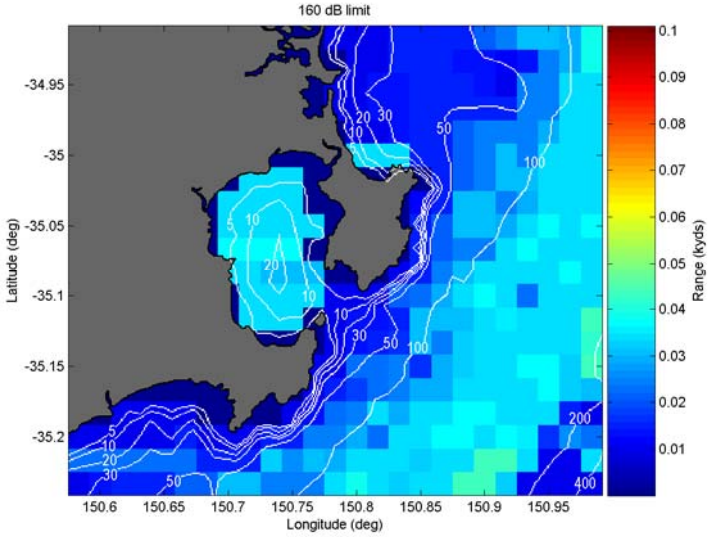

Figure 90: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

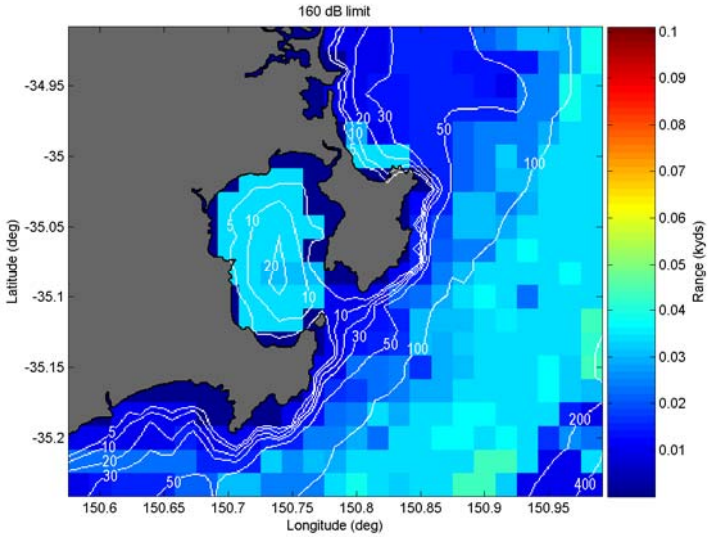

Figure 91: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

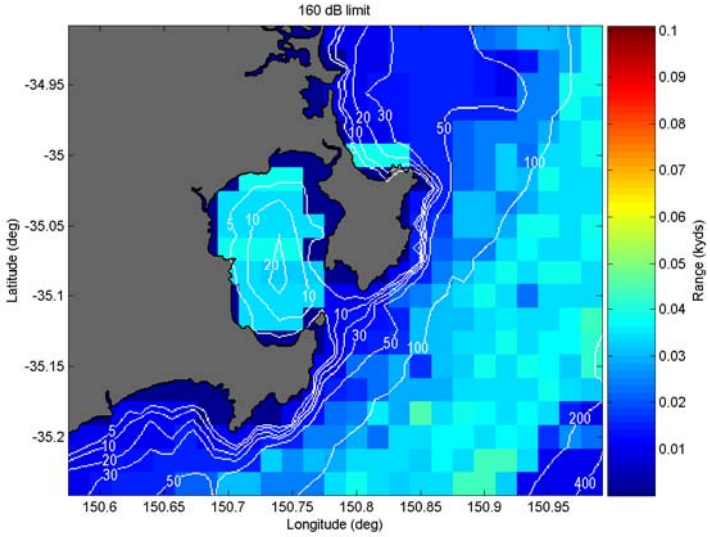

Figure 92: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

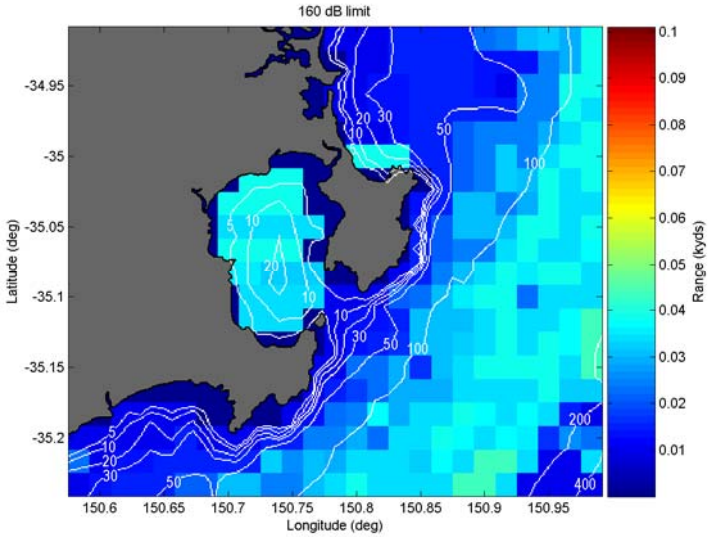

Figure 93: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

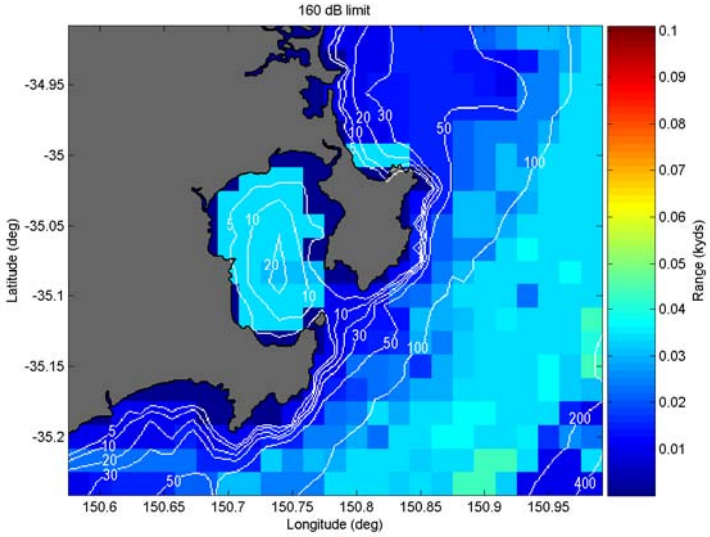

Figure 94: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

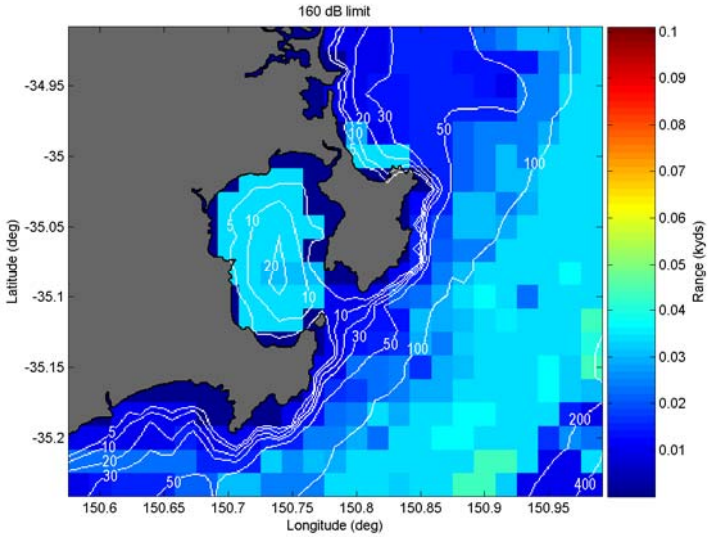

Figure 95: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

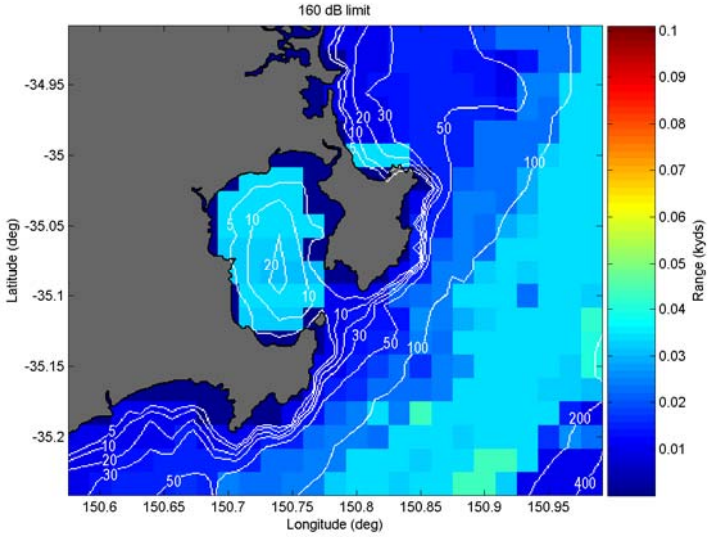

Figure 96: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

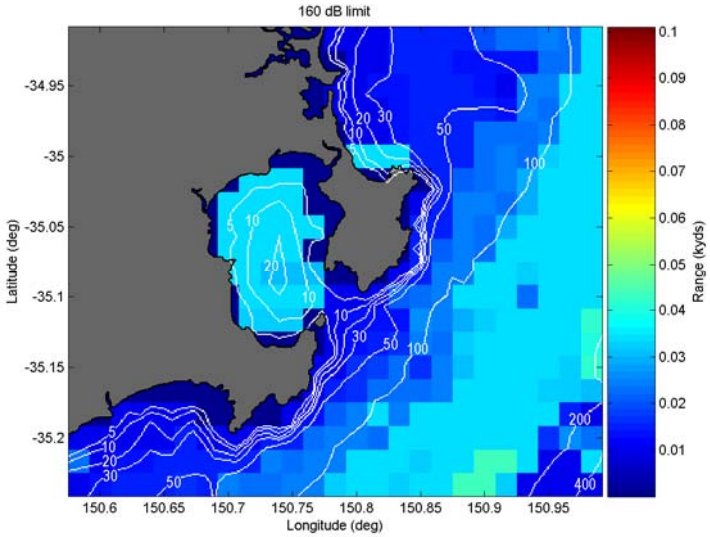

Figure 97: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

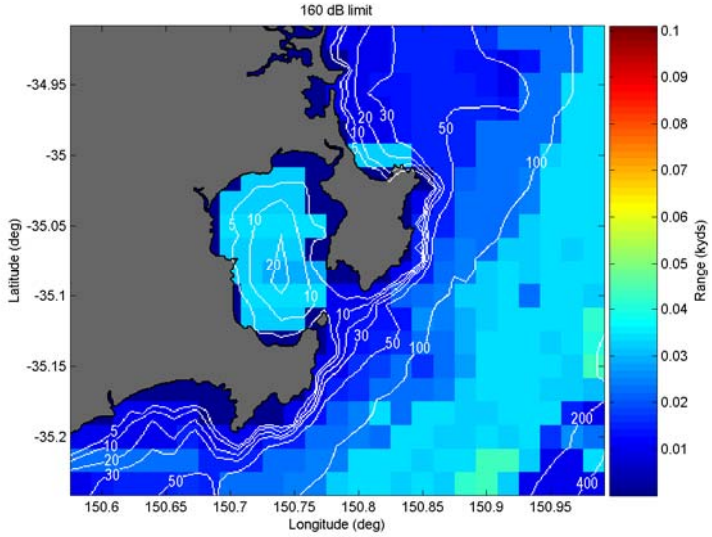

Figure 98: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

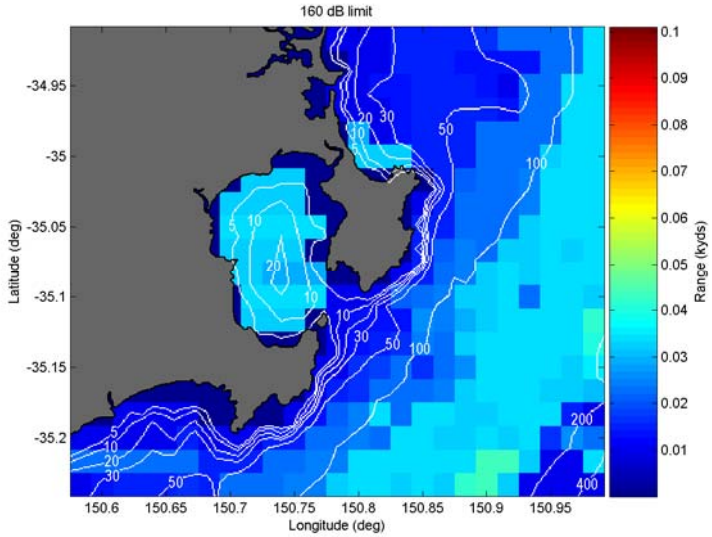

Figure 99: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

A.5. Mitigation Ranges for the CMAS Forward Looking Sonar using 36 kHz at 160 dB Received Pressure Limit over Coarse sand in Jervis Bay

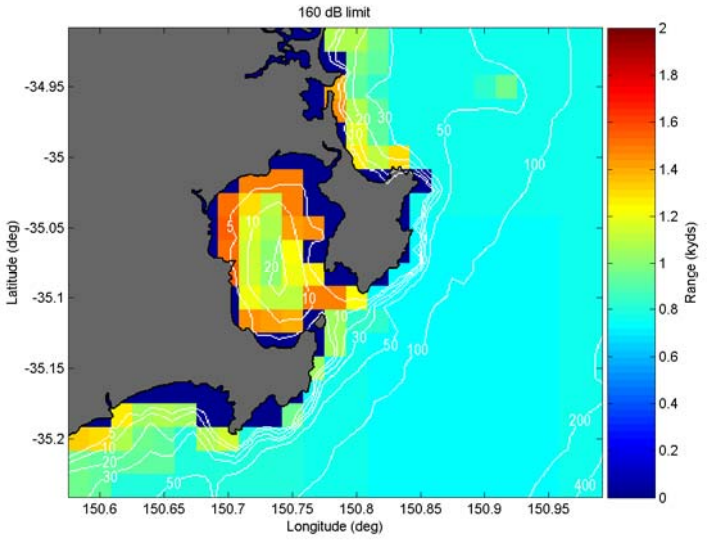

Figure 100: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

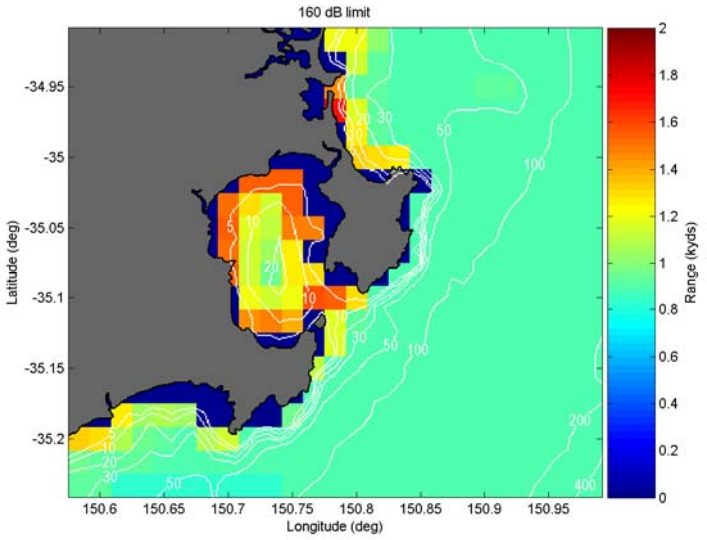

Figure 101: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

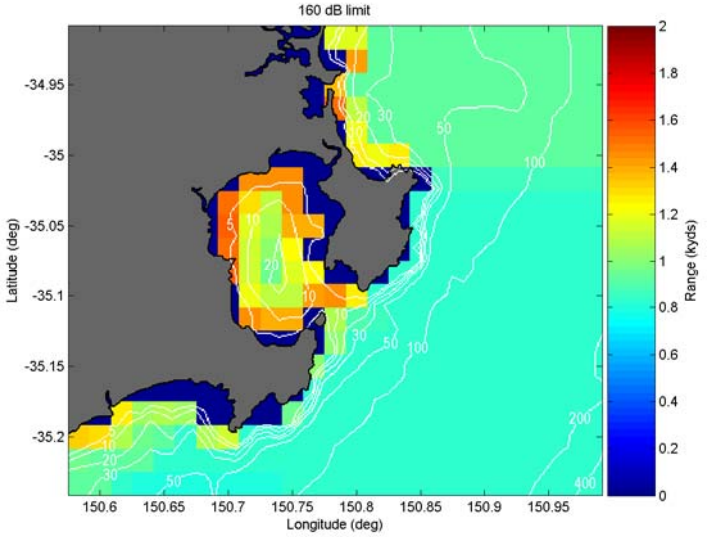

Figure 102: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

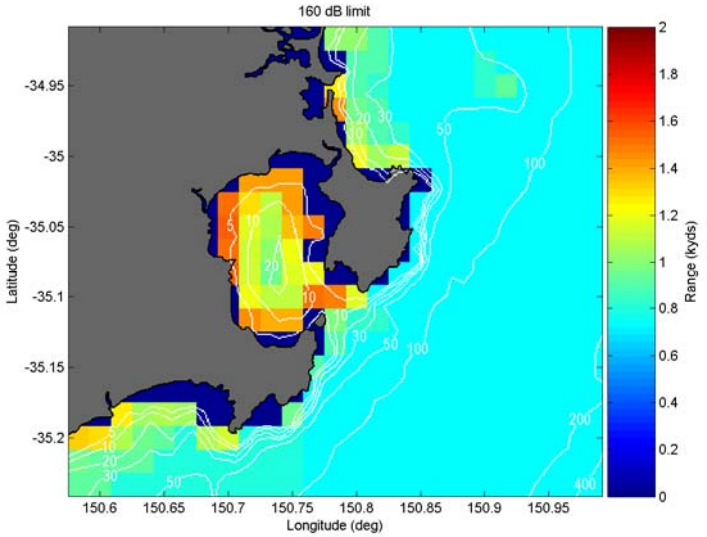

Figure 103: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

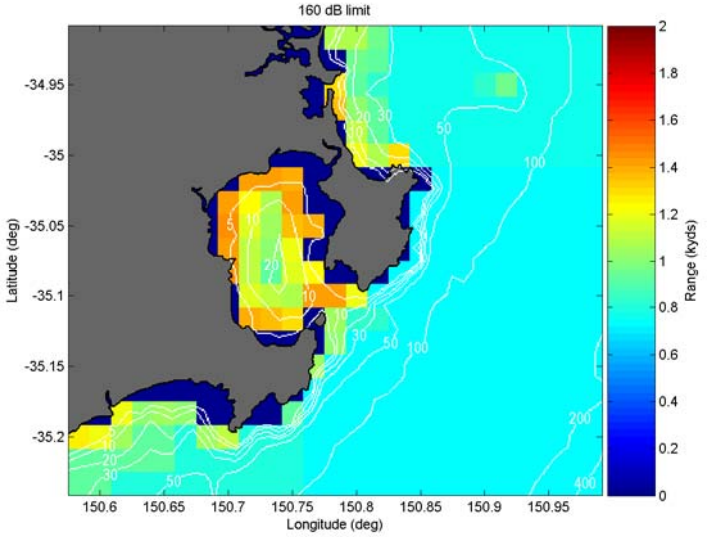

Figure 104: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

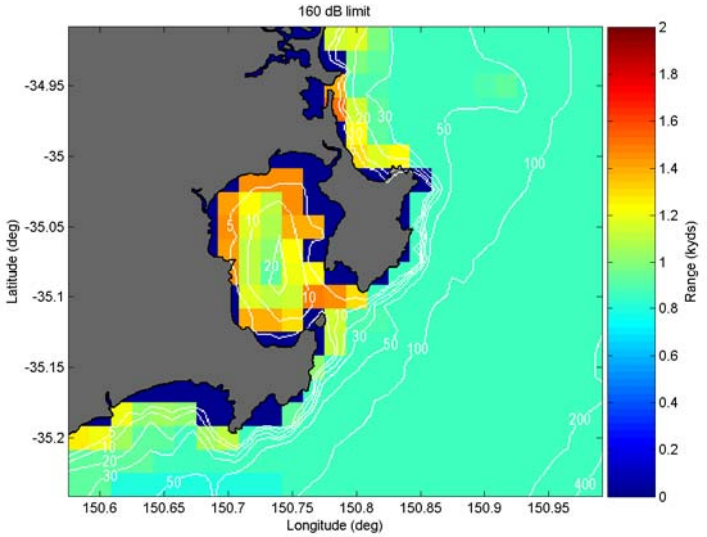

Figure 105: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

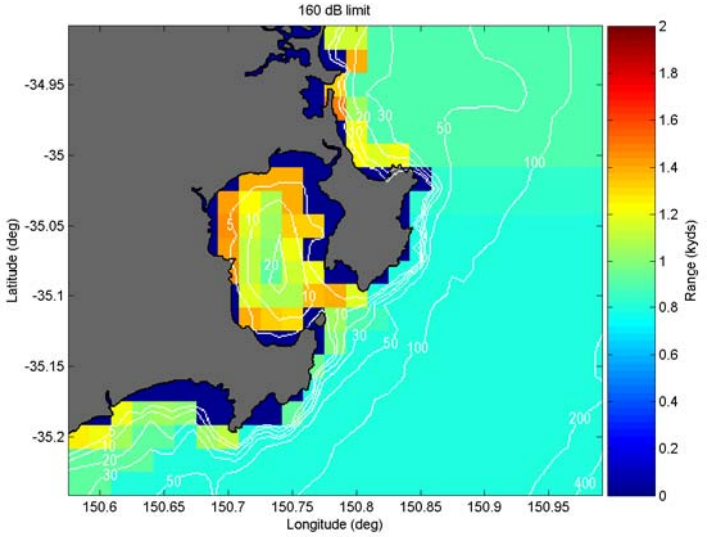

Figure 106: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

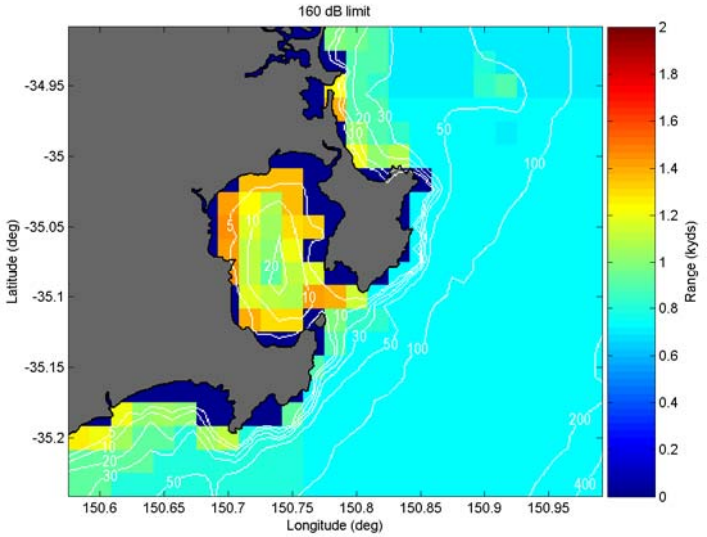

Figure 107: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

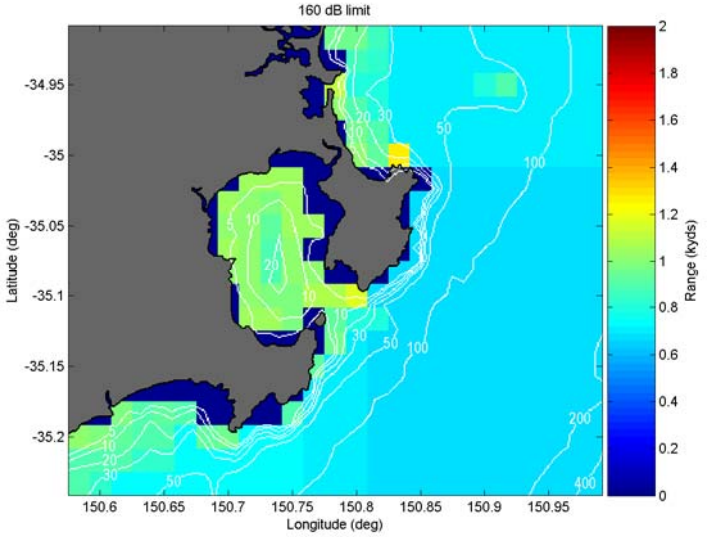

Figure 108: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

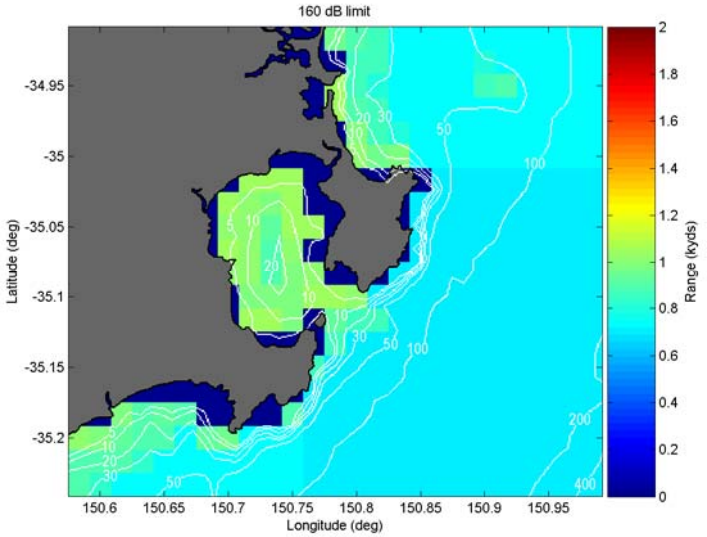

Figure 109: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

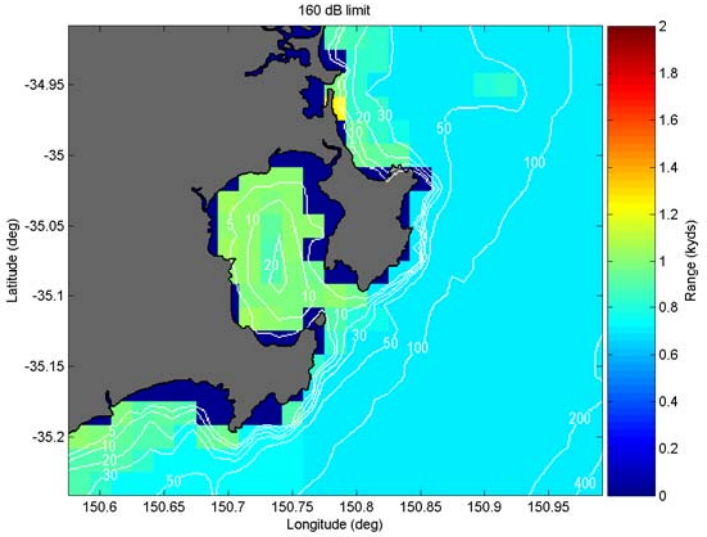

Figure 110: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

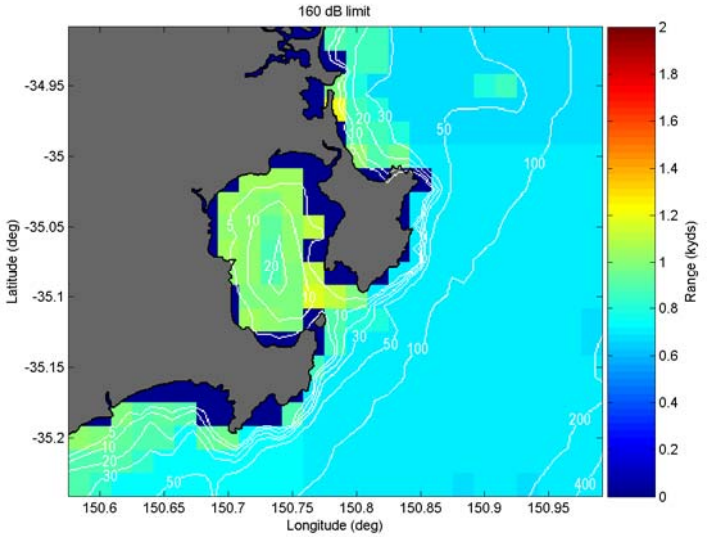

Figure 111: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

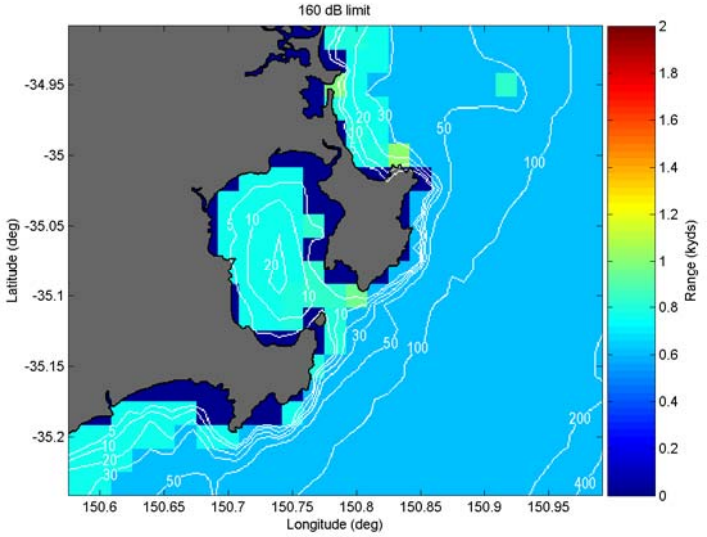

Figure 112: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

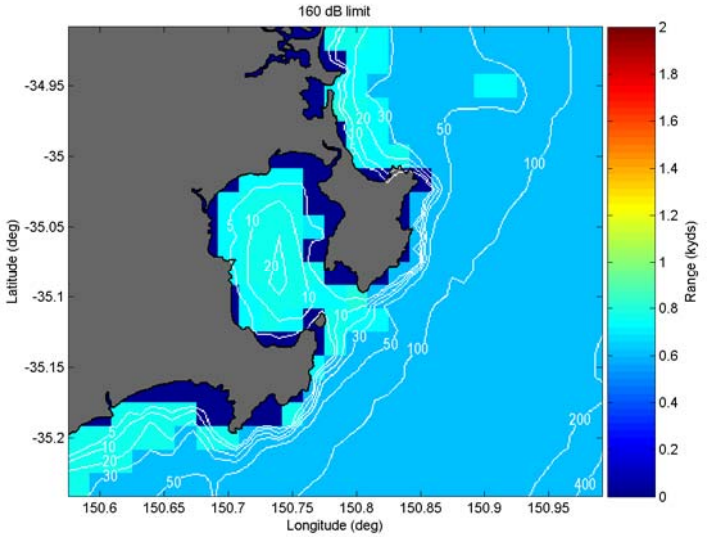

Figure 113: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

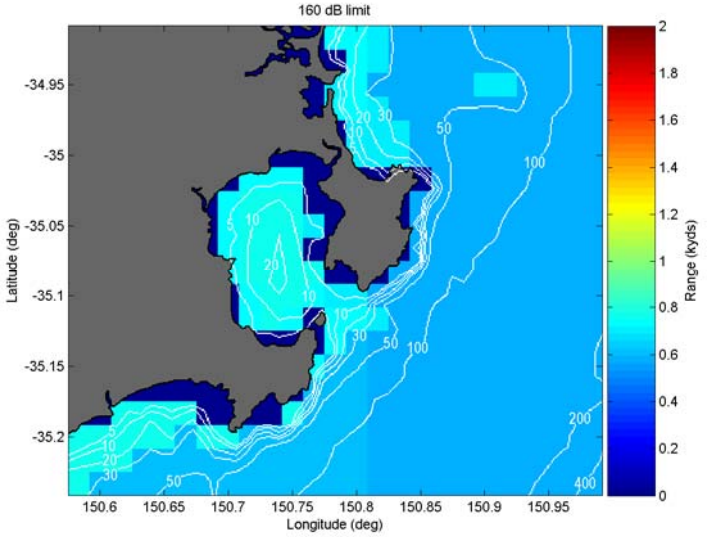

Figure 114: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

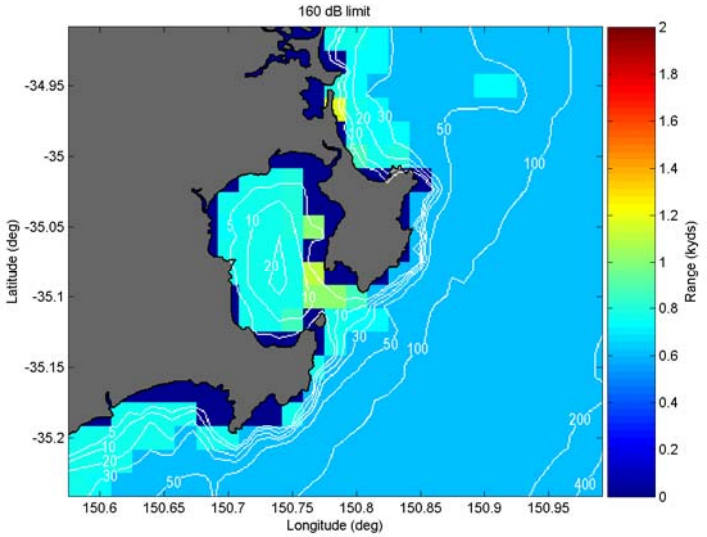

Figure 115: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

A.6. Mitigation Ranges for the CMAS Forward Looking Sonar using 39 kHz at 160 dB Received Pressure Limit over Coarse sand in Jervis Bay

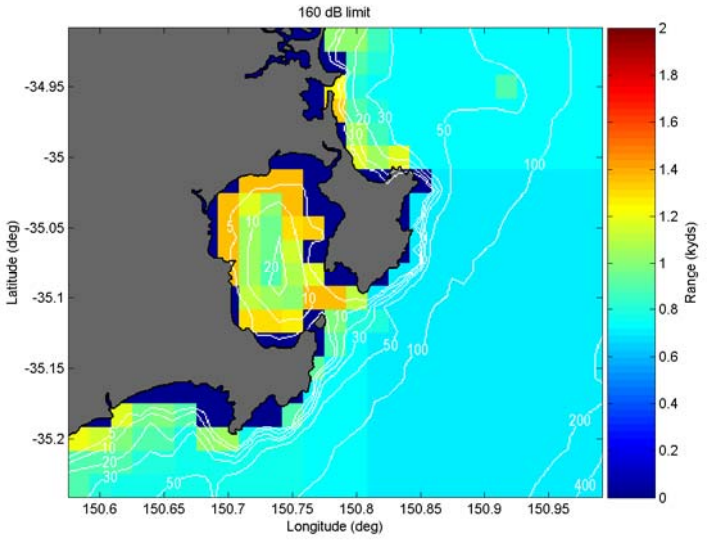

Figure 116: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

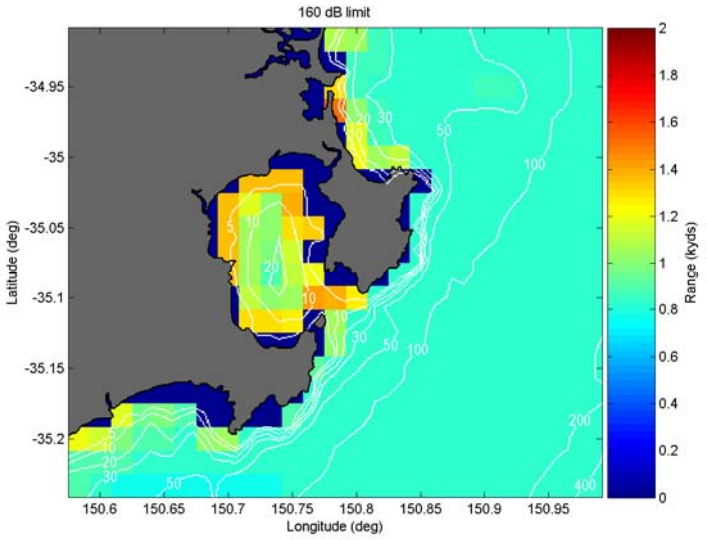

Figure 117: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

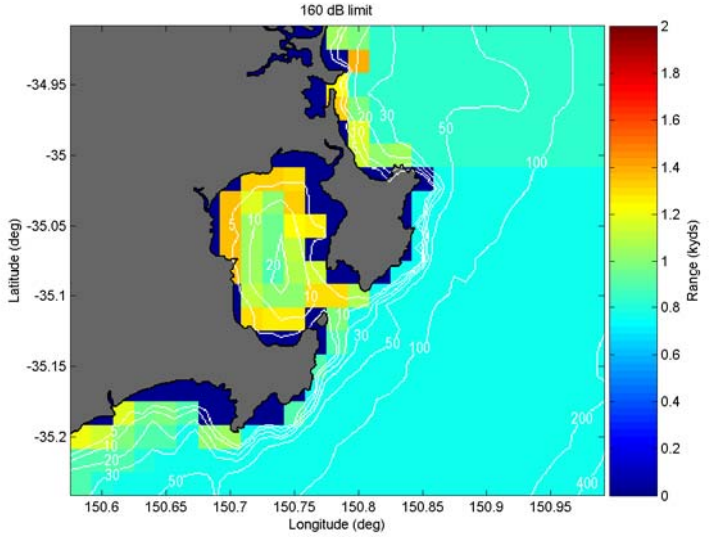

Figure 118: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

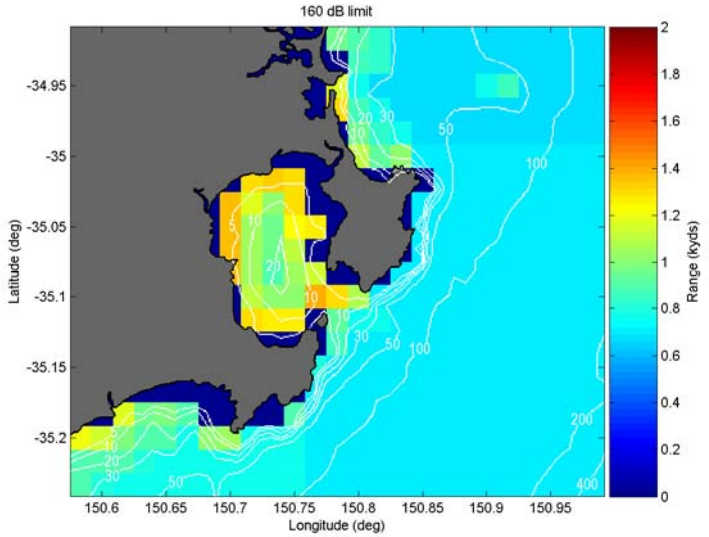

Figure 119: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

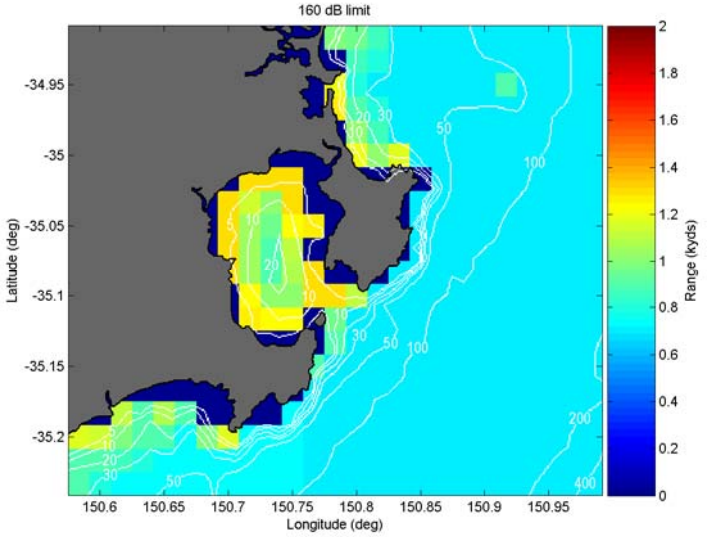

Figure 120: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

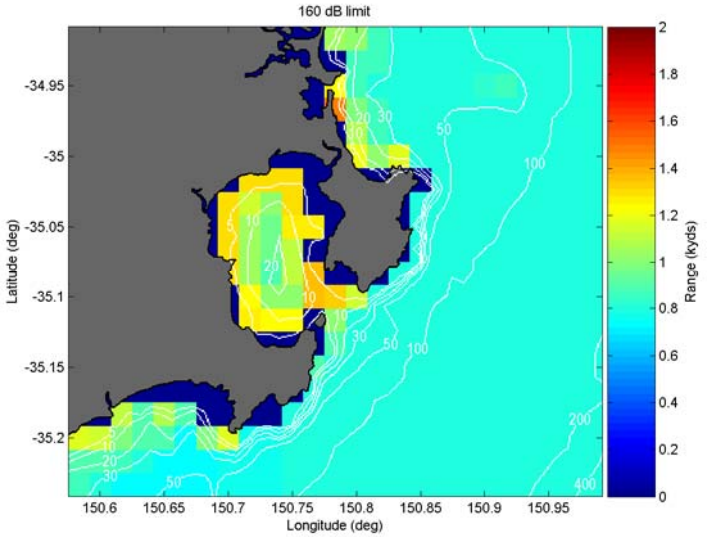

Figure 121: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

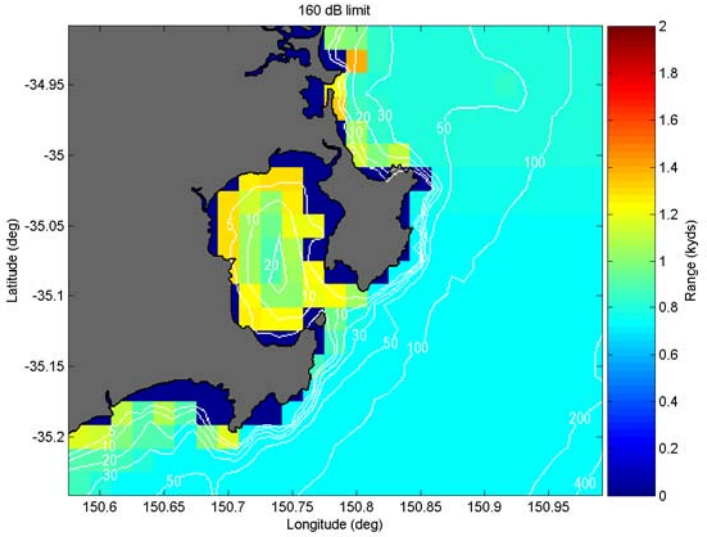

Figure 122: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

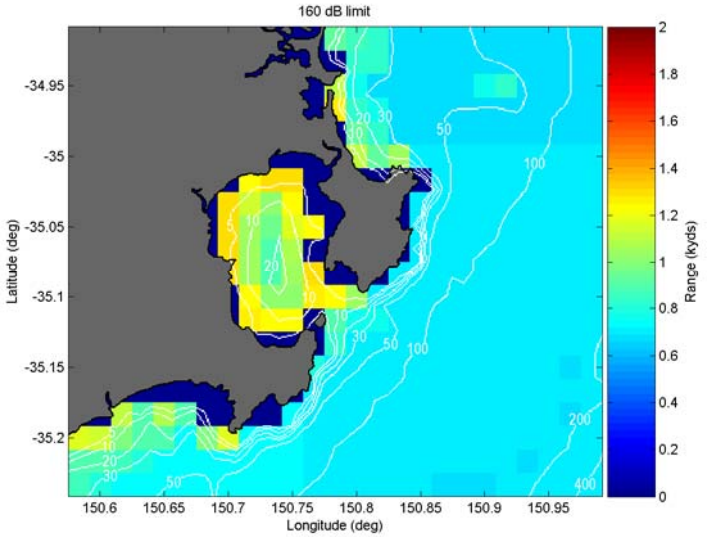

Figure 123: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

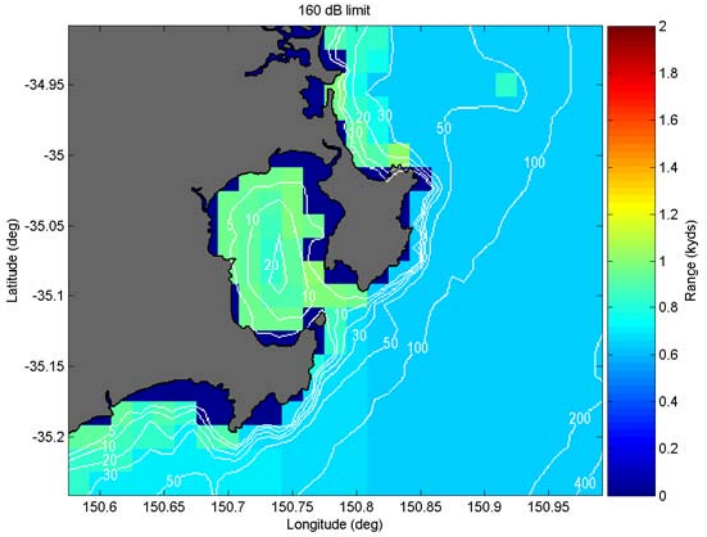

Figure 124: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

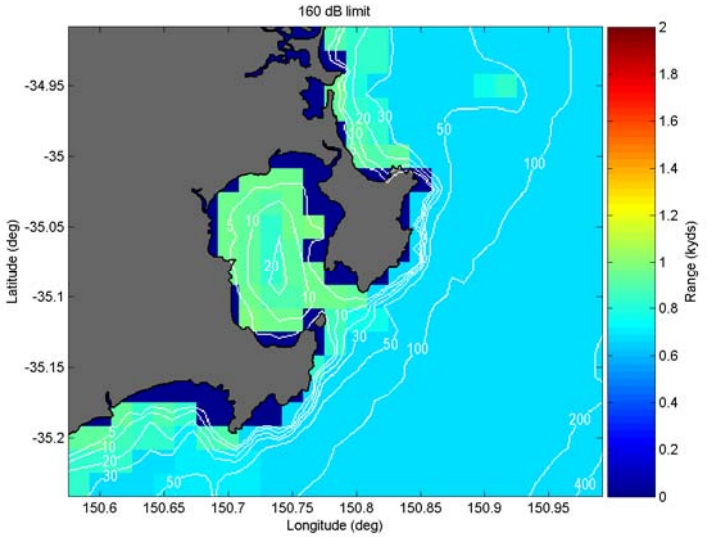

Figure 125: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

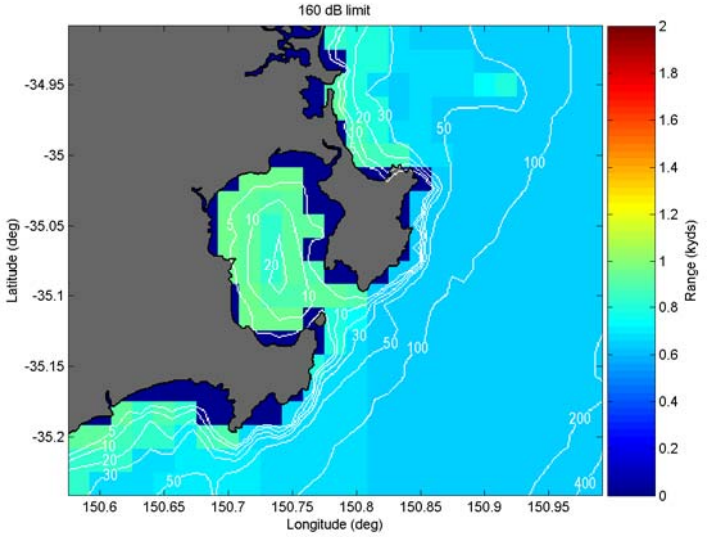

Figure 126: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

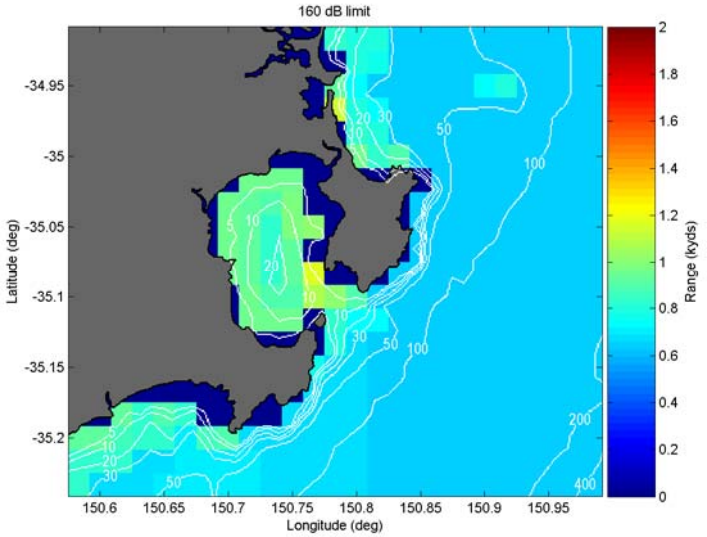

Figure 127: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

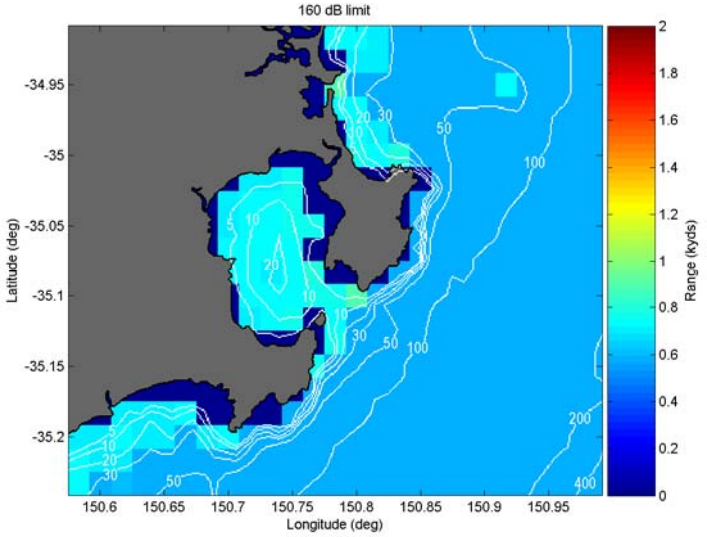

Figure 128: Mitigation ranges required for a received acoustic pressure level of 160 dB during January at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

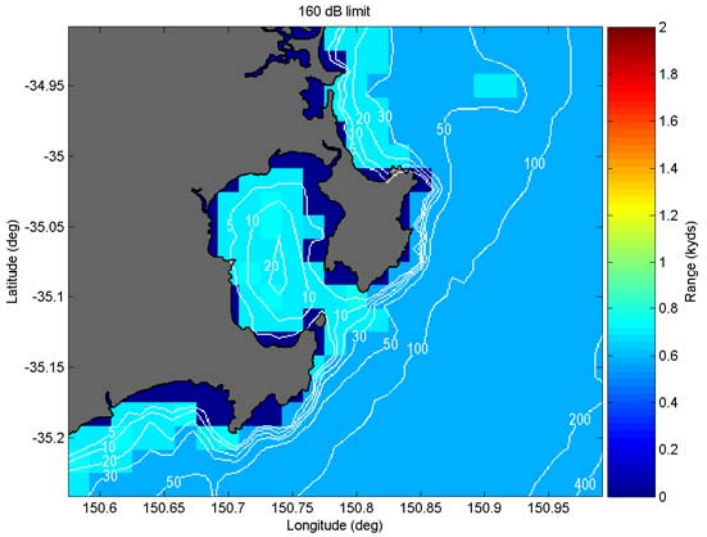

Figure 129: Mitigation ranges required for a received acoustic pressure level of 160 dB during April at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

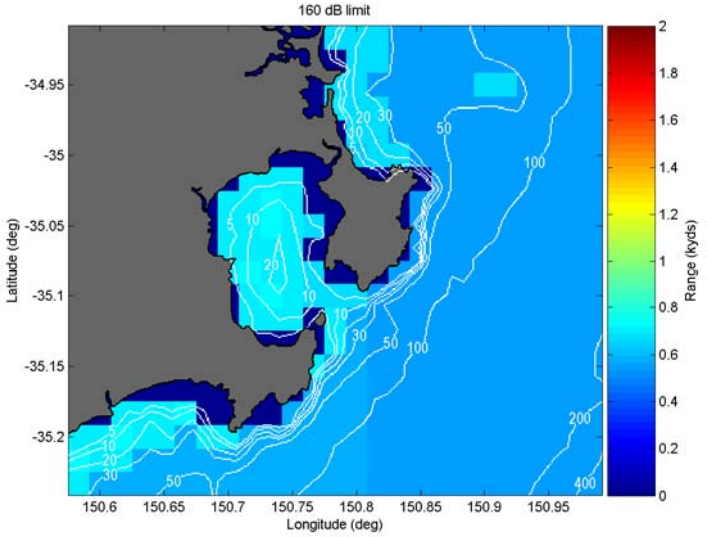

Figure 130: Mitigation ranges required for a received acoustic pressure level of 160 dB during July at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

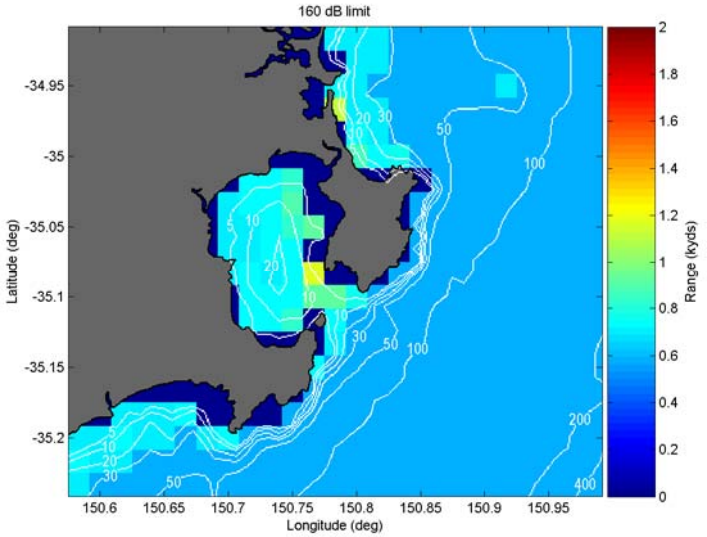

Figure 131: Mitigation ranges required for a received acoustic pressure level of 160 dB during October at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

A.7. Mitigation Ranges for the Fansweep 20 Multibeam Echo Sounder at 182 dB Received Pressure Limit over Coarse Sand in Jervis Bay

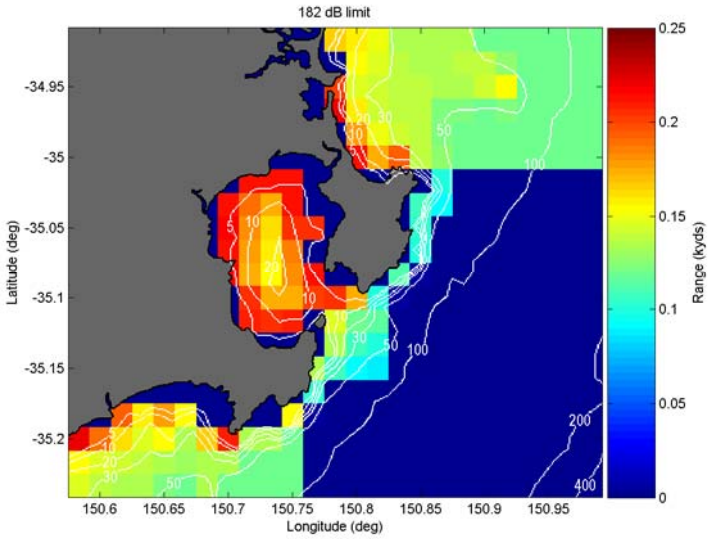

Figure 132: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

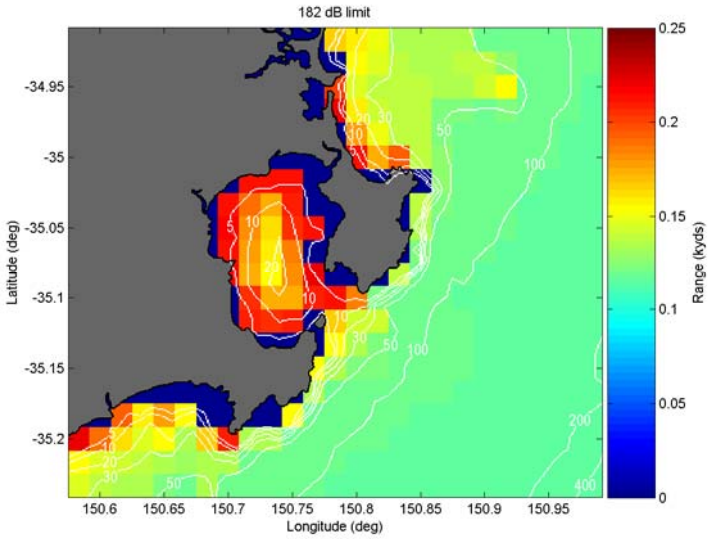

Figure 133: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

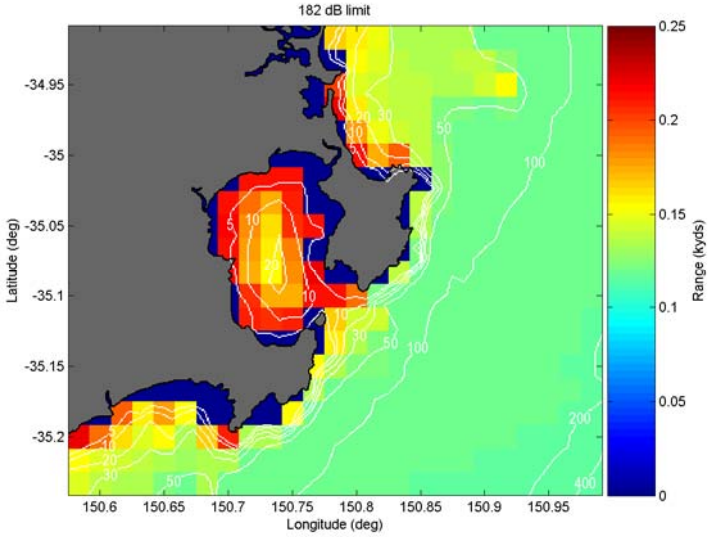

Figure 134: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

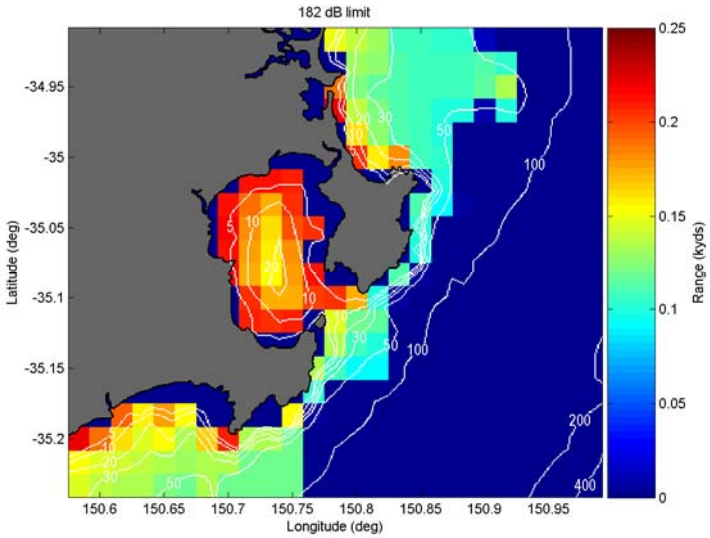

Figure 135: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

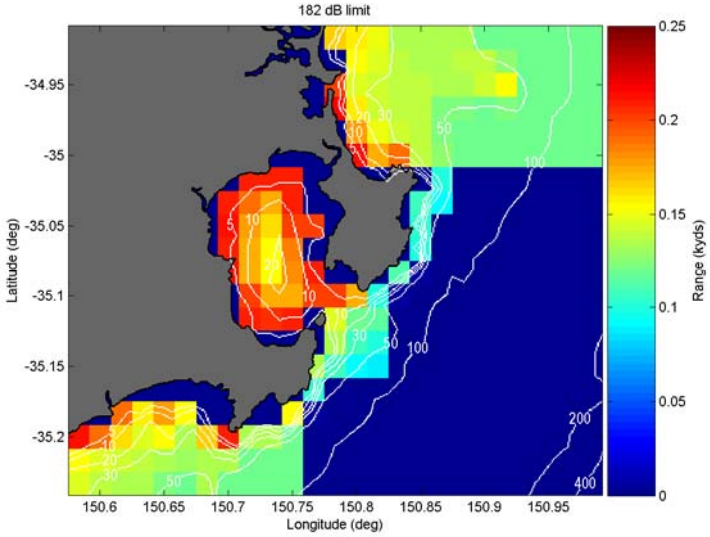

Figure 136: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

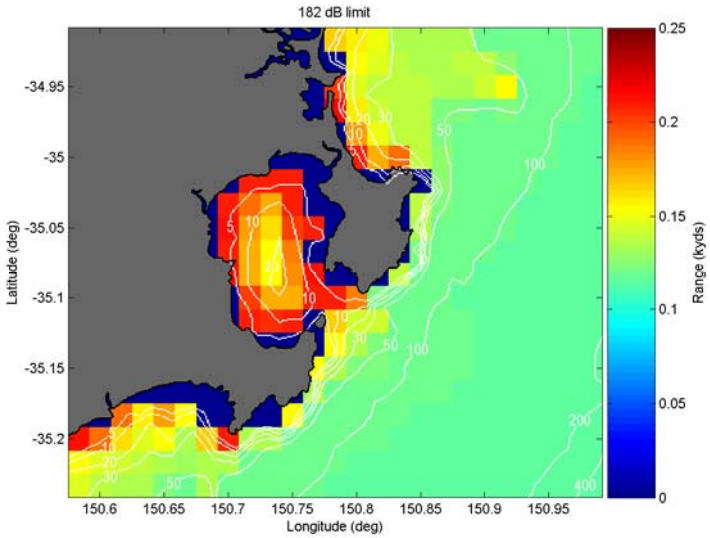

Figure 137: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

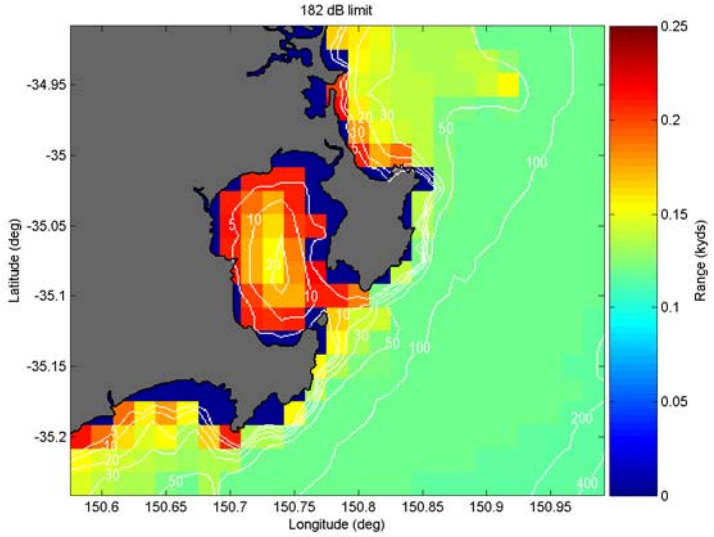

Figure 138: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

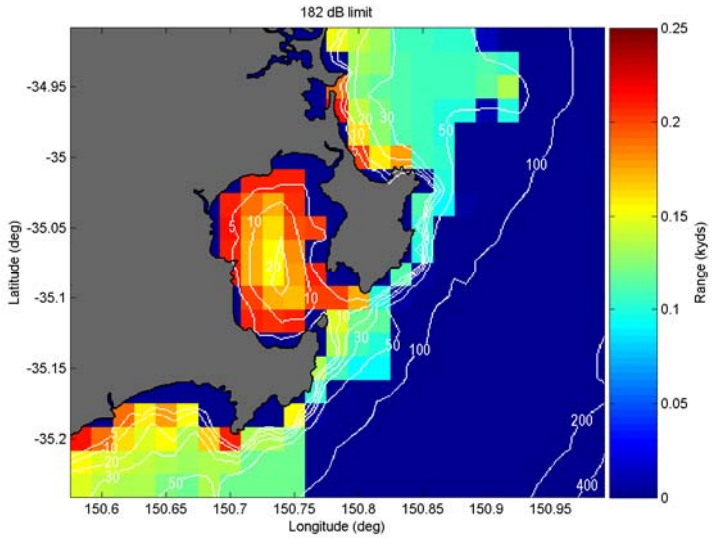

Figure 139: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

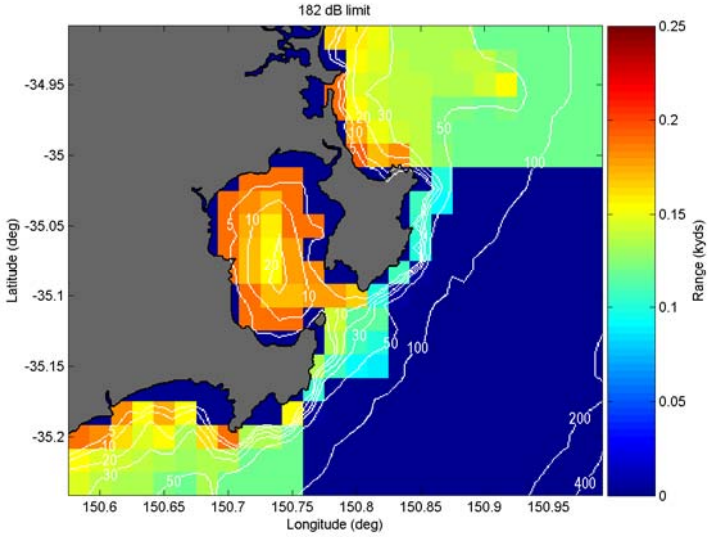

Figure 140: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

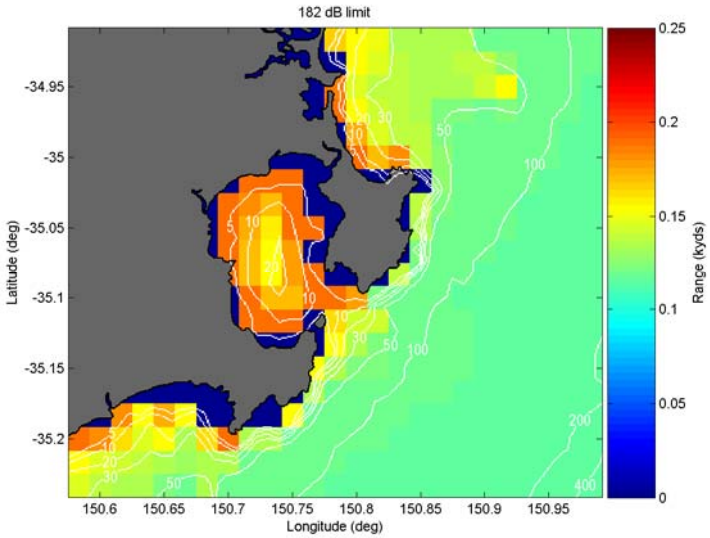

Figure 141: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

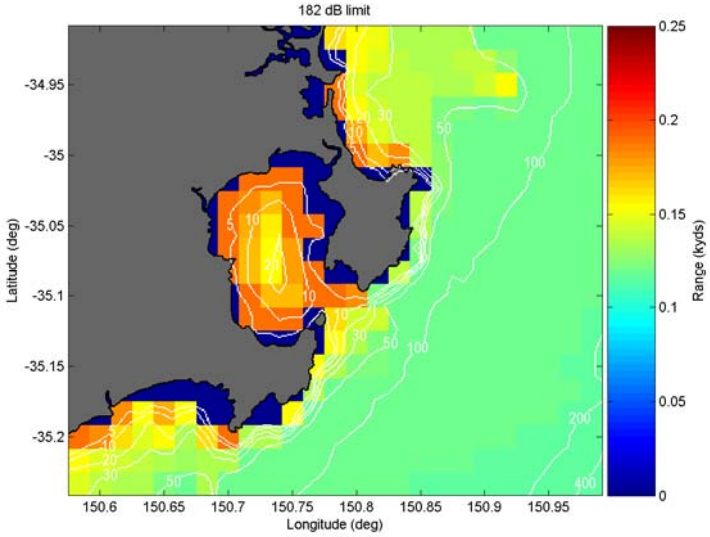

Figure 142: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

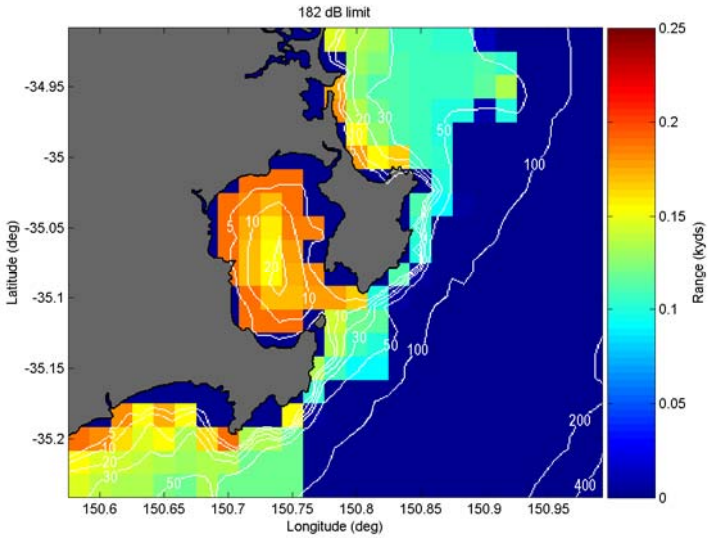

Figure 143: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

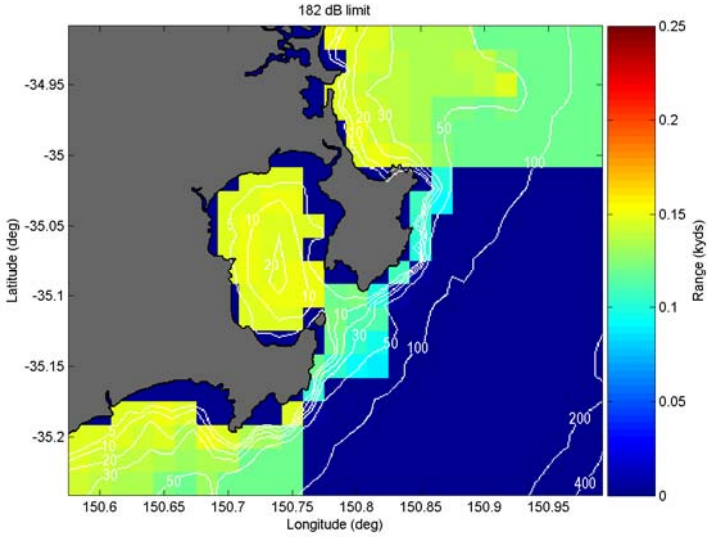

Figure 144: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

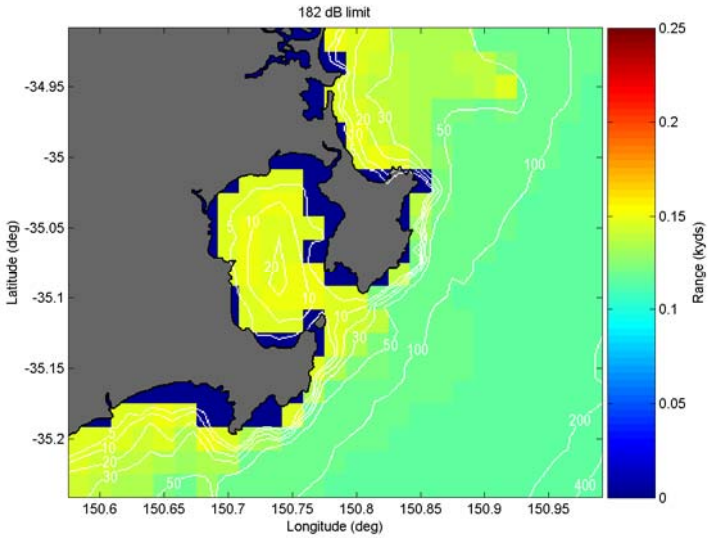

Figure 145: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

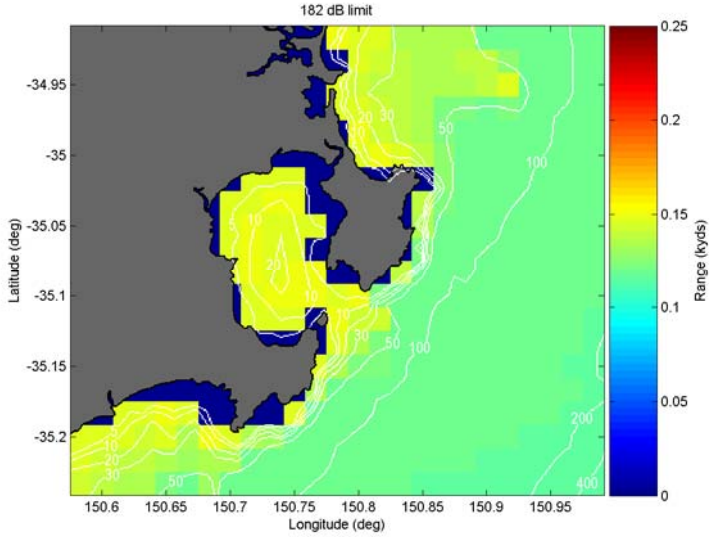

Figure 146: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

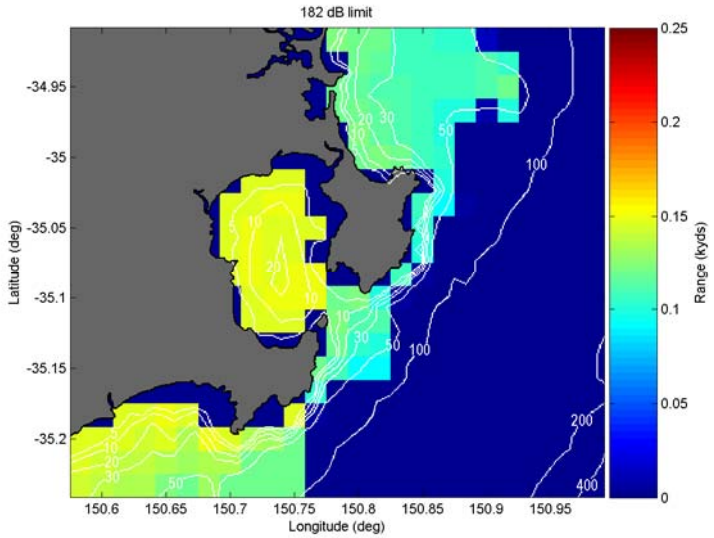

Figure 147: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the Fansweep 20 Multibeam Echo Sounder over coarse sand in Jervis Bay

A.8. Mitigation Ranges for the Klein 2000 Towed Light Weight Side Scan Sonar at 182 dB Received Pressure Limit over Coarse Sand in Jervis Bay

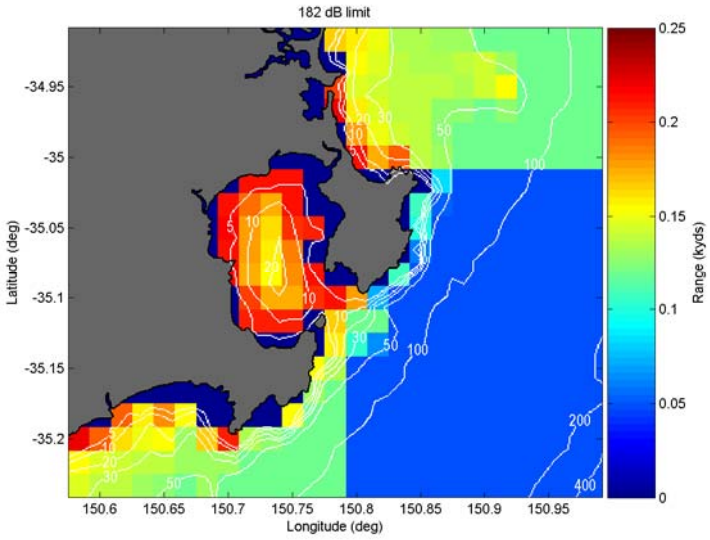

Figure 148: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

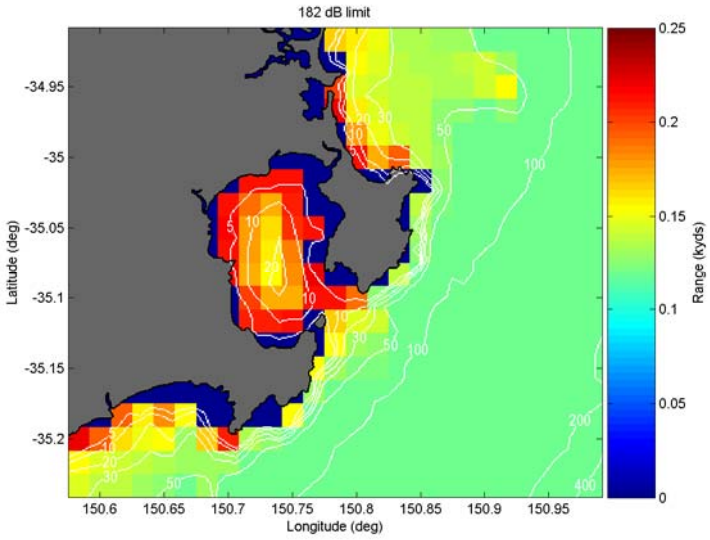

Figure 149: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

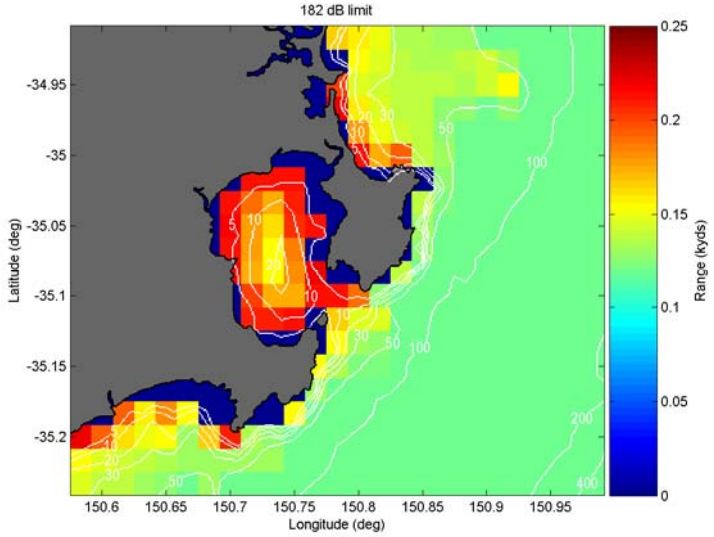

Figure 150: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

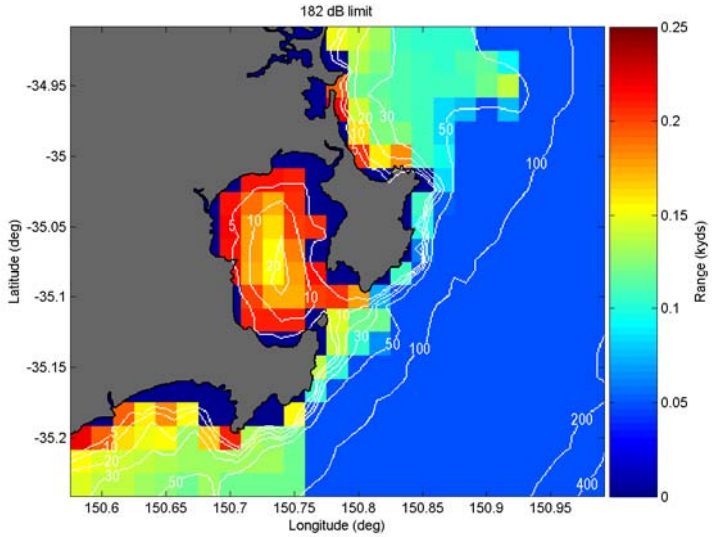

Figure 151: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

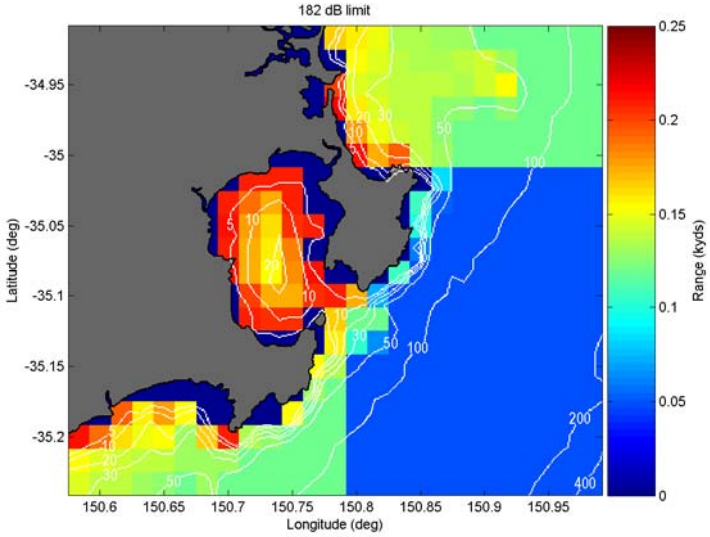

Figure 152: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

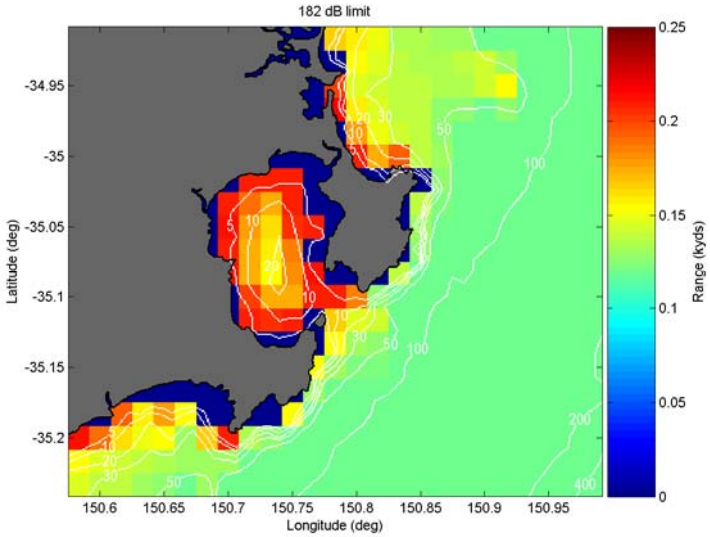

Figure 153: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

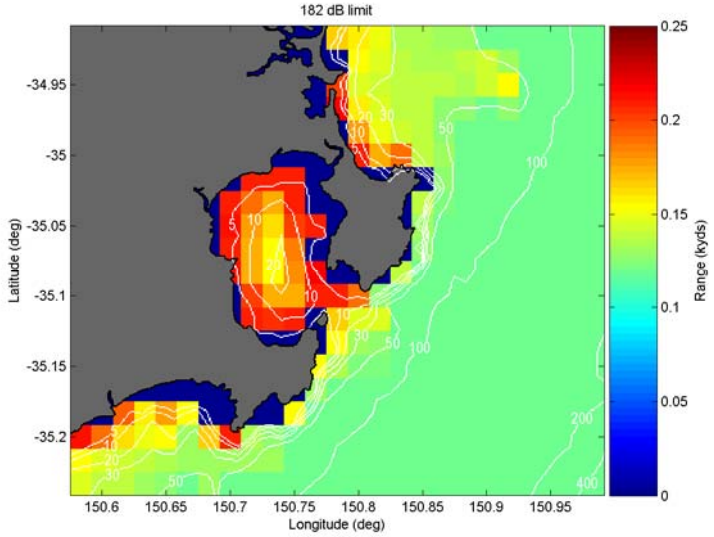

Figure 154: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

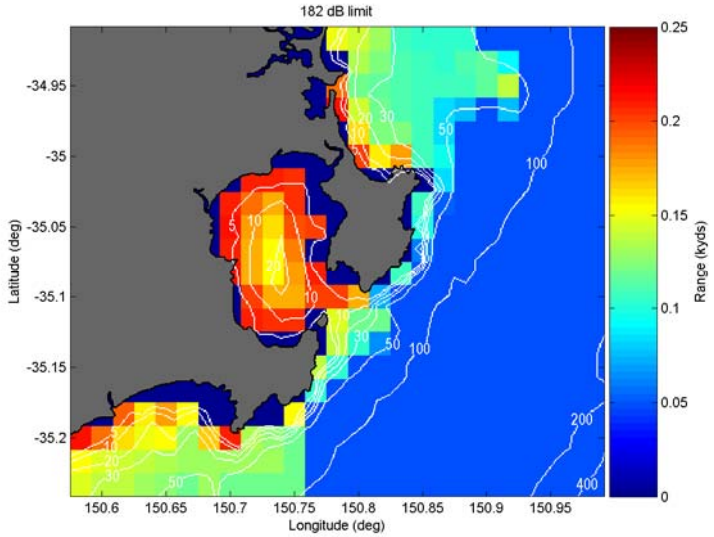

Figure 155: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

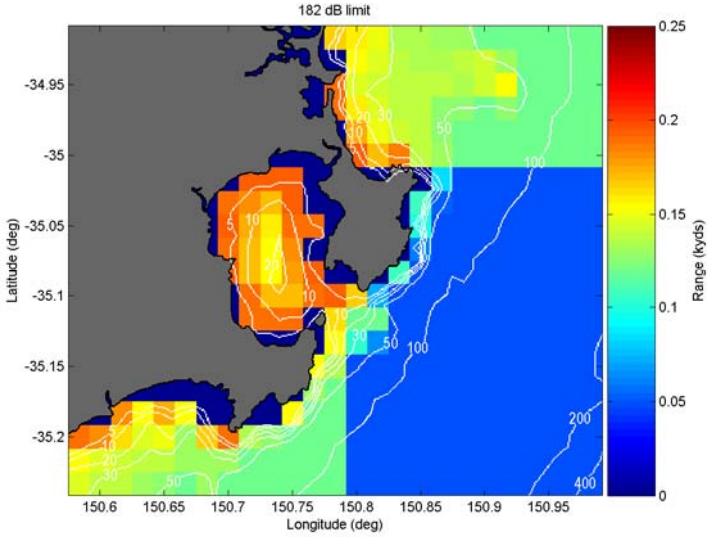

Figure 156: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

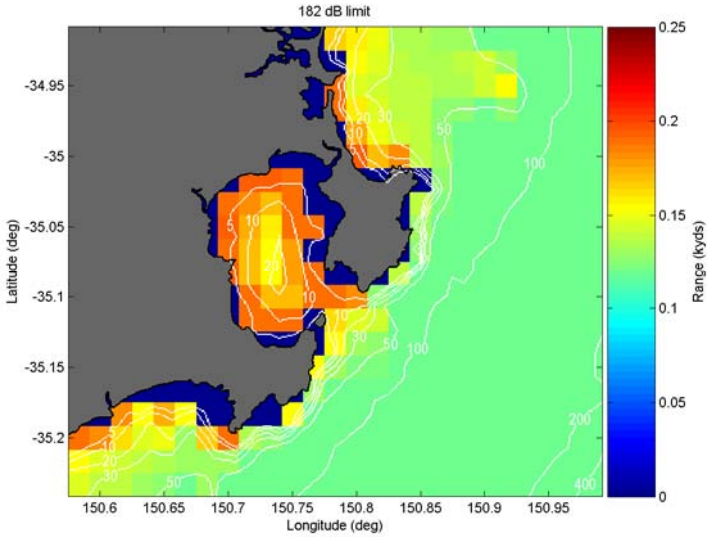

Figure 157: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

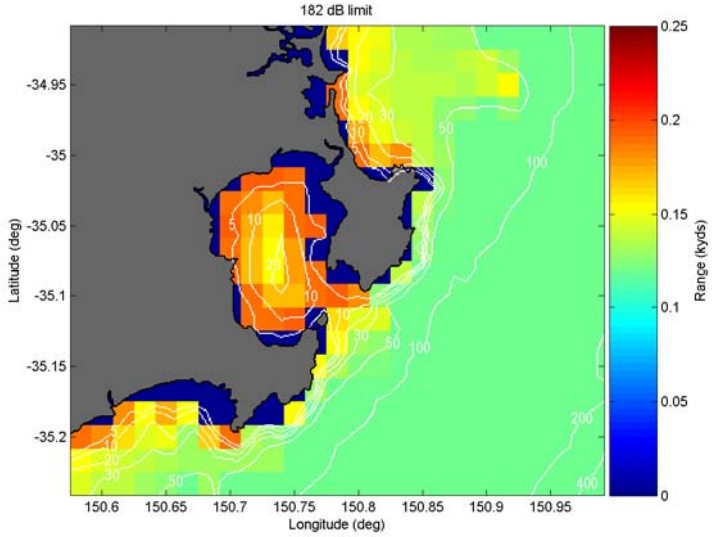

Figure 158: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

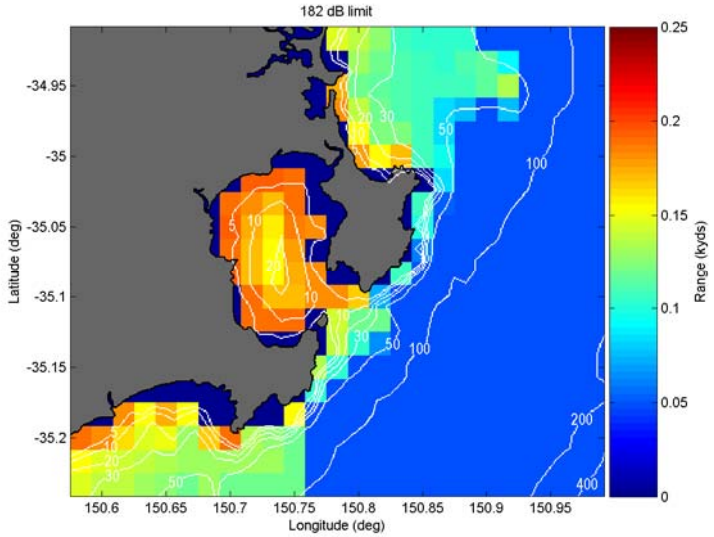

Figure 159: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

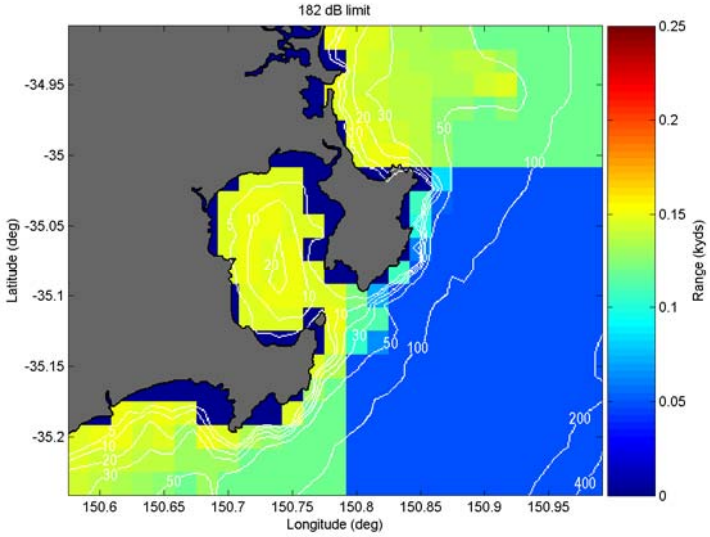

Figure 160: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

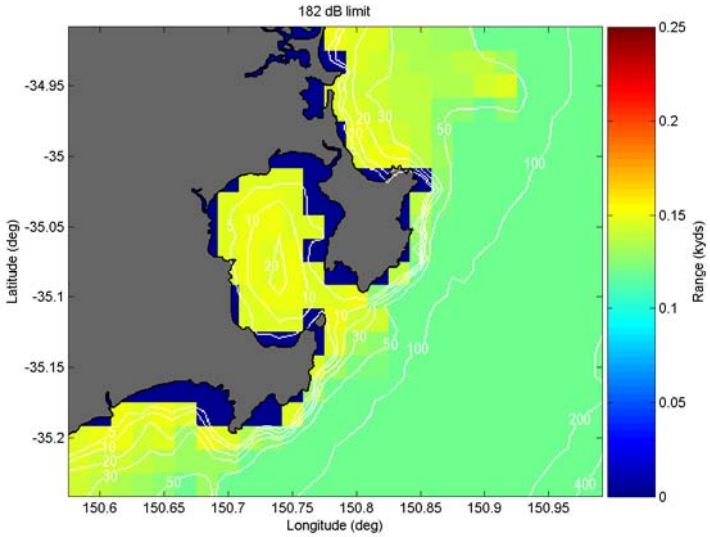

Figure 161: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

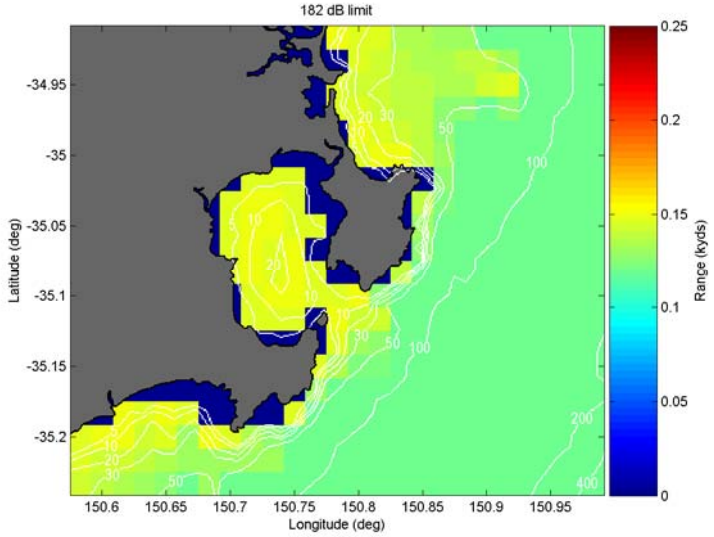

Figure 162: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

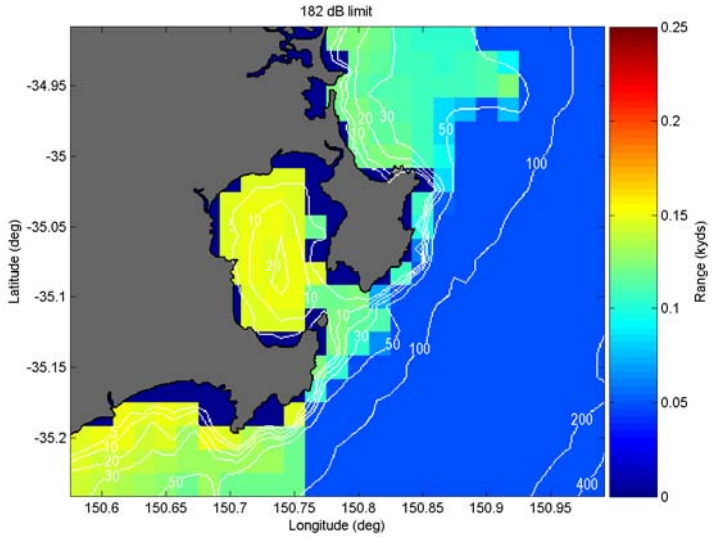

Figure 163: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the Klein 2000 Towed Light Weight Side Scan Sonar over coarse sand in Jervis Bay

A.9. Mitigation Ranges for the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz at 182 dB Received Pressure Limit over Coarse Sand in Jervis Bay

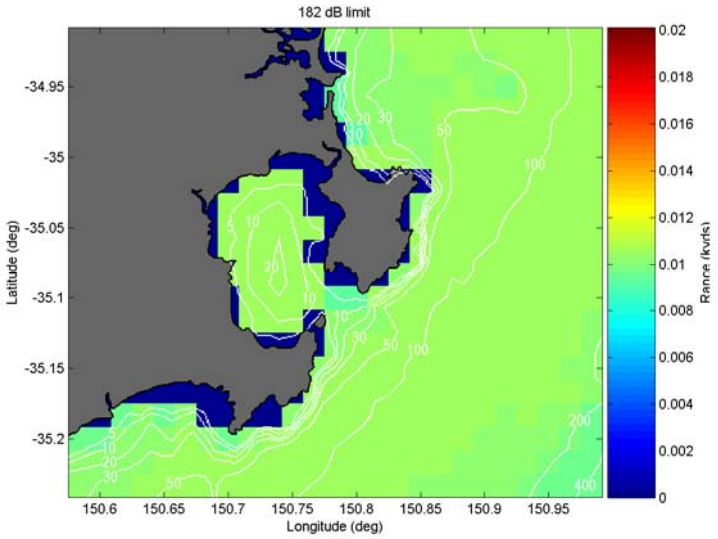

Figure 164: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

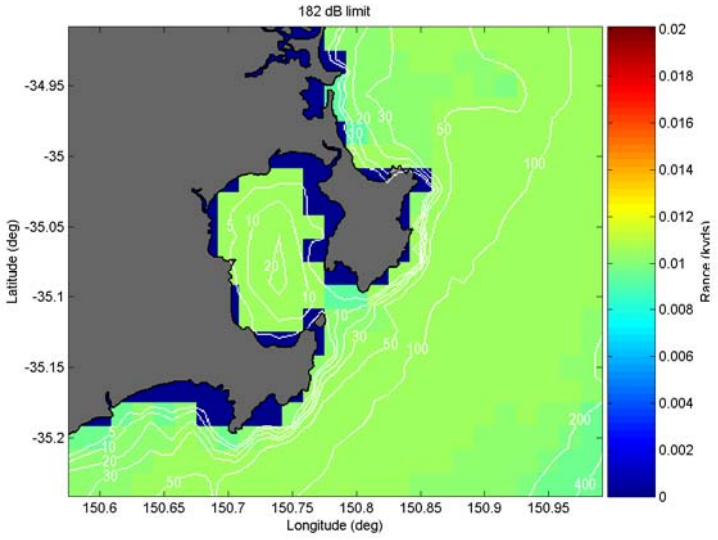

Figure 165: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

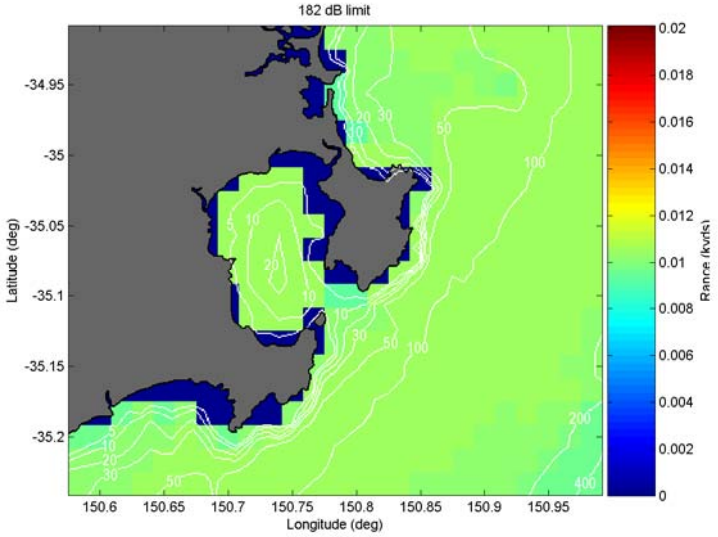

Figure 166: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

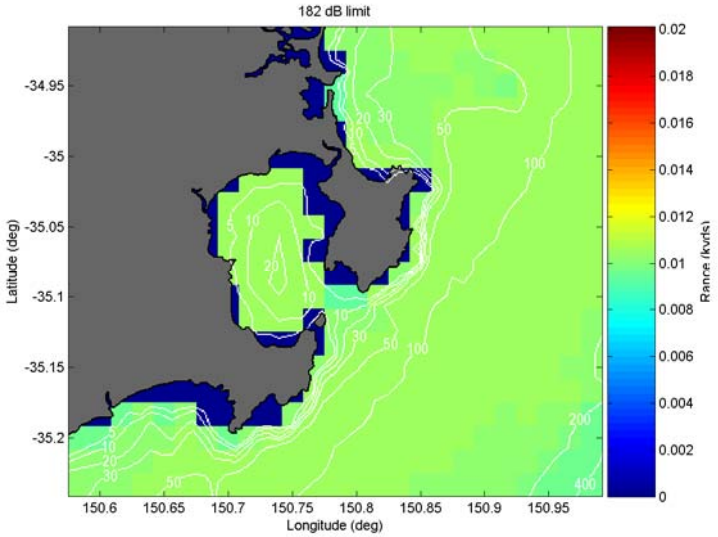

Figure 167: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

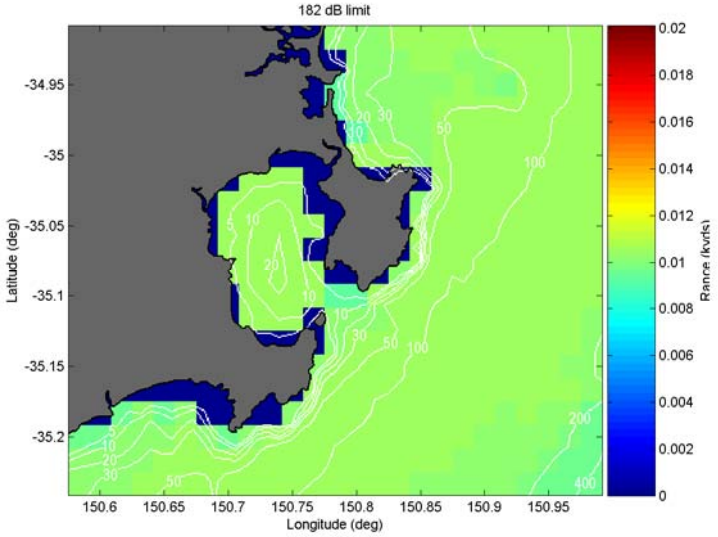

Figure 168: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

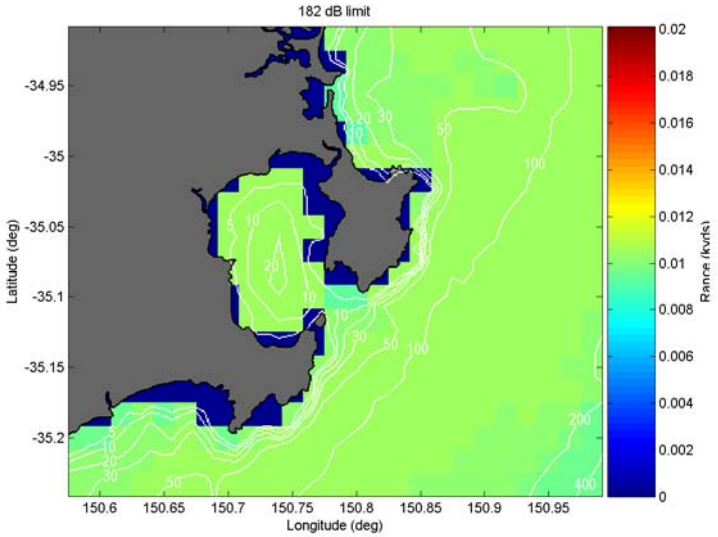

Figure 169: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

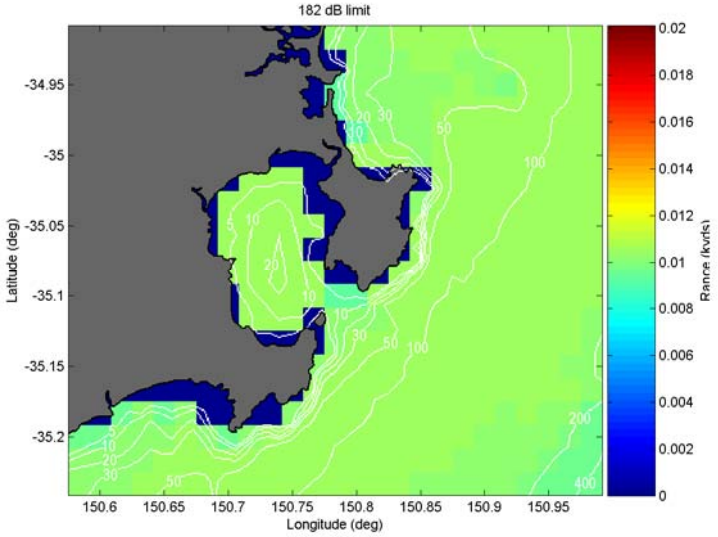

Figure 170: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

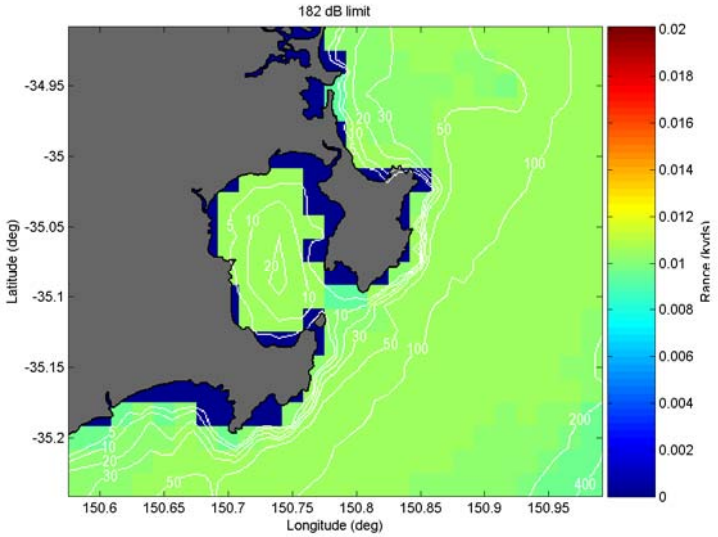

Figure 171: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

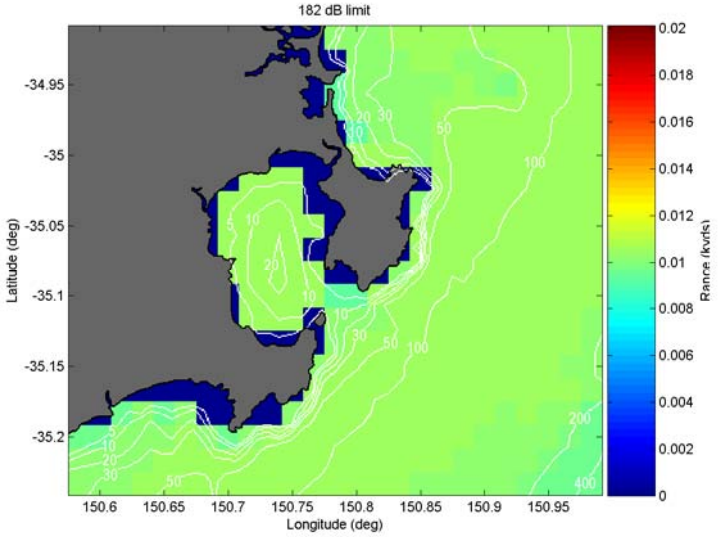

Figure 172: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

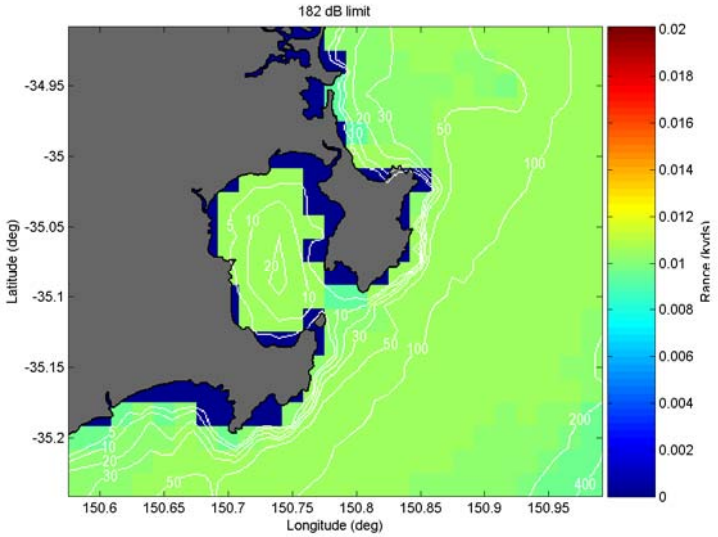

Figure 173: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

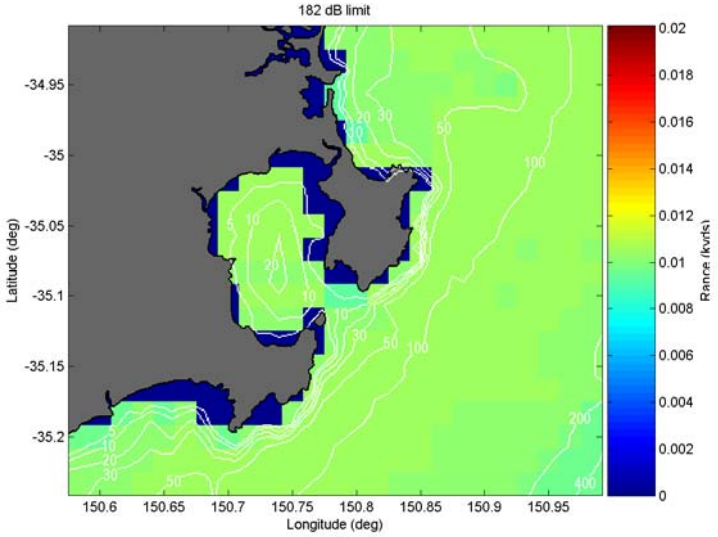

Figure 174: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

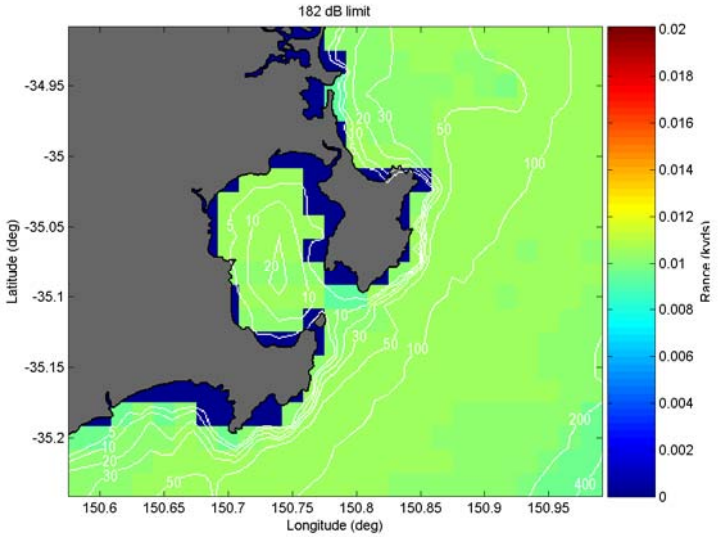

Figure 175: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

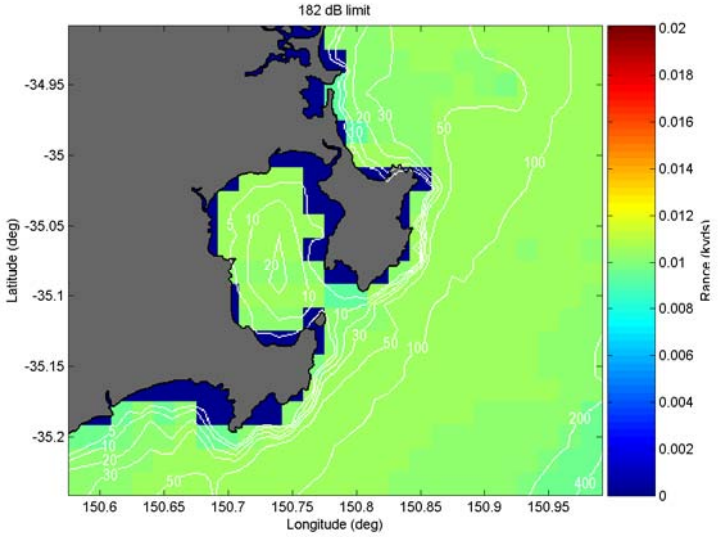

Figure 176: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

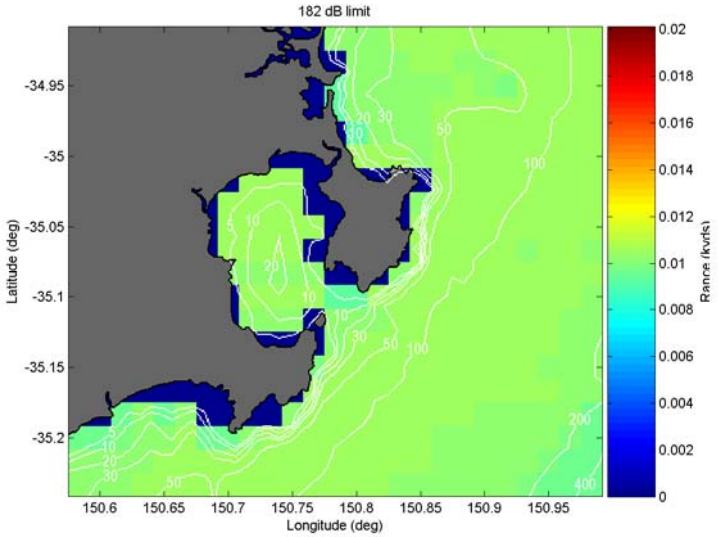

Figure 177: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

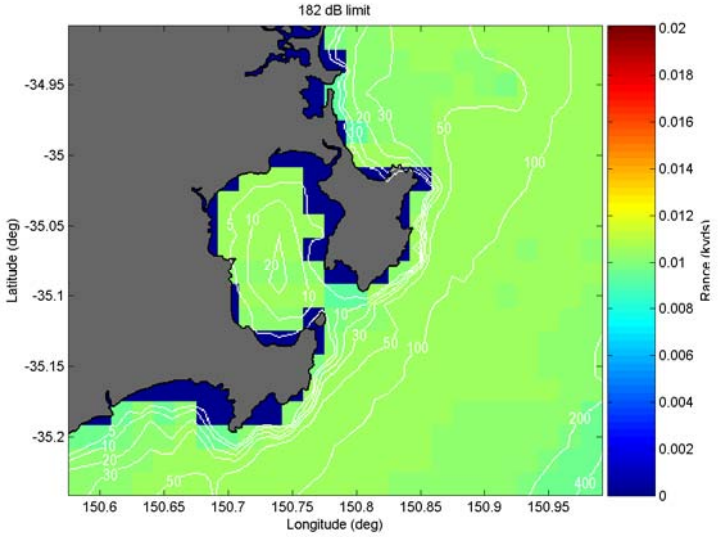

Figure 178: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

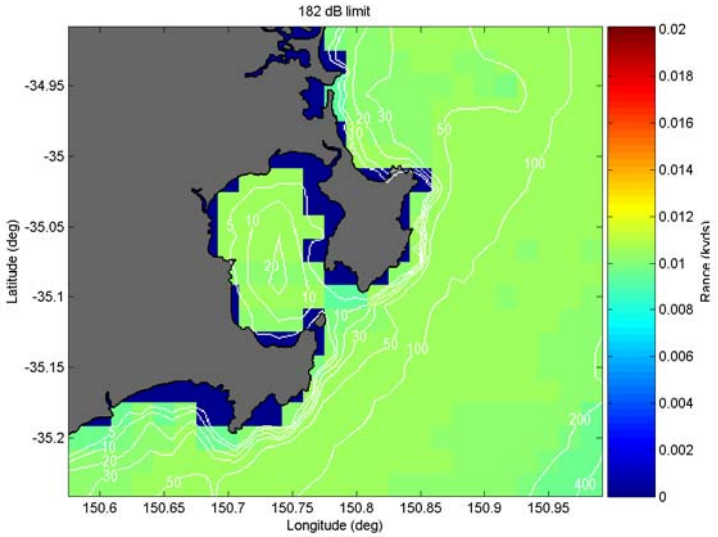

Figure 179: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 12 kHz over coarse sand in Jervis Bay

A.10. Mitigation Ranges for the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz at 182 dB Received Pressure Limit over Coarse Sand in Jervis Bay

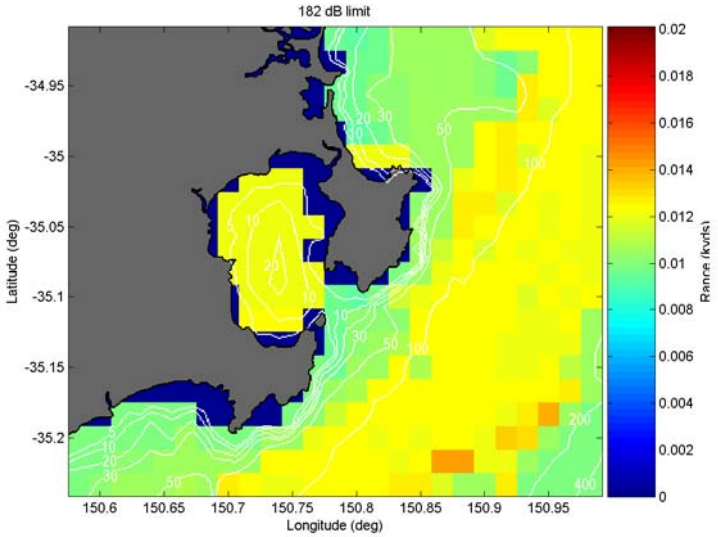

Figure 180: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

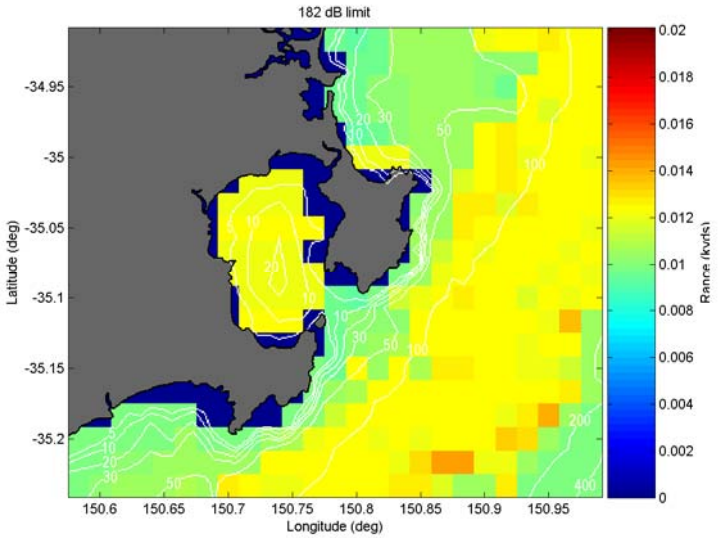

Figure 181: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

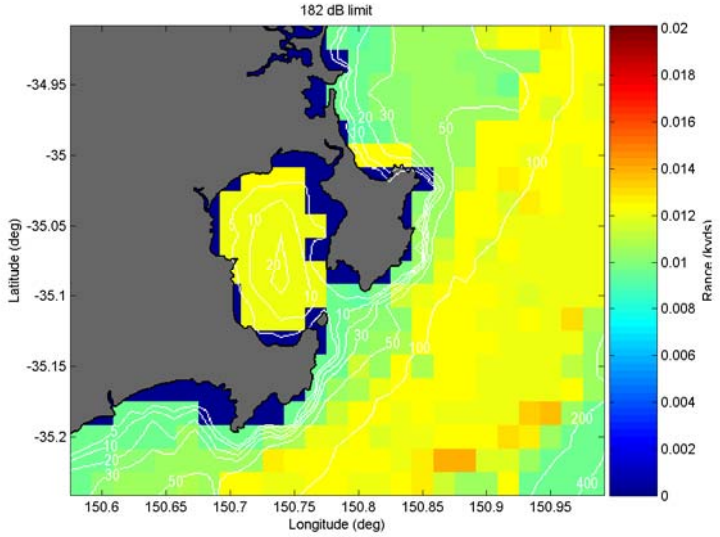

Figure 182: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

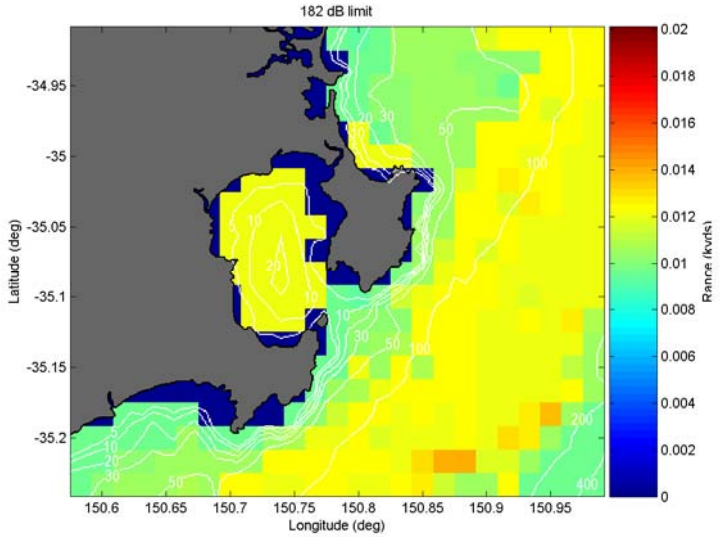

Figure 183: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

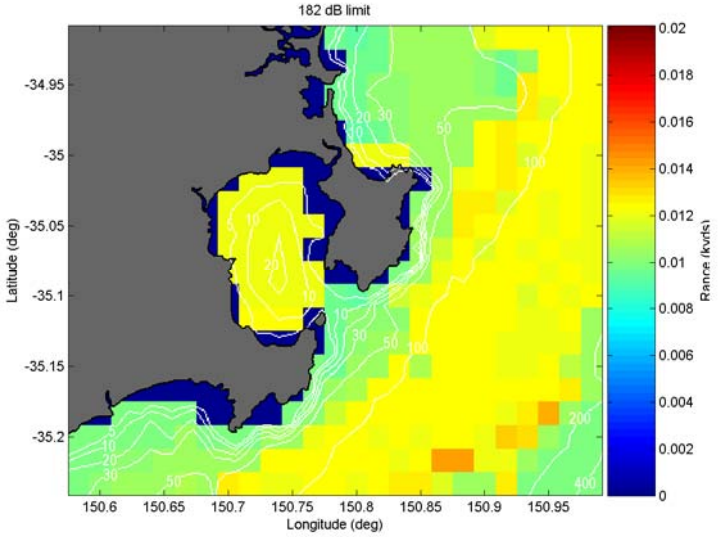

Figure 184: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

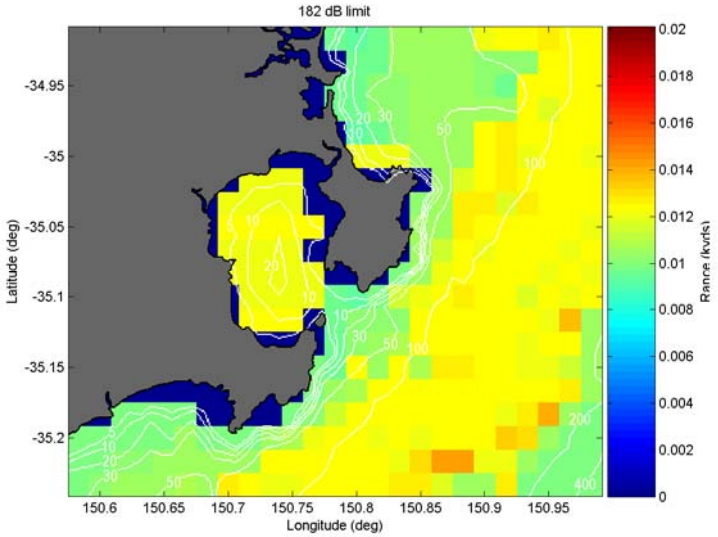

Figure 185: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

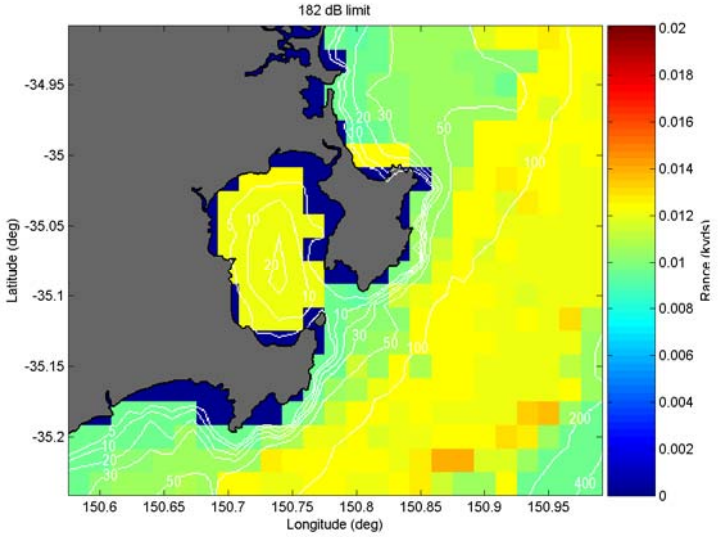

Figure 186: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

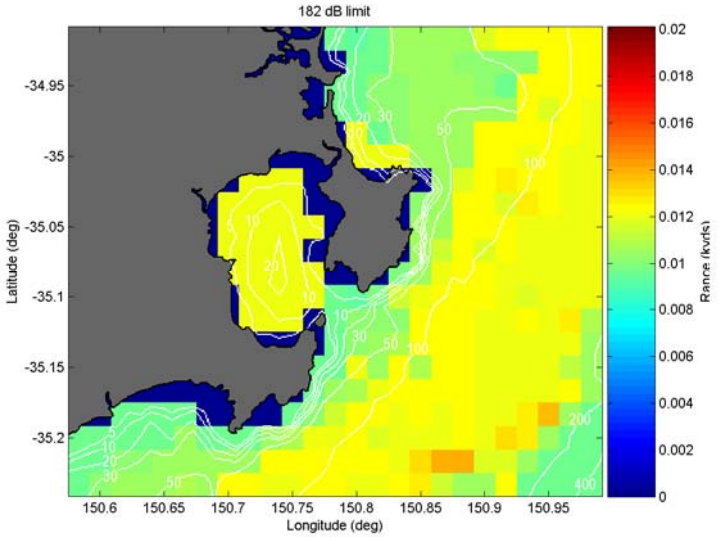

Figure 187: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

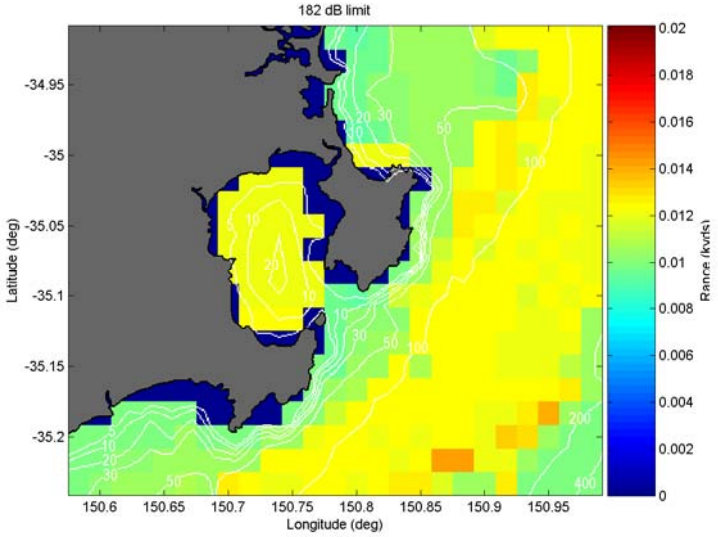

Figure 188: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

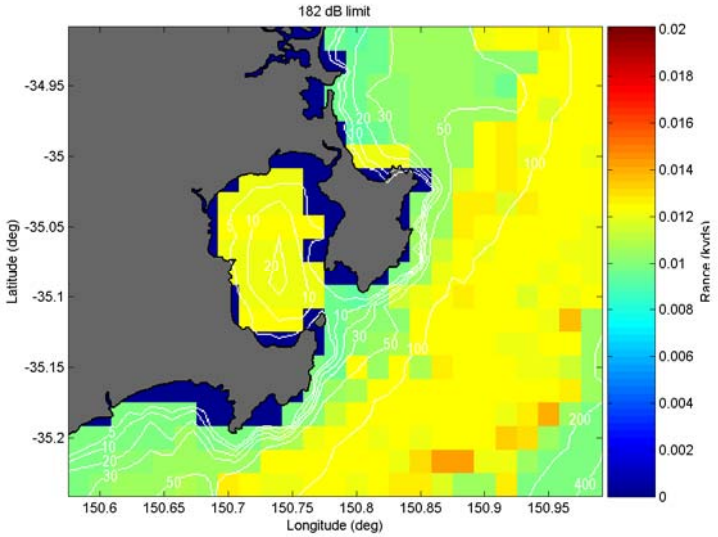

Figure 189: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

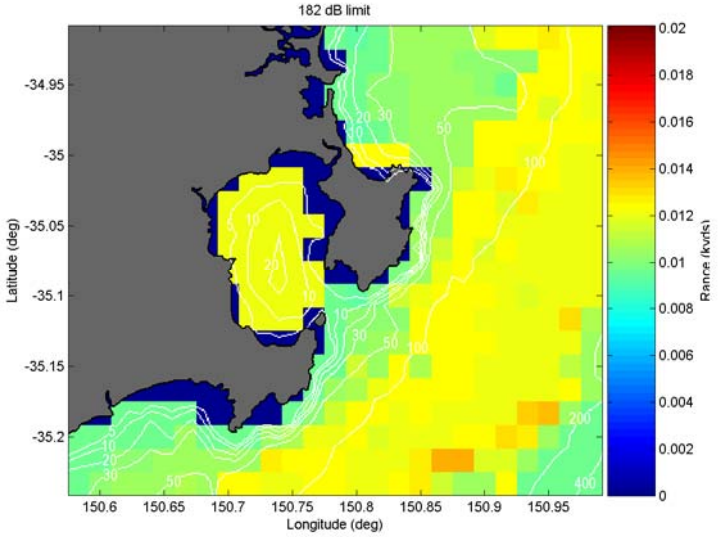

Figure 190: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

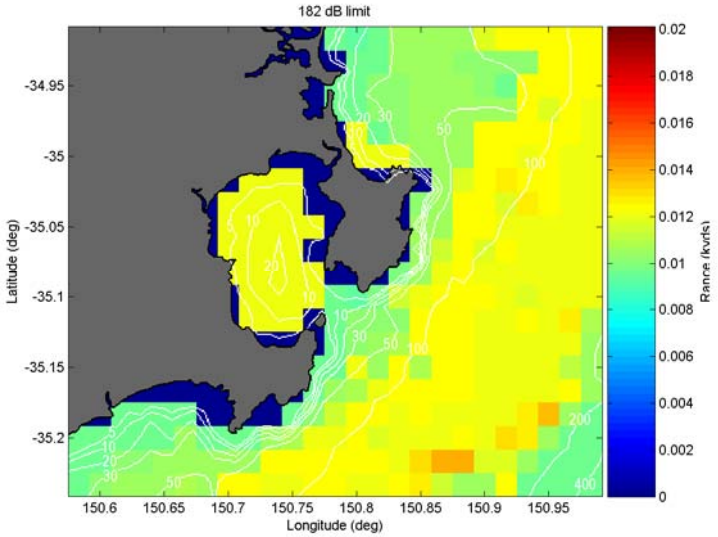

Figure 191: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

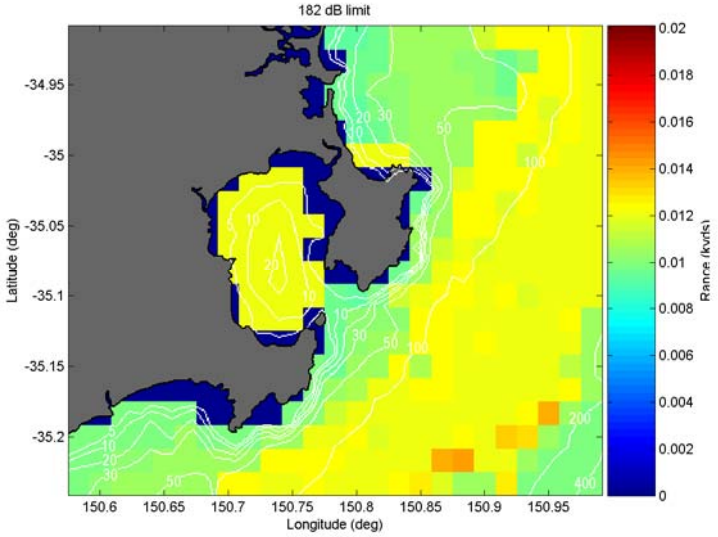

Figure 192: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

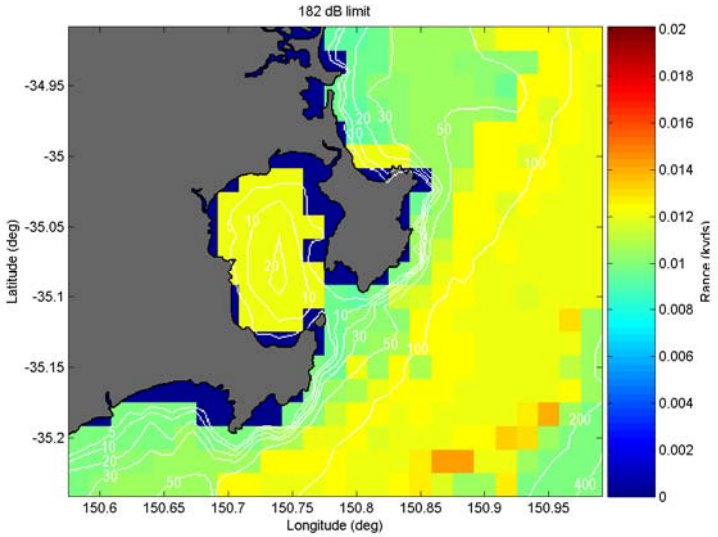

Figure 193: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

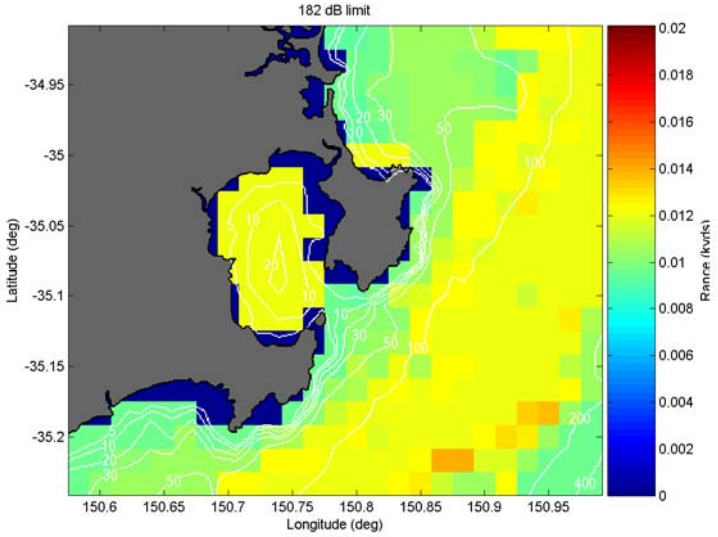

Figure 194: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

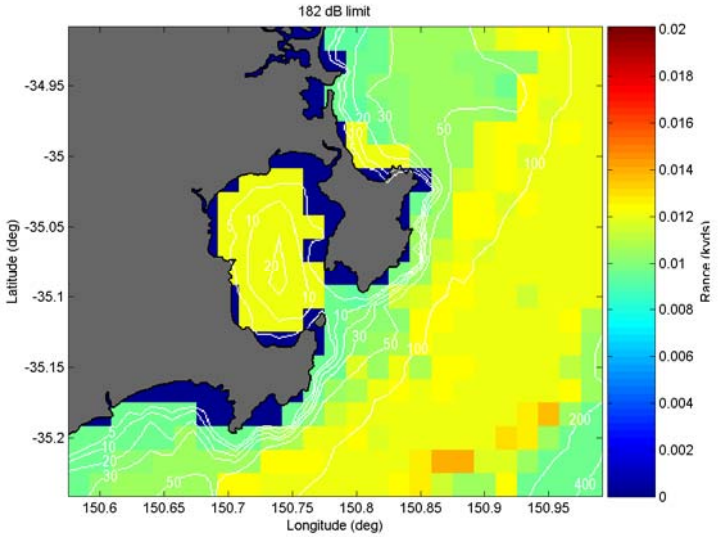

Figure 195: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the Atlas DESO 25 Single Beam Echo Sounder using 33 kHz over coarse sand in Jervis Bay

A.11. Mitigation Ranges for the CMAS Forward Looking Sonar using 36 kHz at 182 dB Received Pressure Limit over Coarse sand in Jervis Bay

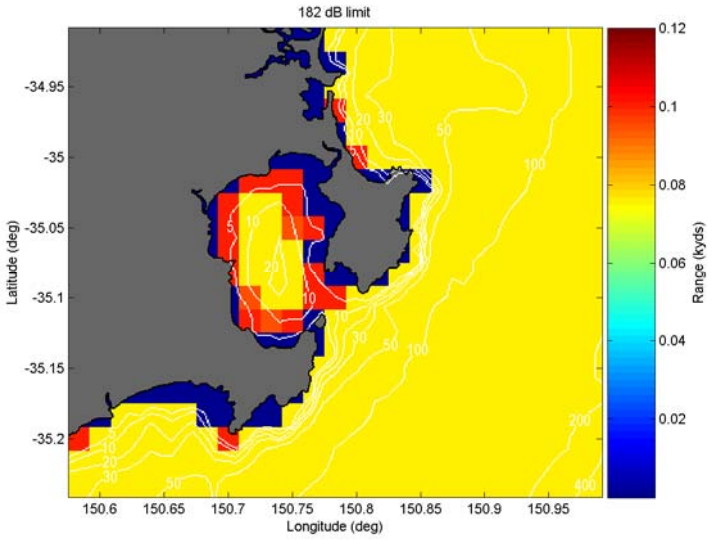

Figure 196: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

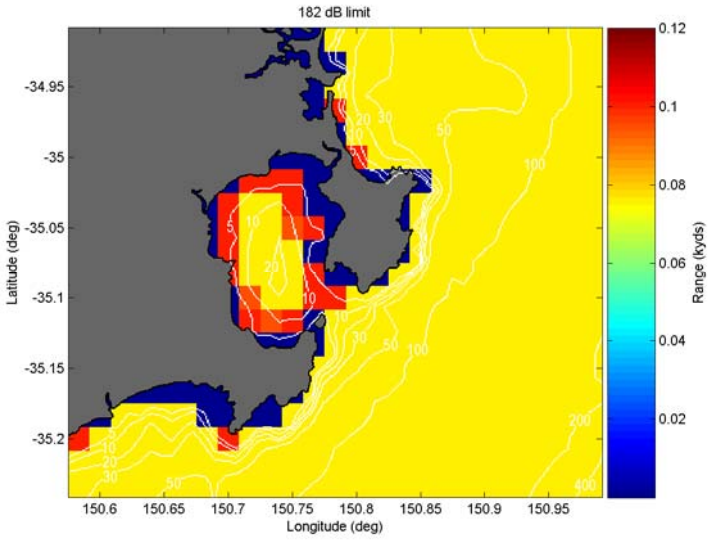

Figure 197: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

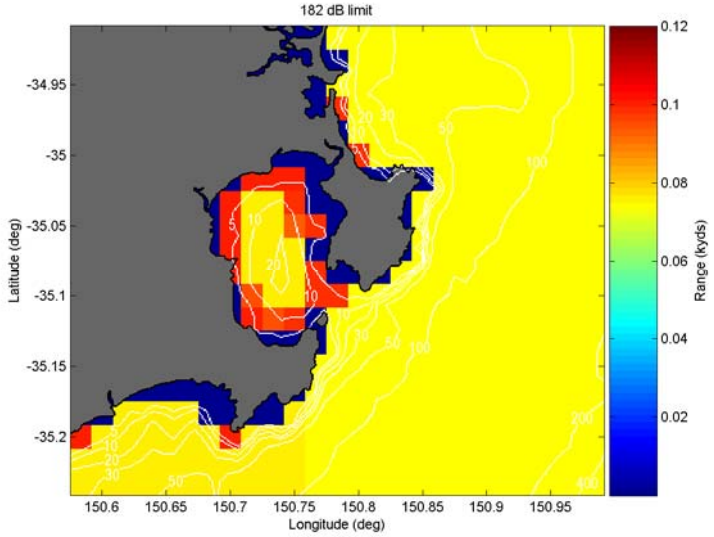

Figure 198: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

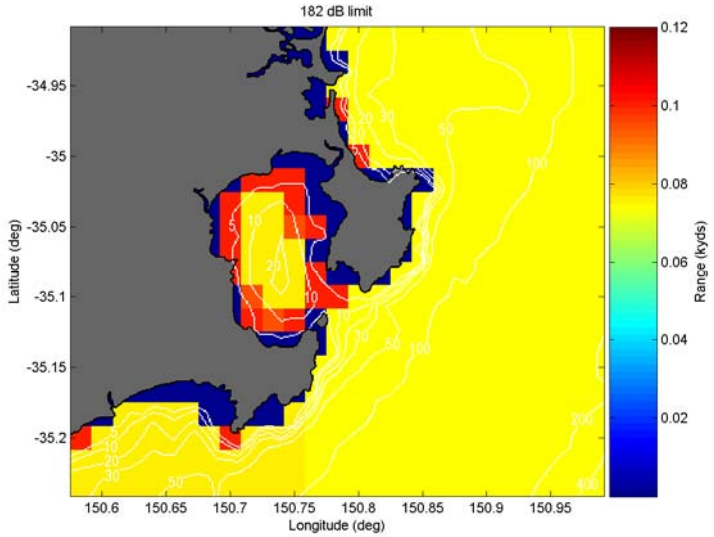

Figure 199: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

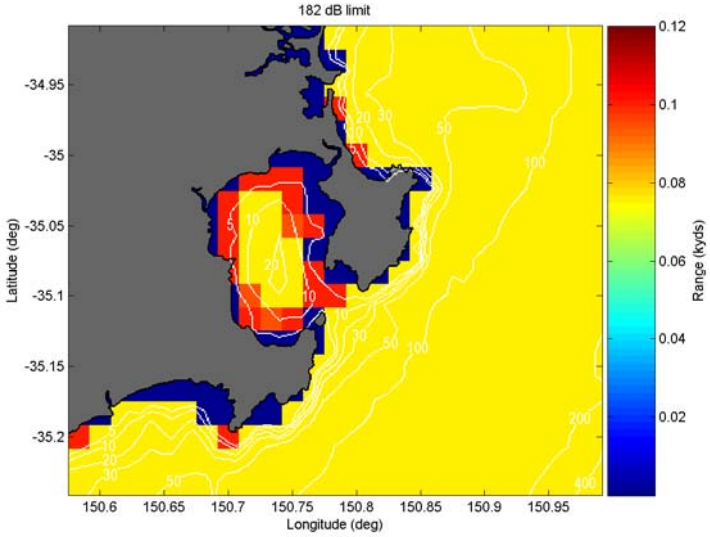

Figure 200: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

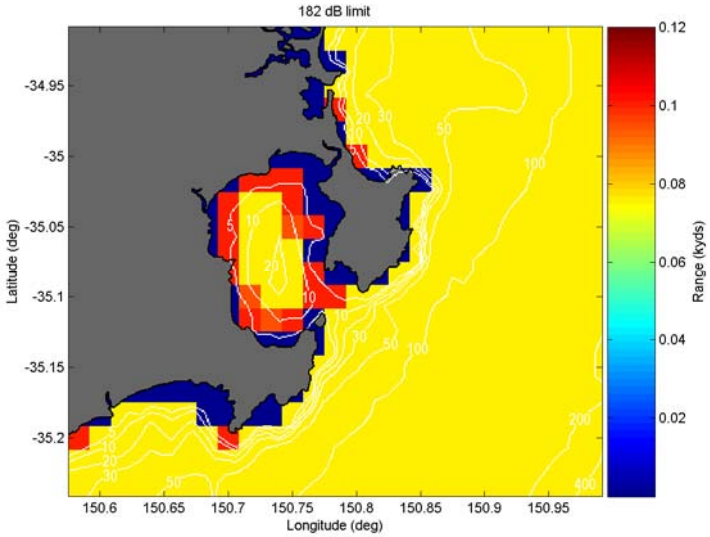

Figure 201: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

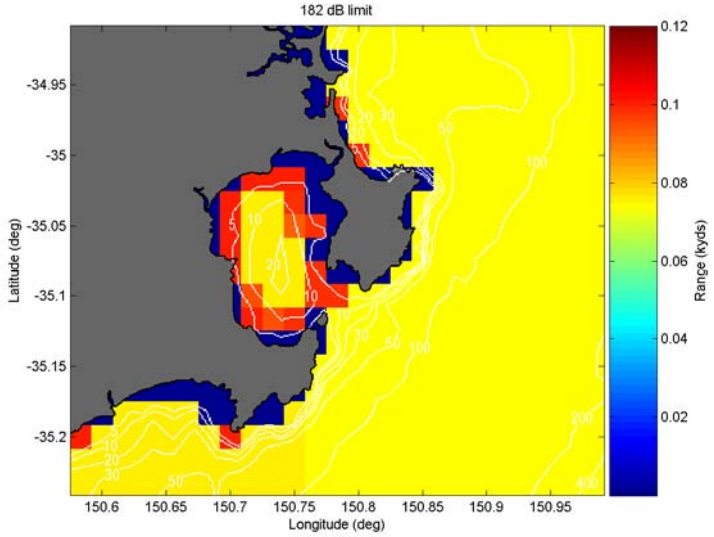

Figure 202: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

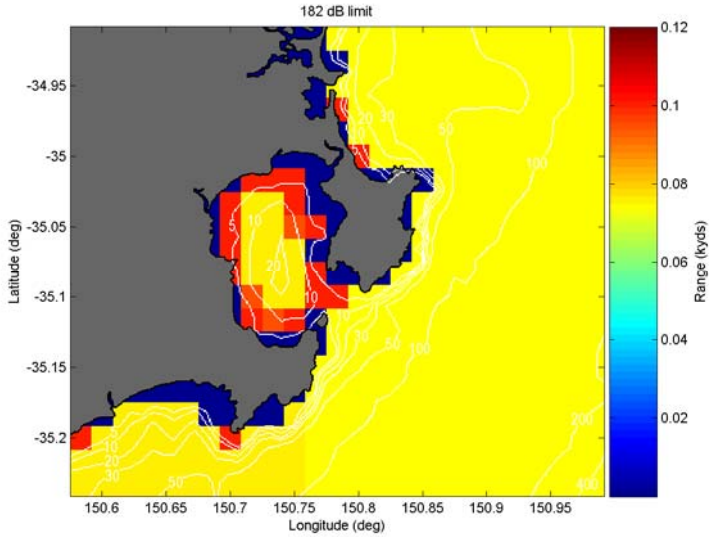

Figure 203: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

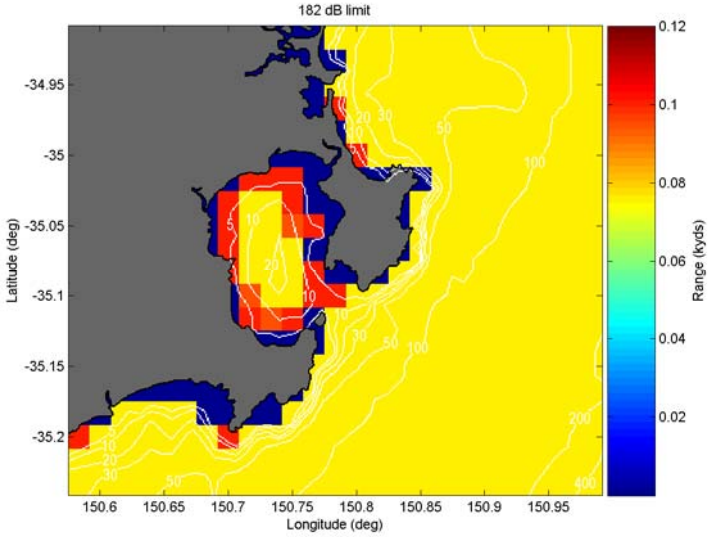

Figure 204: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

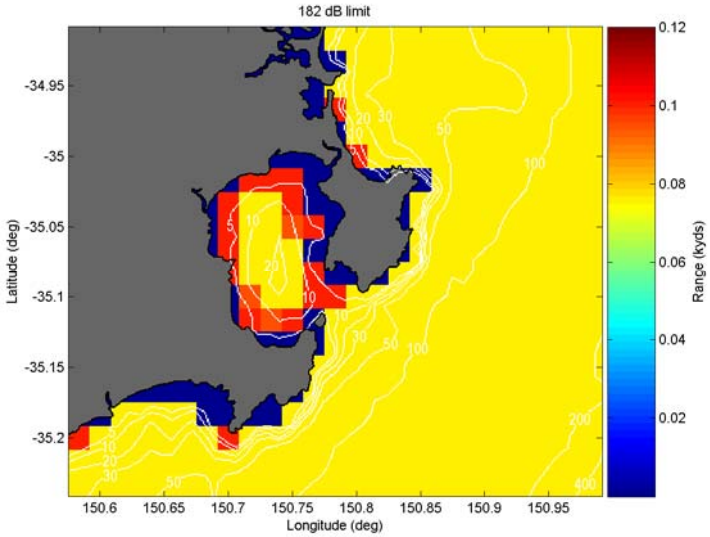

Figure 205: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

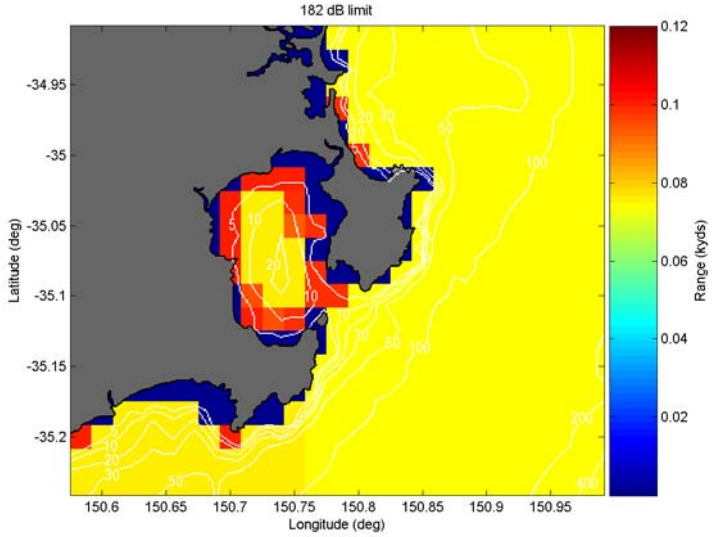

Figure 206: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

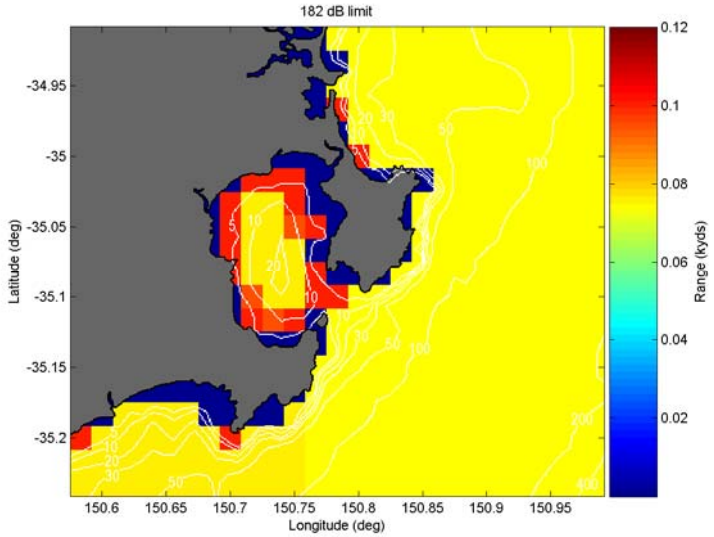

Figure 207: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

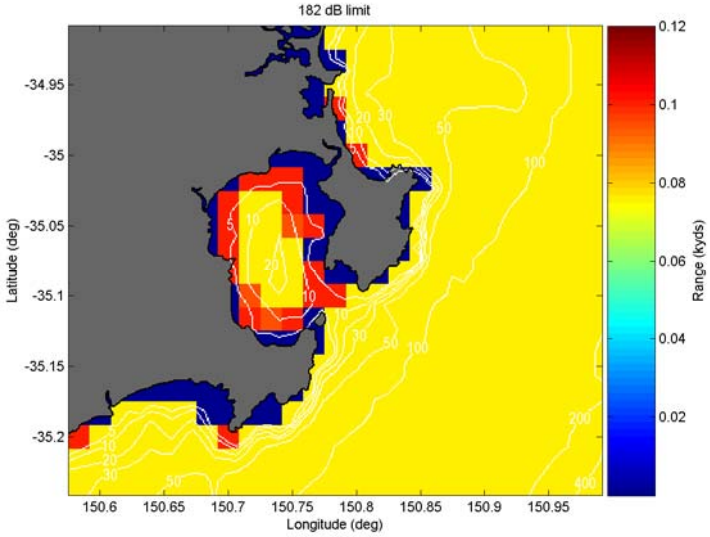

Figure 208: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

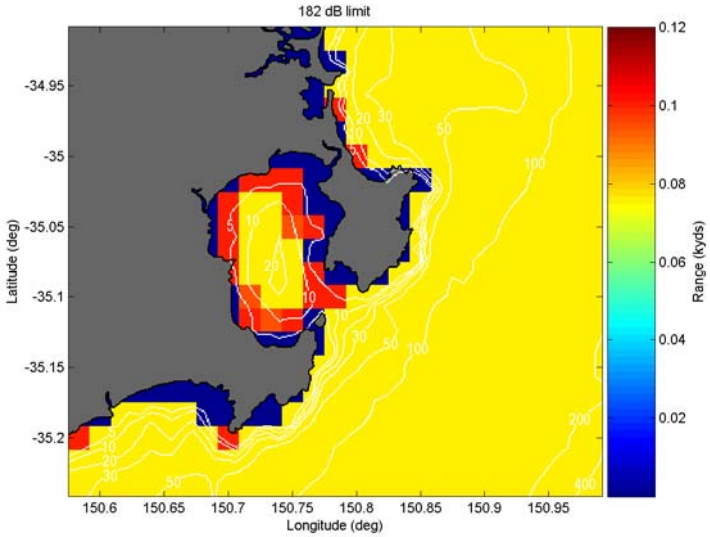

Figure 209: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

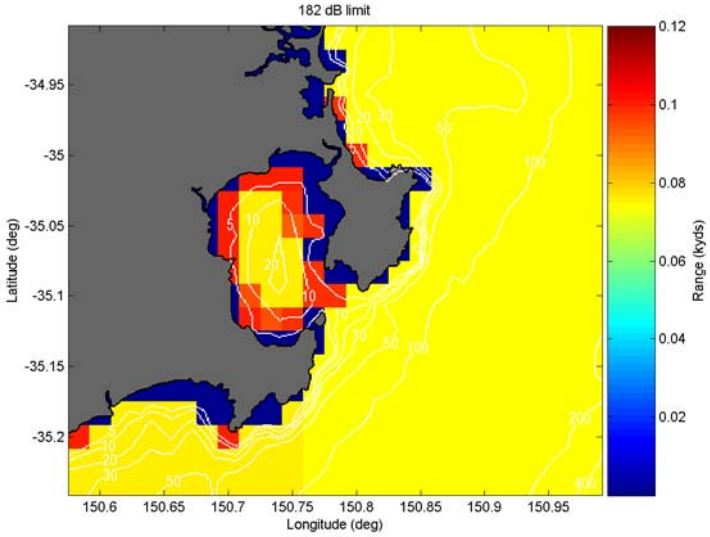

Figure 210: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

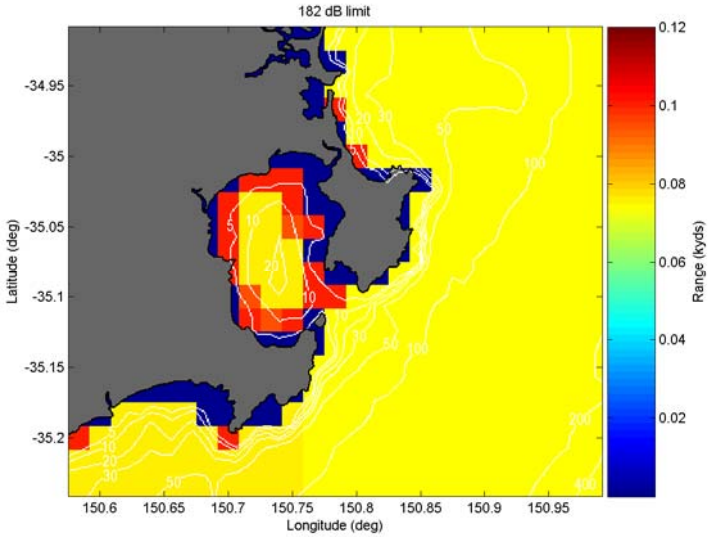

Figure 211: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the CMAS Forward Looking Sonar using 36 kHz over coarse sand in Jervis Bay

A.12. Mitigation Ranges for the CMAS Forward Looking Sonar using 39 kHz at 182 dB Received Pressure Limit over Coarse sand in Jervis Bay

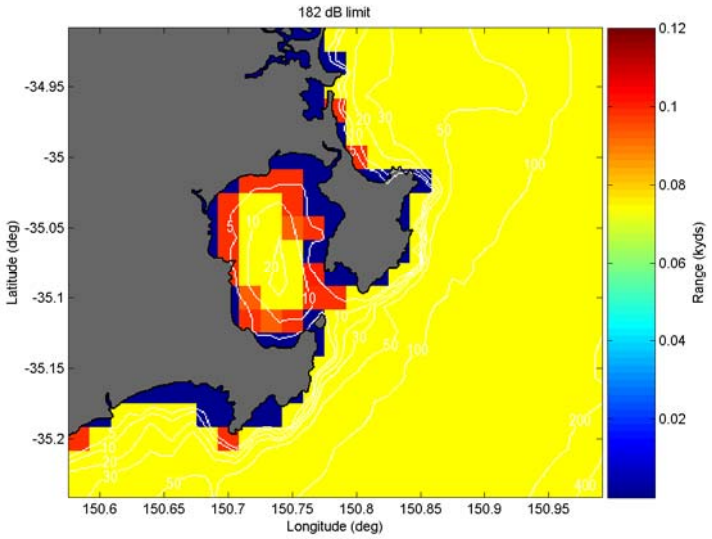

Figure 212: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

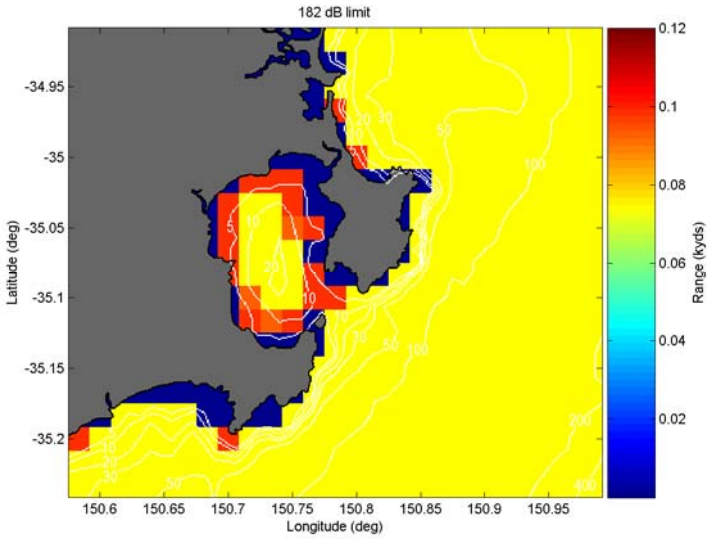

Figure 213: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

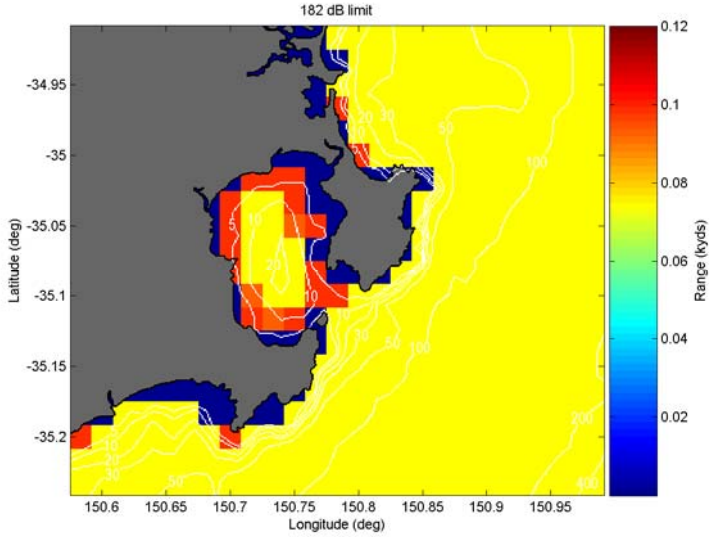

Figure 214: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

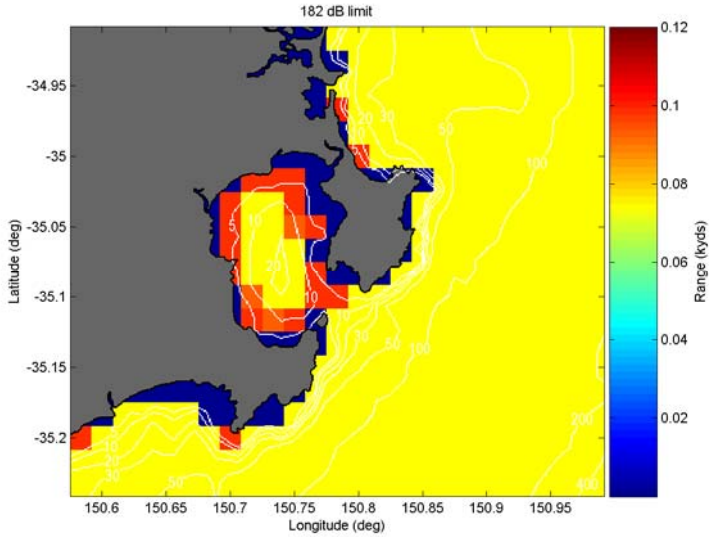

Figure 215: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 0 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

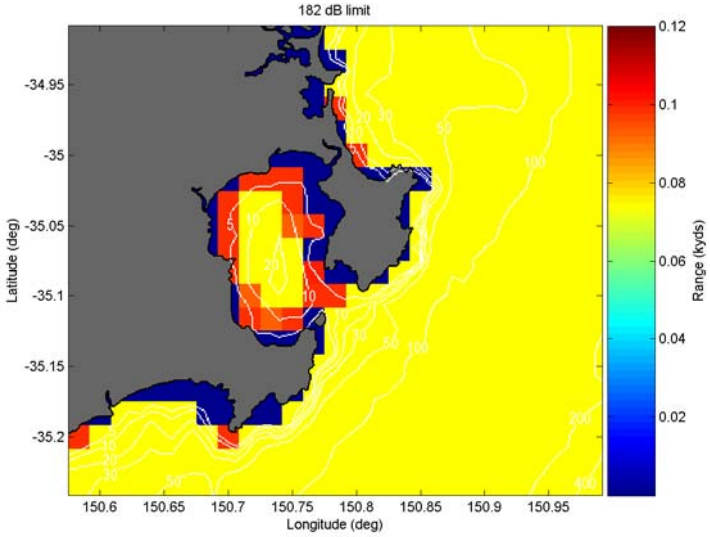

Figure 216: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

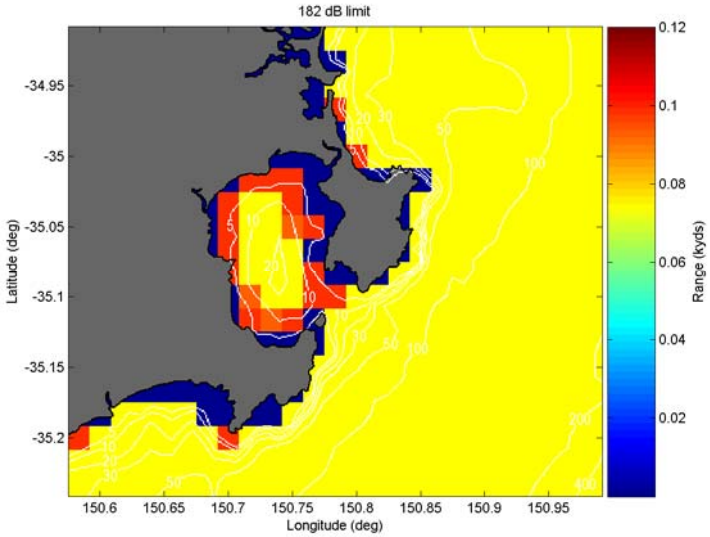

Figure 217: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

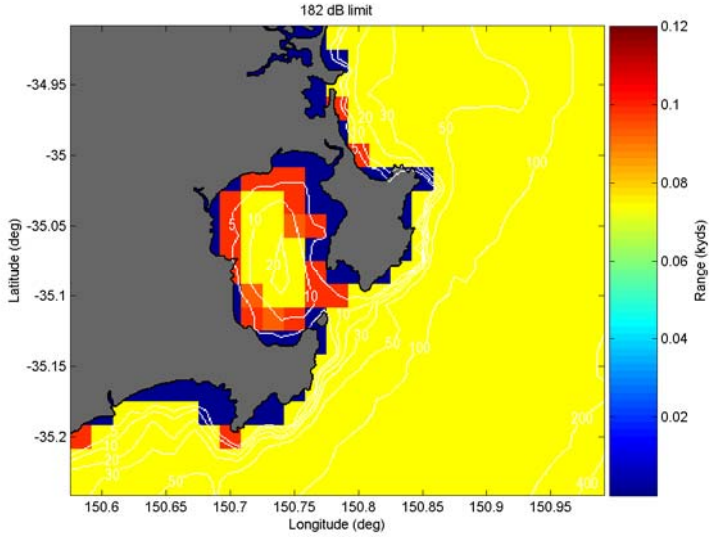

Figure 218: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

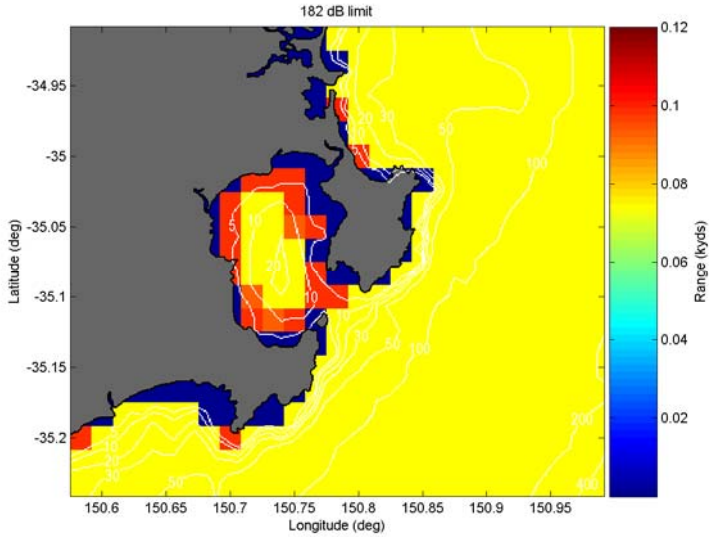

Figure 219: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 1 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

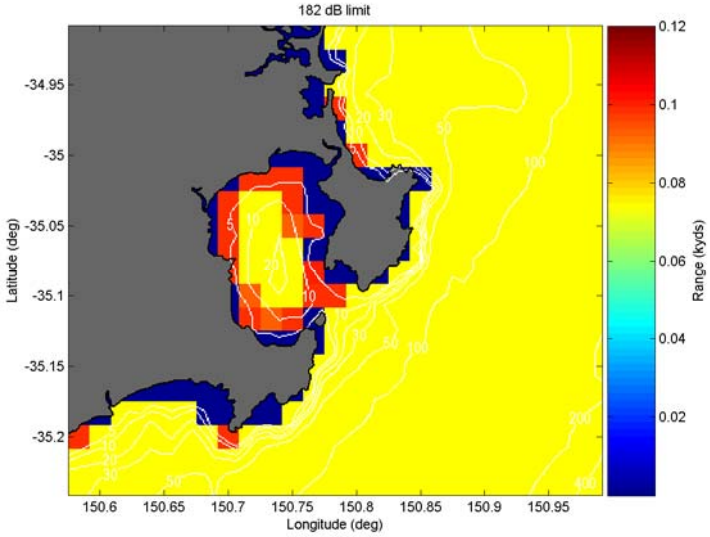

Figure 220: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

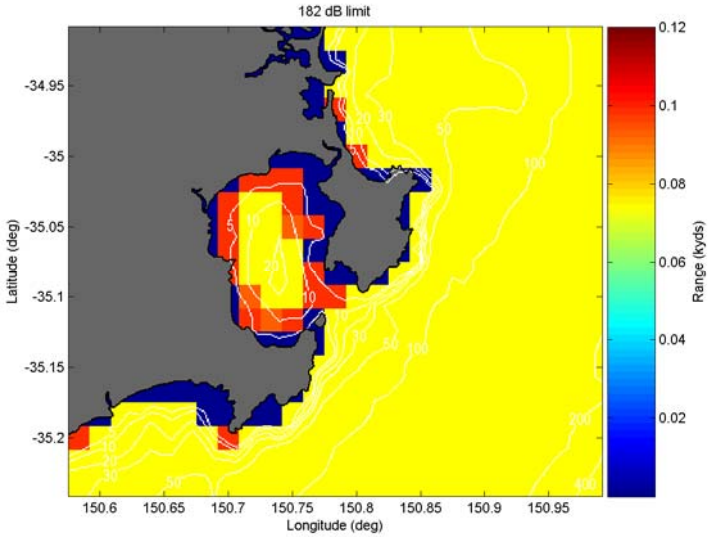

Figure 221: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

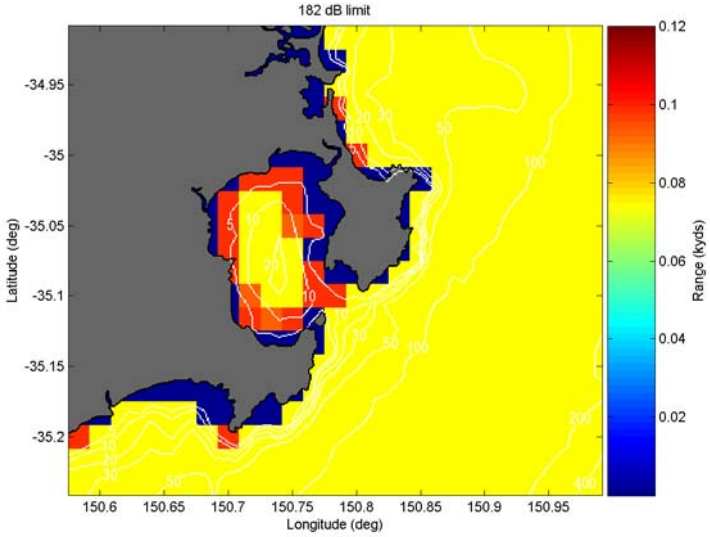

Figure 222: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

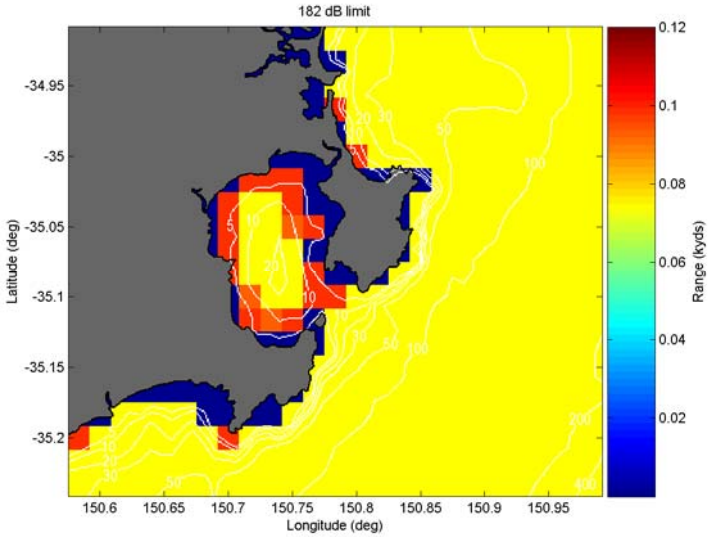

Figure 223: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 2 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

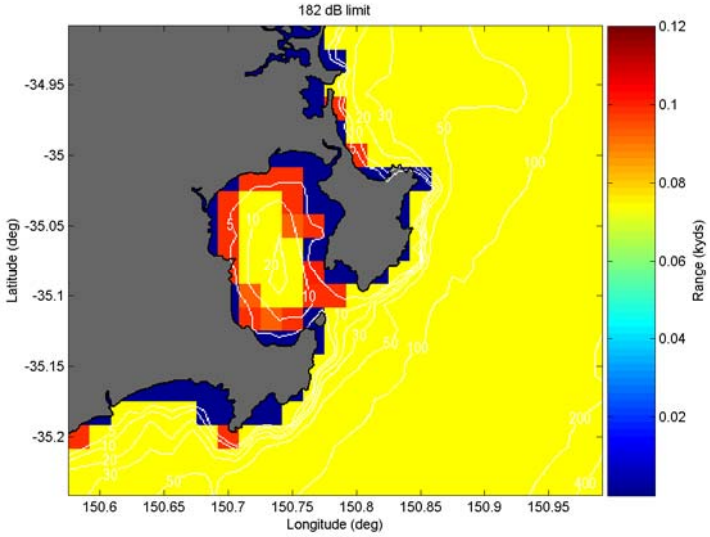

Figure 224: Mitigation ranges required for a received acoustic pressure level of 182 dB during January at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

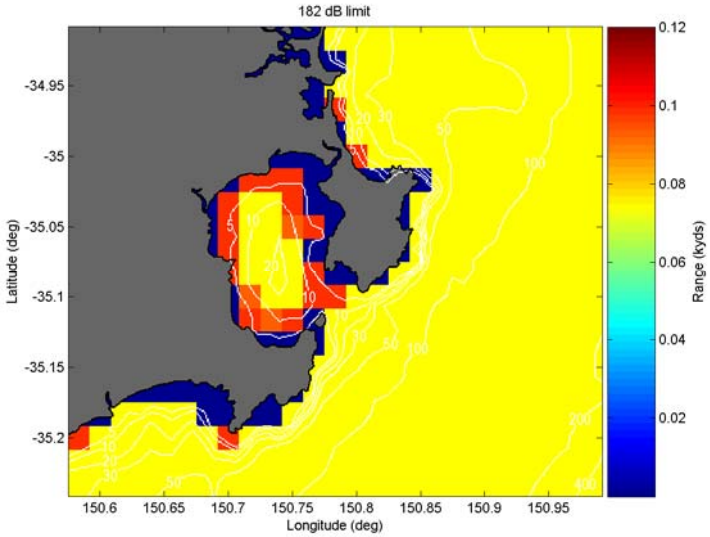

Figure 225: Mitigation ranges required for a received acoustic pressure level of 182 dB during April at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

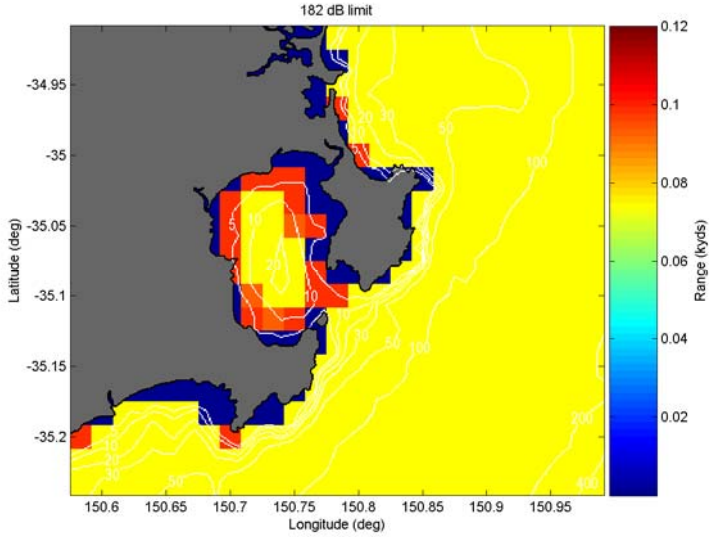

Figure 226: Mitigation ranges required for a received acoustic pressure level of 182 dB during July at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

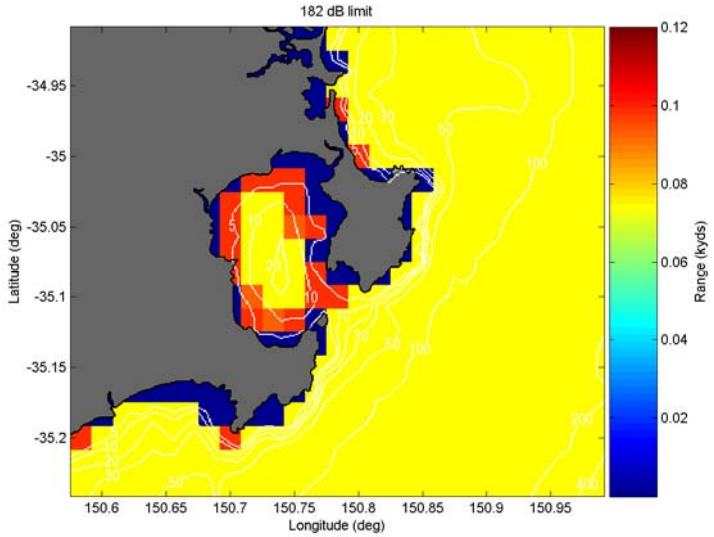

Figure 227: Mitigation ranges required for a received acoustic pressure level of 182 dB during October at sea state 4 on the CMAS Forward Looking Sonar using 39 kHz over coarse sand in Jervis Bay

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
DOCUMENT CONTROL DATA

1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE

Mitigation Modelling of the Leeuwin Class Hydrographic Sonars in Jervis Bay

3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)

Document	(U)
Title	(U)
Abstract	(U)

4. AUTHOR(S)

Paul Clarke

5. CORPORATE AUTHOR

DSTO Defence Science and Technology Organisation
PO Box 1500
Edinburgh South Australia 5111 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-2120	AR-014-170	Technical Report	December 2009

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2007/1100995	NAV 07/085	DGNSPF	124	14

13. URL on the World Wide Web

http://www.dsto.defence.gov.au/corporate/reports/DSTO-TR-2120.pdf

14. RELEASE AUTHORITY

Chief, Maritime Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

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Marine animals, Maritime environments, Signature management, Acoustic models

19. ABSTRACT

Jervis Bay is an important training area for the Royal Australian Navy. To conduct operations in Jervis Bay in an environmentally sensitive manner Navy use mitigation strategies during any training exercises. One such mitigation strategy is to have established stand-off ranges, and to cease sonar operations when a marine mammal is within these ranges. This document describes an improved determination of these stand-off ranges based on the effect of acoustic energy emanating from the Leeuwin class hydrographic ship sonars. Modelling methods used and the mitigation ranges calculated are shown.