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Mitigation measures to reduce entanglements of migrating whales with commercial fishing gear

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1. Executive Summary

2014/004	Mitigation measures to reduce entanglements of migrating whales with commercial fishing gear

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Objectives:

1. Determine and implement appropriate gear modifications and management changes to reduce entanglements with migrating humpback whales
2. Produce fine-spatial and temporal information on whale migrations along the west coast of Western Australia necessary for a tailored spatio-temporal closures and/or areas for gear modifications.
3. Provide clear scientific methods behind the testing of selected gear modifications to reduce whale entanglements
4. Incorporate any new practices that may reduce entanglements with migrating whales in the CoP for the fishery and ensure its extension and adoption

The West Coast Rock Lobster Managed Fishery (WCRLMF) transitioned to a quota based fishery, and year-round fishing, which corresponded with a spike in whale entanglements in 2013. This presented industry with a challenging social issue, to reduce entanglements without impacting on the financial benefits that the shift to year-round quota fishing had afforded. Gear modifications which were identified and trialled as part of FRDC 2013-037 were introduced into the lobster and octopus fisheries off the Western Australian coast. This report examined the effectiveness of these gear modification, and the appropriateness of the management arrangements associated with the gear modifications.

Gear modifications were focused around reduction in the amount of rope and floats used by fishers, and eliminating surface floating rope in deeper waters. Negotiations between the Department of Fisheries (WA) and industry saw refinements to the specifics of the management arrangements due to operational and occupational health and safety issues, though the premise behind the gear modifications remained the same. Fishers operating in waters generally greater than 20 m were required to use no more than three floats (maximum two floats in less than 56 m), and a maximum of two times the water depth worth of rope, with the top ⅓being held vertical in the water column. In addition, fishers were only allowed to 50% of their pot entitlement, further reducing the number of vertical lines in the water.

Entanglements declined after the introduction of gear modifications, with two, four and six entanglements reported in WRLF gear in 2015, 2016 and 2017 respectively. An empirical assessment of gear modification effectiveness, which accounted for changes in fishing effort, increasing whale abundances, various reporting rates and inter-annual variation in the timing of whale migration was undertaken. Modelling indicated that the gear modifications were effective in reducing entanglements by ~60%. Modelling also highlighted the northward migration (May-August) and water depths of 55 – 73 m as the times and areas with the greatest rate of entanglements.

Gear modifications were clearly effective in reducing entanglement rates. Therefore, the second major component of the study was to determine the appropriateness of management arrangement pertaining to the gear modifications. As mentioned previously, gear modifications were generally required in waters > 20 m, though some restrictions also applied in these shallower waters. Modifications are required for the duration of the migration period, from 1 May to 31 October inclusive. These temporal and spatial management arrangements were based on the limited data available on humpback whale migration off the Western Australian coast. Therefore, there was a clear need to better understand the migration dynamics of this population to inform future temporal and spatial management arrangements. This was addressed through satellite tracking of humpback whales to provide fine-spatial scale data, and a more detailed examination of existing data sources.

Sixty-two humpback whales were successfully tagged with satellite transmitters on both their northern and southern migrations between September 2014 and September 2016. Their locations along the west coast of Western Australia where the WCRLMF and octopus fisheries operate revealed that there were very few detections in waters <20 m depth, with detections increasing in waters > 20 m. This corresponded well with the model assessment which indicated waters from 55 m depth being more associated with entanglements. This indicates that the initial assessment requiring more robust gear modifications in deeper waters (> 20 m) was appropriate.

Satellite tracking did highlight how humpback whales migrate relative to the location of the Leeuwin Current, a southward flowing, warm water current and dominant oceanographic feature of the west Australian coast. During their northern migration they migrate inshore of the current, and utilise the southern flow of the current on their southern migration. As the Leeuwin Current strength varies inter-annually, so does its location, with the stronger flow years seeing the current more prevalent on the continental shelf. This is therefore likely to influence the location of migrating humpback whales. Indeed, the 2013 season when entanglement reports in WCRLMF gear peaked, the Leeuwin Current was flowing strongly and pushed across the continental shelf. This is likely to have forced northern migrating whales into shallower waters, causing a greater overlap with fishing gear and hence an increase in entanglements. Therefore, while the current assessment revealed few detections of tracked whales in shallow (<20 m) water, this was over two years with relatively weak Leeuwin Current flow, suggesting that more shallow water detections may occur in stronger current years.

Commercial whale watching vessel logbooks were used to examine possible inter-annual changes in the timing of humpback whale migration. A standardised mean timing of peak abundances revealed a generally very consistent inter-annual trend in the timing of whale migration. For nine of the 13 years from 2000 to 2012, the peak in whale abundances occurred within a one-week period. There were some significant deviations from this, with peak whale abundances occurring almost two weeks earlier in 2006 and 2013. Prior to the recent increase in whale entanglements, 2006 was the previous high for entanglements, while 2013 represents the current peak in whale entanglements in the WCRLMF. There was also a clear distinction in the general timing of migrations after 2012, with more recent years occurring generally a week earlier than pre 2013 migrations. With a relatively consistent timing of migration, and significant deviations from this being in the order of two weeks, the current start of the gear modification period appears to be appropriate. Modelling indicated that the northern migration was most associated with entanglements, with few entanglements associated with the southern migration (September – November). Therefore, based on current available data, there may be scope to shorten the gear modification period, though consideration should be given to the increase in risk of permitting fishing during this period as this is when mothers with calves migrate south, and may cause a significant public issue should they be reported entangled in gear which had previously required modifications.

An assessment on the effectiveness of acoustic alarms as another gear modification to reduce whale entanglements was undertaken. Southbound humpback whales were tracked moving through four arrays of modified lobster fishing gear. This gear had acoustic alarms placed on them on random days during the 10-day trial, and responses of whales to the alarms were examined. There was no difference in the movement patterns of whale through the arrays when alarms were present or absent, indicating that there was no overt directional change elicited by whale alarms.

This project provided a robust assessment that gear modifications introduced into the WCRLMF and octopus fisheries have reduced the number of reported entanglements. The management arrangements around the implementation of these modifications are appropriate in light on the new spatial and temporal information on the migratory behaviours of humpback whales off the west Australian coast. Therefore, it is recommended that the current management arrangements that are in place to reduce whale entanglements remain. It should be noted however, that while gear modifications have been effective, the whale population off the west Australian coast is predicated to continue to increase. As a result, entanglements may increase in the future as a result of this population increase, and additional research may be required to assess possible additional gear modifications or management arrangements.

2. Introduction

Several large cetaceans migrate past the west Australian coast including the southern right whale *Eubalaena australis*, pygmy right whale *Caperea marginata*, minke whale *Balaenoptera acutorostrata*, sei whale *Balaenoptera borealis*, Bryde's whale *Balaenoptera edeni*, blue whale *Balaenoptera musculus*, fin whale *Balaenoptera physalus* and humpback whale *Megaptera novaeangliae* (Bannister et al. 1996). Generally, only humpback and southern right whales, which are a coastal species, become entangled in commercial fishing gear. In an assessment of entanglements off the Western Australian coast humpback whales were the dominant species involved in >90% of entanglements (Groom and Coughran 2012a), with this pattern continuing over recent years (How et al. 2015).

Entanglements in have been confirmed in gear from 10 fisheries in Western Australia with most occurring in the West Coast Rock Lobster Managed Fishery (WCRLMF) (Groom and Coughran 2012a, How et al. 2015). The WCRLMF is Australia's largest single species wild-caught fishery. It is almost exclusively an export fishery with an estimated annual GVP of over $400 million. In 2010, the fishery transitioned from an effort controlled to a quota based fishery, which among other management changes saw an increase in the season length. By the 2013 season, the fishery was operating year round. The shift to more winter fishing, which was the fishery's traditional off season, resulted in an increase in the number of humpback whale entanglements (How et al. 2015).

Whale entanglements peaked in 2013 with 31 overall and 17 in WCRLMF. This coupled with the progressive increase from zero entanglements in 2010 saw a number of conditions from the Federal government placed on the WCRLMF to reduce whale entanglements and maintain access to export markets. A closure to lobster fishing during the humpback migration (1 May-30 Nov) was estimated to potentially reduce the gross value of production for the fishery by ~$50 – $100 million. Therefore a series of mitigation options were identified and assessed as part of FRDC 2013-037 (How et al. 2015). This was a preliminary study and detailed gear testing and migration information was not possible in the scope of the project. Therefore, it was necessary to assess the effectiveness of gear modifications while accounting for changes in fishing effort distribution, reporting rates of entanglements and an increasing whale population.

Humpback whales off Western Australia were commercially exploited until the closure of the whaling station off Carnarvon in 1963. At that time, the population was estimated to be approximately 800 individuals (Chittleborough, 1965; Ross-Gillespie et al., 2014). Estimates of current population size for this stock of humpback whales is difficult (Hedley et al., 2011b; Jackson et al., 2015) but a recent stock assessment model puts the population size around 20,000 (Ross-Gillespie et al., 2014), with estimates of its increase as high as 12% per annum (Hedley et al., 2011b). This recovery has seen recent work suggesting that the population should no longer be considered as 'threatened' (Bejder et al. 2015).

Research from commercial whaling (Chittleborough 1965), surveys (Jenner et al. 2001b) and satellite tracking (Double et al. 2010, 2012a) have provided some preliminary information on the movement patterns of this stock along the west Australian coast. Whales leave Antarctic feeding areas usually between 70-130º E (Chittleborough, 1965; Figure 1) before migrating north to the west Australian coastline. While some whales arrive from April, most whales move through from May to November (Groom and Coughran 2012a), moving north to calving / breeding grounds on the states north coast (Jenner et al. 2001b). Surveys from Point Cloates (Figure 1) showed that the changed from a net northerly to net southerly migration for whales occurred in late August (Chittleborough, 1965) when they migrate back to feeding grounds in Antarctica (Jenner et al. 2001b). These studies provide a good broad understanding of the humpback whale migration, but lack the fine scale details necessary for spatial management to mitigate whale entanglements.

The detailed spatial data necessary for some spatial management approaches required satellite tracking. Some satellite tracking of humpback whales has occurred in Western Australia, though they were concentrated on understanding whales movements in the calving / breeding grounds on the north coast of Western Australia (Double et al. 2010, 2012a). However, the majority of reported entanglements occur on the mid and lower west coasts of Western Australia (Groom and Coughran 2012a, How et al. 2015), with these previous satellite tracking studies only providing limited data from four whales which traversed the mid and lower west coasts.

Therefore this project extends on the initial project (How et al. 2015) to statistically examine the effectiveness of introduced gear modifications, and provide more detailed spatio-temporal information on whale migration to better inform current or future entanglement mitigation management options.

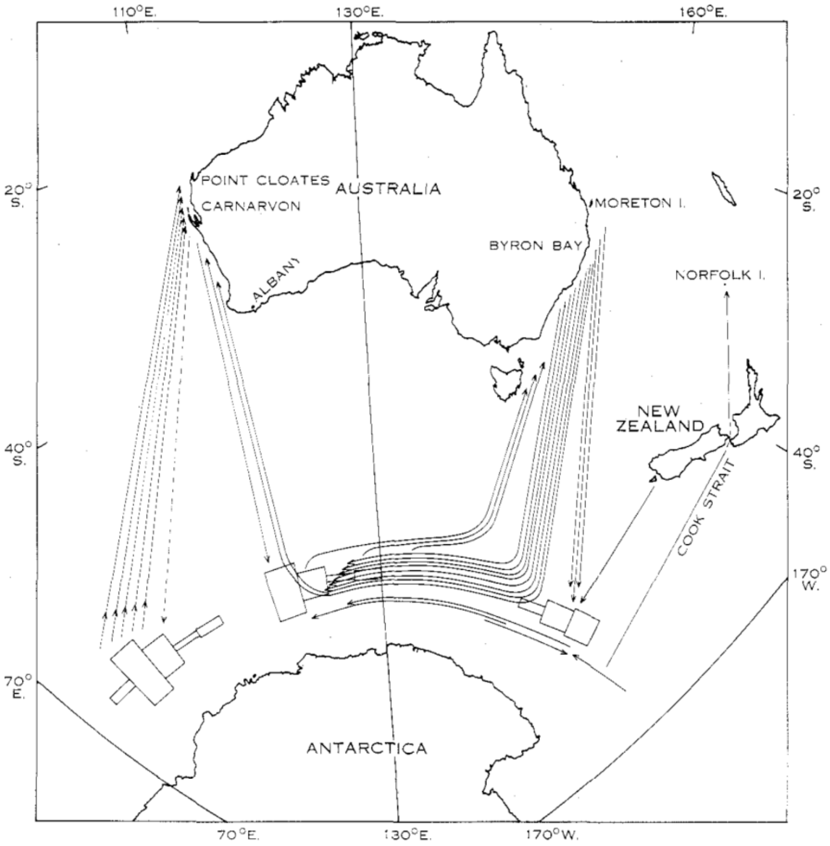


Figure 1 Individual movements (simplified) by 27 marked whales whose recapture provided evidence of migrating behaviour in 1958-59. Rectangles indicate location of Antarctic humpback whale catch in February 1959 (Chittleborough 1965).

3. Objectives

1. Determine and implement appropriate gear modifications and management changes to reduce entanglements with migrating humpback whales
2. Produce fine-spatial and temporal information on whale migrations along the west coast of Western Australia necessary for a tailored spatio-temporal closures and/or areas for gear modifications.
3. Provide clear scientific methods behind the testing of selected gear modifications to reduce whale entanglements
4. Incorporate any new practices that may reduce entanglements with migrating whales in the CoP for the fishery and ensure its extension and adoption

4. Method

4.1 Determine and implement appropriate gear modifications and management changes to reduce entanglements with migrating humpback whales

4.1.1 Gear Modifications and Implementation

Potential gear modifications were examined previously (How et al. 2015). These gear modifications were then presented to an Operational Whale Entanglement Reference (OWER) Group consisting predominantly of active western rock lobster and octopus fishers. The OWER recommendations were intern presented to government and industry representatives through a Ministerial Taskforce. Recommendations once ratified by the Ministerial Taskforce, were presented to the Minister who legislated the gear modifications.

These gear modifications came into effect on 1 June 2014, though an educative approach was adopted for the first month to allow fishers to adjust to the rapid implementation of the regulations. Therefore, 1 July was the beginning of mandatory gear restrictions and modifications. At the conclusion of each whale migration season the OWER met to discuss the mitigation measures, with recommendations progressing through the Taskforce before either being endorsed and regulated or rejected.

Mitigation measures were highlighted to industry at annual management meetings (see Extension and Adoption) and also through updates to the code of practice (Appendix 2, Appendix 3, Appendix 4).

4.1.1.1.1 West Coast Rock Lobster Managed Fishery

Gear restrictions were a reduction in float numbers and rope length used, while gear modifications were introduced to eliminate surface rope in waters generally deeper than ~20 m (Table 1; Figure 2). A number of operational or occupational health and safety measures were identified by industry which led to a few minor changes to the gear restriction regulations in the ‘shallow’ waters (Table 2). These operational or safety issues primarily occurred when using the maximum unweighted rope (Table 2) at depths which were at the limit fishing that rope length’s capacity. Despite this the overall objectives of reduced rope length and float numbers, with no surface rope in “deeper” water remained. In addition, fishers were only allowed to fish with 50% of the pot entitlement, further reducing the number of vertical lines in the water.

Table 1 Gear modification requirements for maximum rope length, surface rope, floats and float rig length and periods between pulling pots for both shallow and deep water. * Shallow water was defined by the depth that could be fished with the maximum unweighted rope component (see Table 2) (adapted from Bellchambers et al. 2017).

	Shallow Water * (~< 20 m)	Deeper Water (> 20 m)
Rope length	No rope / water depth ratio	Rope (bridal-float) < 2x water depth
Surface rope	Surface rope permitted	No surface rope [negatively buoyant rope (top third)]
Float rig	Float rig inc. in total rope	Max float rig 5 fathoms (inc. tail)
Floats	Max. 2 floats	Max. 2 floats (<30 fathoms)
		Max. 3 floats (>30 fathoms)
Pull Period	No max pull period	Pots pulled once every 7 days

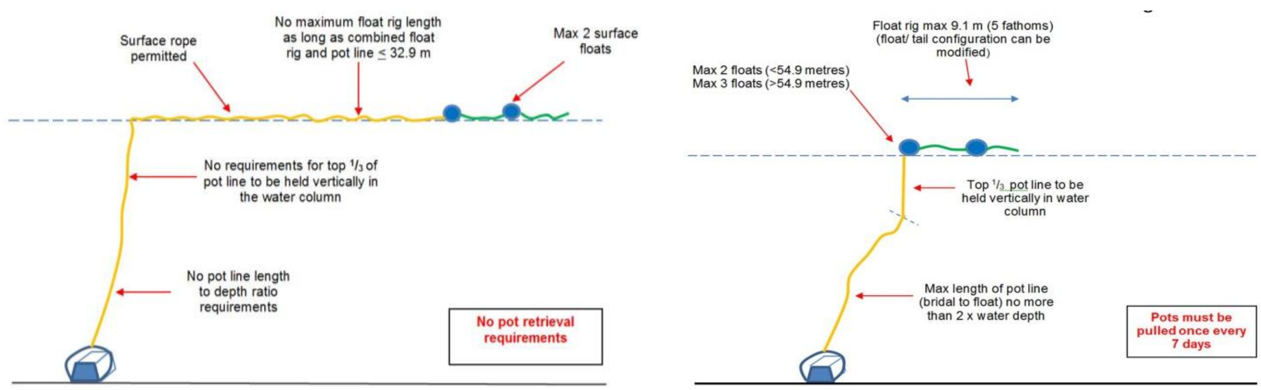


Figure 2 Diagrammatic representation of the gear modifications required in a) shallow (~<20 m) and b) deep (~>20 m) water depth

Table 2 Changes to the maximum unweighted rope and season timings by season since the gear modifications were introduced. (adapted from Bellchambers et al. 2017).

Season	Maximum Unweighted Rope	Whale mitigation season
2014	15 fathoms	1 Jul – 14 November
2015	18 fathoms (inside whale zone[1])	1 May – 14 November
2016 & 2017	18 fathoms	1 May – 31 October

[1] The ‘whale zone’ was a defined region within the fishery that generally encompassed waters less than 20 m (Figure 3).

Figure 3 The ‘whale zone’ which was implemented for the 2015 migration season to demarcate the “shallow” water where gear modifications were not required

4.1.1.1.2 Octopus Interim Managed Fishery and Cockburn Sound Line and Pot Managed Fishery

Gear modifications were also introduced to the two octopus fisheries, Octopus Interim Managed Fishery (OIMF) and Cockburn Sound Line and Pot Managed Fishery (CSLPMF). They covered the full extent of the CSLPMF and Zones 1 and 2 of the OIMF, which both occur on the state's west coast.

Due to the different fishing methods in the octopus fisheries, two sets of gear modifications were available to fishers. Those fishers that longlined (a series of pots/cradles connected by an underwater line) must have at least 20 pots/cradles per longline. This served to reduce the number of vertical lines in the water column. They had no other restrictions on their gear configuration. Those fishing with less than 20 pots (usually fished as single pots/cradles) were required to have no surface rope with at least one third of the line held vertical in the water column. Gear modifications in both octopus fisheries, regardless of fishing method, were from 1 May to 14 November in all water depths. There were no alterations to the gear restrictions in these two octopus fisheries since their initial implementation, as had occurred in the rock lobster fishery (Table 2).

4.1.2 Fisher Surveys

As part of a preliminary assessment of gear modifications, an on-line survey (Appendix 5) was conducted of fishers regarding their perceptions of the gear modifications and the whale migration. A total of 53 fishers undertook the survey from ports throughout the fishery. This was collected to provided supplementary anecdotal data to corroborate statutory effort returns (Methods: West Coast Rock Lobster Managed Fishery – Fishing Effort) and official entanglement reports (Methods; Cetacean Stranding Database).

4.2 Produce fine-spatial and temporal information on whale migrations along the west coast of Western Australia necessary for a tailored spatio-temporal closures and/or areas for gear modifications.

4.2.1 Temporal Information

Data sources to examine the temporal components of the humpback migration along the West Australian coast included Cetacean Stranding Database, Commercial Whale Watching Logbooks and sightings from the commercial operators and members of the public. Full details of these data streams can be found in How et al. (2015).

4.2.1.1.1 Cetacean Stranding Database

Entanglements or interactions of cetacean species with gear in the ocean were systematically recorded and entered into the Department of Parks and Wildlife cetacean stranding database. The date, species, gear type, reporter, fate and location among other variables are recorded. An entanglement was deemed an interaction with equipment in the ocean (generally fishing gear), from which the whale is observed to be carrying gear and is unable to release itself. This is distinct from interactions where the whale is observed coming into contact with gear and is able to free itself or reports of entanglement scarring on whales where no gear is present.

4.2.1.1.2 Commercial Whale Watching Logbooks

Vessels licenced to undertake commercial whale watching activities in Western Australia are required to provide a daily return. These vessels undertake multiple trips per day with each trip consisting of a number of encounters. For each encounter operators record the number and species of whales encountered and the location (GPS) and environmental conditions for each contact.

4.2.1.1.2.1.1.1 Analysis

A re-examination of the commercial whale watching logbooks resulted in a similar regional approach adopted to that of How et al. (2015), though with additional regions incorporated (Figure 4). For regions with sufficient inter-annual coverage (Table 6), a linear model incorporating factors of region and year was used to assess the day of the year when whale watching encounters occurred, weighted by the number of whales seen. This produced a mean (±95 CI) estimate of year day standardised by area for each year from 2000-2017.

4.2.1.1.3 Whale Sightings

Whale sightings were supplied by water users through several means. Some commercial fishers returned logbooks of whale sightings though the vast majority were available electronically through either the WhaleSightingsWA app or recorded on their catch disposal records which are either electronically submitted or digitised from paper forms.

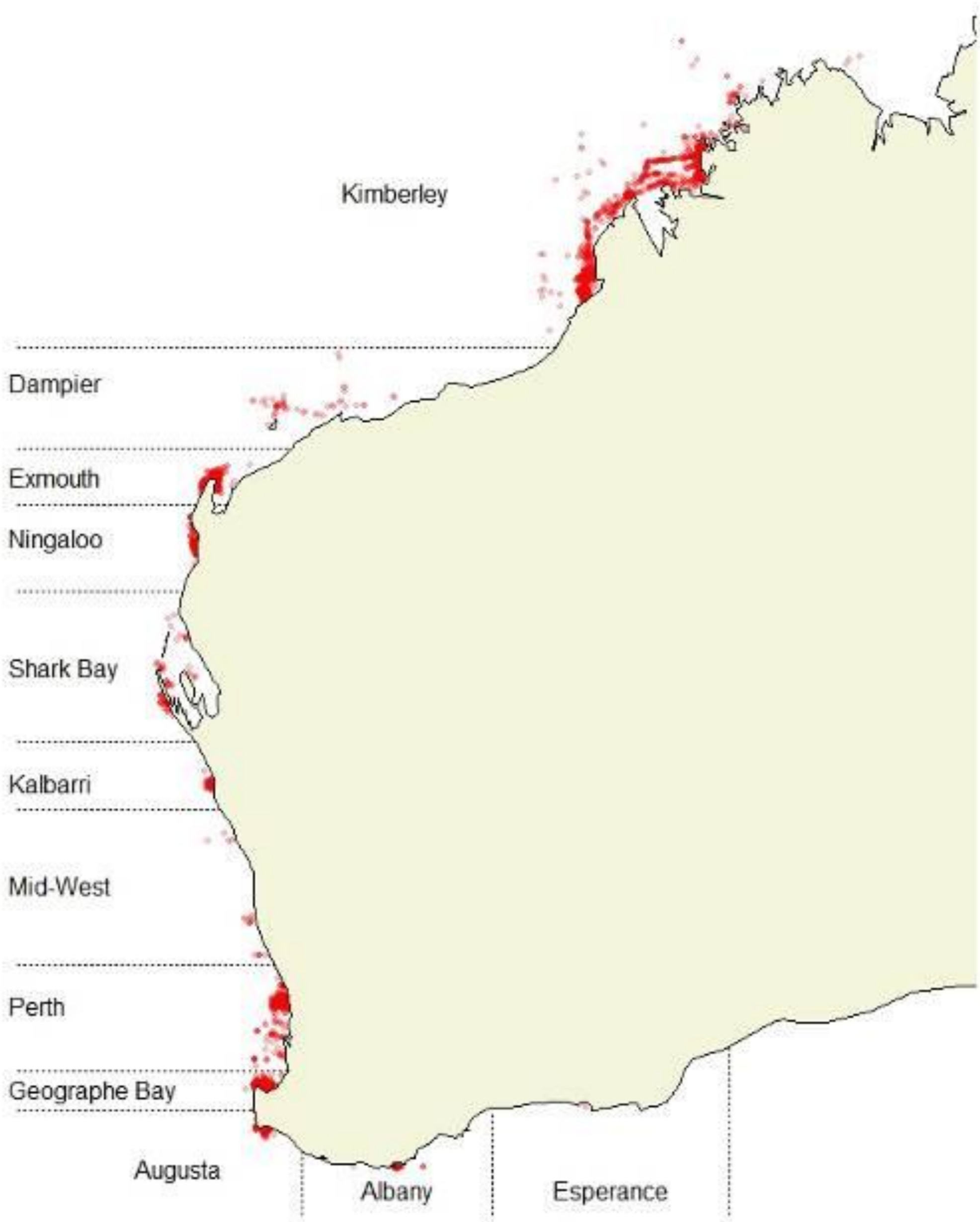


Figure 4 Location of commercial whale watching encounters (red) and their associated region (marked by dotted lines)

4.2.2 Spatial Information – Satellite Tracking

Tagging of migrating humpback whales occurred at the northern and southern extent of the West Coast Rock Lobster Managed Fishery (WCRLMF). Northern migrating whales were tagged at the southern border of the fishery off Augusta, while southern migrating whales were tagged at, or near the northern border of the fishery in Exmouth and Carnarvon (Figure 5). The prevailing weather conditions for each trip played a significant part in where whales could be successfully tagged. At Augusta, favourable weather conditions in 2015 permitted tagging west of the cape. This wasn't possible in 2016, resulting to whales tagged within the bay (Figure 5). Tag deployments occurred just off Carnarvon in 2014, though tagging opportunities here were considerably reduced in 2016 due to prevailing weather conditions. This resulted in whales being tagged not only off Carnarvon, but also in Exmouth Gulf, and the northern part of Dirk Hartog Island (Figure 5).

Tagging was conducted from a 5.45 m fiberglass rigid-hull inflatable vessel equipped with a modified tagging bowsprit. A typical crew of three was aboard, with the tagger located on the bow sprit, biopsy shooter seated forward of the centre console with the skipper at the helm (Plate 1). Whales were approached gradually, with the vessel accelerating as the whale surfaced such that the tagger was parallel to the whale as it surfaced at a distance of 2-6 m. The satellite transmitter was deployed using a 'rocket' fired from a pneumatic tagging gun (Restech-Mini) which causes the transmitter to be implanted on impact, with the 'rocket' bouncing off the whale's blubber and being retrieved from the water.

A biopsy sample was also taken when possible, using a modified .22 calibre rifle with a large bore barrel (Paxarm). The rifle fired a plastic dart with a stainless steel biopsy head propelled using .22 blank charges. This enabled a small skin sample to be taken to determine the sex of the individual. The biopsy sample shot was taken immediately after the tagger fired to minimise the contact time (whale actively pursued) with the whale. Biopsies were stored in 70% ethanol before subsequent genetic analysis for sex determination as per Double et al. 2012.

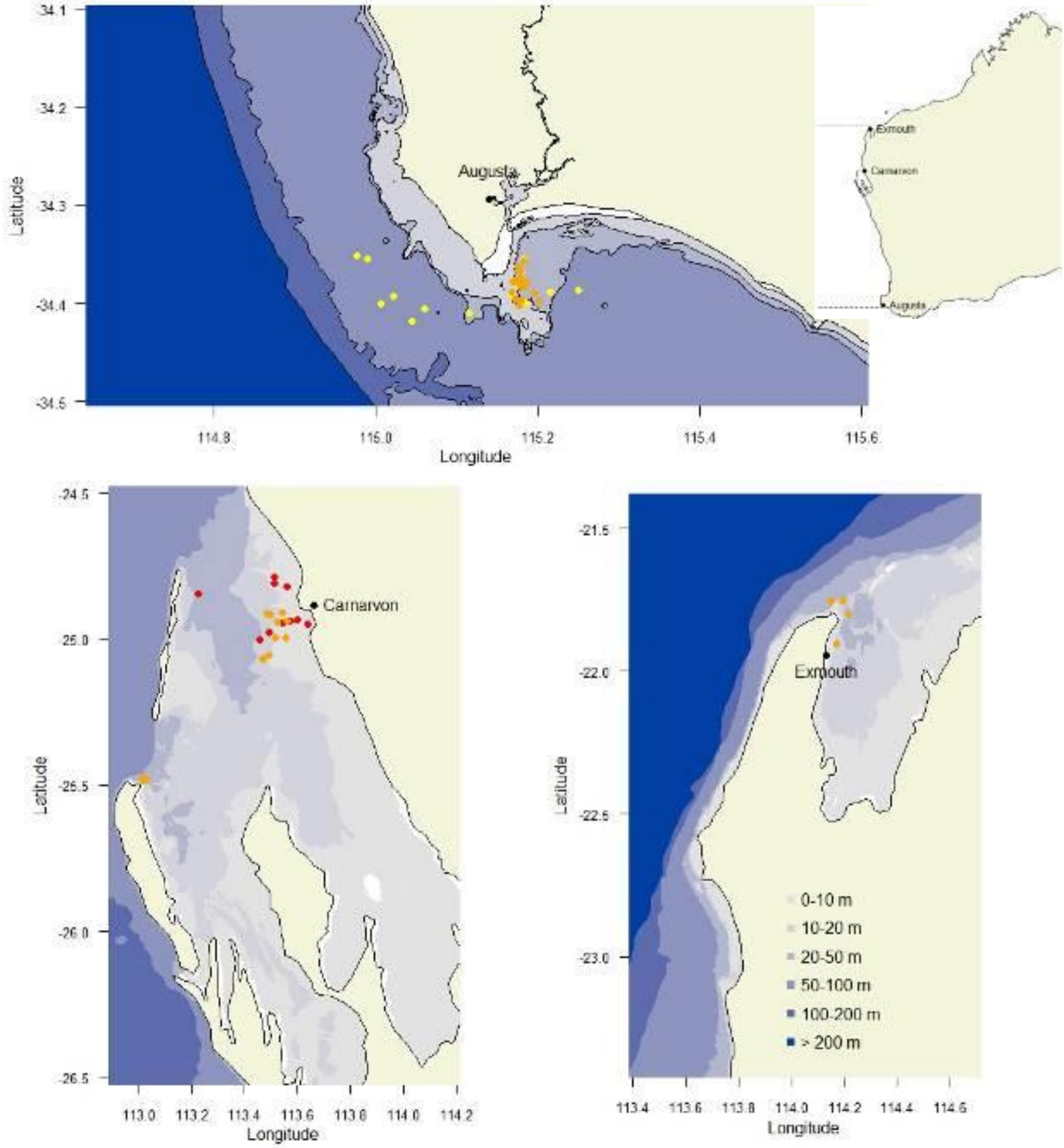


Figure 5 Location of satellite tag events in Augusta (top), Carnarvon (bottom left) and Exmouth (bottom right) during 2014 (red), 2015 (yellow) and 2016 (blue). Inset: dotted lines represent the boundaries of the West Coast Rock Lobster Managed Fishery relative to tagging locations

Plate 1 Image showing the tagging vessel and the configuration of personnel involved during a tagging approach

4.2.2.1.1.1.1.1 Analysis

All data analysis was performed using R (R Core Team 2016)

Positional data was obtained from Argos polar orbiting satellites with subsequent filtering using the speed-distance-angle function in the package *argosfilter* (Freitas et al. 2008) based on the algorithm developed by McConnell et al. (1992). A conservative maximum swimming speed of 12 km/h was applied despite faster speeds being recorded for humpback whales (Noad and Cato 2007). Additional 'end locations' which were obvious erroneous positions were removed, and occurred either just after the tag was initially deployed, or when the tag started providing positional data again after an extended period of not providing locational data.

Distance and bearings between successive positions for individual whales were determined using functions in the *argosfilter* package (Freitas et al. 2008). Circular variance measures were obtained from the package *circular* (Agostinelli and Lund 2013).

4.2.3 Spatial Model

The satellite tag data were used to develop a spatial distribution model. The Argos satellite tag data were first pre-processed using a two stage process involving the application of a speed filter and then running the data within a state-space model by applying the Kalman filter (Patterson et al. 2010). The speed filter "trip" was implemented within the R package to remove aberrant locational data that produces implausible speeds of travel by whales from the Argos data and to calculate an error distribution for use within the Kalman filter. The remaining locational data from the speed filter was then used within a state-space model by fitting a simple non-isotropic random walk model using the Kalman filter. The Kalman filtering algorithm first calculates the likelihood of the data given parameters that describe movement and observation error that are fitted using maximum likelihood estimation (MLE). Then from the MLE of the parameters, the smoothing part of the Kalman filter is used to interpolate the data and infer position estimates and uncertainties at 6-hour time steps and corrects the position for when an Argos position arrives.

Predictive models of humpback whale distribution were developed using the software Maxent (version 3.3.3), which is based on machine learning and the maximum entropy method (Phillips et al. 2006, Elith et al. 2010). This was chosen to remain consistent with earlier spatial modelling of humpback whales within the bounds of the WRLF (How et al. 2015b), due to the variable temporal occurrence and spatial precision of the Argos data and that this method performs as well as Generalized Linear Models in fitting highly complex, nonlinear relationships. The underlying theory and assumptions for Maxent have been described in detail elsewhere (Phillips et al. 2006, Elith et al. 2010, 2011, Merow et al. 2013). Essentially, MaxEnt takes a list of species presence locations as input and a set of environmental predictors (e.g. bathymetry) across a user-defined landscape (area of interest) that is divided into grid cells. From this landscape, MaxEnt extracts a sample of background locations that it contrasts against the presence locations and produces a predictive model of the probability of occurrence based on habitat suitability.

The bounds of the spatial modelling and background landscape were the entire extent of the WCRLMF, due to satellite tag tracks of whales indicating whales could travel throughout this whole area. However, the majority of whale movement was within the 200m bathymetric contour. These locational positions were then clipped to the fishery area of interest in ArcGIS 10.2. Predictive spatial habitat models were derived using topographical variables of water depth, seafloor slope and seafloor rugosity (benthic terrain complexity) as well as geophysical variables consisting of distance from the coast and distance from the 200 m contour line. These were selected based on their importance identified in previously published literature investigating relationships between humpback whale distribution and the environment (Ersts and Rosenbaum 2003, Johnston et al. 2007, Smith et al. 2012). Bathymetry data were obtained from the Geoscience Australia Bathymetry and Topography Grid 2009 (Whiteway 2009). The geophysical variables distance to coast and distance to 200 m contour were calculated in ArcGIS 10.2 using the Spatial Analyst Tools and seafloor slope and seafloor rugosity were calculated using the Benthic Terrain Modeller add in for ArcGIS 10.2 (Wright et al. 2012). All environmental layers used were raster data at a resolution of 300 x 300m (Universal Transverse

Mercator (UTM) GDA 1994 Zone 50 projection) that were converted to ascii files for use in Maxent.

The satellite tag data was divided into the northward and southward migration movements of whales to derive two final spatial models. Model evaluation was conducted by undertaking K-fold cross validation, for which we used a 10-fold, wherein the data are split into k independent subsets, and for each subset the model is trained with k - 1 subsets and evaluated on the kth subset. Response curves of the environmental variables were conducted and a jack-knife test was undertaken to evaluate the relative contributions of each environmental variable to the model. Each Maxent predictive model was evaluated using the area under the curve (AUC) of the receiver operator characteristic (ROC), which evaluates how well model predictions discriminate between locations where observations are present and random background data (pseudoabsence points).

4.3 Provide clear scientific methods behind the testing of selected gear modifications to reduce whale entanglements

4.3.1 Rope Associated Modifications

4.3.1.1 Model Description

To examine the effect of the gear modifications on the entanglement rate of whales in the WCRLF a Bayesian modelling approach was employed.

Number of whales vulnerable to entanglement on northwards or southward migrations by month and year are given by:

$$W_{\bullet,y,m} = W_y\left(\mathrm{Z}\left(\mathrm{J}(m+1),\mu_{\bullet,y},\sigma_d\right)-\mathrm{Z}\left(\mathrm{J}(m),\mu_{\bullet,y},\sigma_d\right)\right) \tag{0.1}$$

where:

$\bullet$	denotes either north (N) or south (S) migration
W_y	the number of whales in the population in year y
$\mathrm{Z}(.,\mu,\sigma)$	denotes a cumulative normal function with mean μ and standard deviation σ
$\mathrm{J}(m)$	a function returning the Julian day for the first day of month m
$\mu_{\bullet,y}$	the mean migration date through the fishing grounds

σ_d the standard deviation of the normally distributed pulse of migration (fixed at 28.33 days based on the residual standard deviation of whale watching daily counts)

The total number of whale vulnerable to entanglement by month and year are

$$W_{y,m} = W_{N,y,m} + W_{S,y,m} \mid \sigma_d > 21 \tag{0.2}$$

The condition $\sigma_d > 21$ ensures that $W_{y,m} < W_y$ for the likely range of the difference between northward and southward migration mean dates.

The number of whales in the population in each year is:

$$W_y = W_0 \, \mathrm{e}^{\rho y} \big| y = 0 \cdots n_y \tag{0.3}$$

where

W_0 is the population in a specified start year (has a log-normal prior with CV = $\hat{k}_W$ based on the survey abundance)

ρ is the exponential rate of population change (has a prior distribution bounded above by the demographically maximum feasible rate of population increase)

n_y is the number of years in the model

The mean migration dates for north and south through the fishing grounds are

$$\mu_{\bullet,y} = \mu_{y,d} + O_{\bullet} \tag{0.4}$$

$\mu_{y,d}$ year specific mean date for migration (estimated from whales sightings at a specified location (d), these parameters have a prior multi-normal distribution using the estimates and standard errors σ_y from the linear model)

$O_{\bullet}$ is the difference between the standard migration date and the north or south migration date applicable to the fishing grounds (these have uniform prior distributions)

The expected number of whales becoming entangled during each month and depth stratum (z) is given by:

$$\tau_{y,m,z} = q_z W_{y,m} E_{y,m,z} q_{y,m} \tag{0.5}$$

q_z the relative risk that a whale on the fishing ground becomes entangled in depth stratum z (has a uniform prior distribution with upper bound $\mathrm{Sup}\left(E_{y,m,z}\right)^{-1}$ and a lower bound at one thousandth of the upper bound; the upper bound thus ensures that the probability of entangling a whale in a given stratum is ≤ 1)

$E_{y,m,z}$ the recorded fishing effort by year, month and depth stratum (data)

$q_{y,m}$ is the relative effect of gear modification by year and month (= 1 in the years and months prior to the introduction of the gear modifications and a constant value having a prior distribution in the months where the gear modifications were applied thereafter).

The total number of whales in the population that are entangled in a given year in month m (except for m = 1) are those accumulated to the beginning of the month (entanglements occurring during month m are not added until the beginning of the next month). Therefore:

$$\tau_{y,1} = \sum_z \tau_{y,1,z} - s_{y,1}$$
$$\tau_{y,m} = \sum_{i=1}^{m-1} \left(\sum_z \tau_{y,i,z} \right) \psi^{m-i-1} - s_{y,m-1} \mid m > 1 \qquad (0.6)$$

where

$s_{y,m}$ are the numbers of entangled whales sighted by year and month

ψ is the proportion of entangled whales from a given month that remain available for resighting after a lag of one month. This is a composite of the whales that have not died as a result of entanglement, nor left the region, nor become disentangled.

In order to calculate the log-likelihood (see below) any values of $\tau_{y,m} < 0$ are replaced by a very small positive number. The expected number of whales to be sighted in a year and month is:

$$s'_{y,m} = q_s V_{y,m} \tau_{y,m} \qquad (0.7)$$

where:

q_s is the number of entangled whales sighted per sightings effort (has a uniform prior distribution [10^{-6}, 1])

$V_{y,m}$ sightings effort by year and month (parameterised from fishing effort and a general parametric level and linear trend of non-fishing vessel activity) as follows:

$$V_{y,m} = \frac{E_{y,m}}{\sum_y \sum_m E_{y,m}} + \varpi + \phi y \tag{0.8}$$

The first term assumes that the effort relevant to a sighting of an entangled whale by the rock lobster fishery is proportional to the fishing effort. The second two parameters describe a linear trend in the relative number of other vessels at sea.

The sightings are assumed to have a Dirichlet-multinomial distribution with a parameter vector $\boldsymbol{\alpha}$ given by:

$$\alpha_{y,m} = \Phi \frac{s'_{y,m}}{\sum_n s'_{y,m}} \tag{0.9}$$

where Φ is a parameter that determines the over-dispersion relative to a pure multinomial distribution. As Φ becomes large, the over-dispersion becomes small, and in limit (as $\Phi \to \infty$), the distribution approaches a pure multinomial. The uncertainty in the degree of over-dispersion is accounted for by assigning it a wide prior distribution uniform (1,10000). The log-likelihood is given by:

$$\mathrm{L}\left(\mathbf{s}\middle|\boldsymbol{\theta}\right) = \ln(n) + \ln\left(\mathrm{B}\left(\sum_{y=1}^{n_y}\sum_{m}^{12}\alpha_{y,m}, n\right)\right) - \sum_{n|s_{y,m}>0}\left(\ln\left(s_{y,m}\right) + \ln\left(\mathrm{B}\left(\alpha_{y,m}, s_{y,m}\right)\right)\right) \tag{0.10}$$

Where n is the total number of observed entanglements, $\mathrm{B}(.,.)$ is the beta function and $\boldsymbol{\theta}$ is the vector of parameters used in the model to predict the number of entangled animals that are sighted by year and month.

Prior distributions are assigned for each of the parameters (Table 3) and a Metropolis-Hastings Monte Carlo Markov Chain (MCMC) is used to calculate the posterior distributions of the parameters using the log-likelihood (Eqn 1.10). It is not expected that the type of data available will be informative for all of the model's parameters, and in one sense the model is over-parameterised. However, the function of the MCMC analysis is to account for the uncertainty in each of the parameters and hence to produce a marginal posterior distribution for the parameter of interest (the mitigation effect) that is integrated over the uncertainty arising from a range of processes with the potential to explain the observed pattern in entanglements.

A single chain of length 20 million was calculated with a burn-in of 4000 and also thinning of 4000, and hence producing 4999 random replicates. The hit rate was 8.7%. Standard diagnostics for chain convergence using the R CODA package (Plummer et al. 2006) did not provide any reasons to conclude that the chain had not converged nor was there any significant autocorrelation between replicates. The values of the parameters from the point in the chain where the mitigation is at its median value, along with their correlation with the mitigation effect and 95% credible intervals are given in Table 4.

Data used to inform the model were: 1) sightings from whale-watching vessels; 2) reported entanglements within the WCRLF; 3) fishing effort and distribution (Figure 34). In addition, projections were made using the MCMC replicates of the model parameters but with a mean annual effort distribution from 2000-2004 applied to all years in the model. These projections using the same effort across all years in the model were undertaken to inform how a return to a traditional season closure would likely impact whale entanglement numbers. These datasets are described in detail below.

4.3.1.2 Whale watching sightings data

Vessels licenced to undertake commercial whale watching activities in Western Australia are required to provide a daily return of all encounters with large cetaceans. These vessels undertake multiple trips per day with each trip consisting of a number of encounters. For each encounter, operators record the number and species of whales encountered and the location (GPS) and environmental conditions for each contact. Four operations were identified that produced consistent sighting information from 2000 – 2017 and throughout the migration season: two for the northerly migration (Albany and Augusta) and two for the southerly migrating whales (Perth and Cape Naturaliste) (Figure 4).

The annual mean date of migration was estimated using a linear model. This model assumed the frequency of migrating whales follows a normal distribution each season and was used to estimate the peak of migration (mean Julian day of migration) for each year. The model used two factors, location (with four levels, representing each location) and year (with 17 levels, representing 2000 - 2017), which combined, equated to 20 parameters plus one additional parameter for the standard deviation of the error term ($\hat{\sigma}_1$). The difference in the timing at each of the four locations was assumed to be consistent between years, i.e. a later timing of migration seen at Albany would be reflected in a later timing of the same magnitude at the other three locations. This assumption was based on a preliminary examination of the raw data which showed that variation in migration start times between locations was consistent between years (How et al. 2015).

The estimate and associated standard error of each annual mean date of migration were used as priors in the Bayesian model (Eqn 1.4). The offset between theses mean migration dates and the mean dates for the north or south migration applicable to the fishing grounds were estimated within the Bayesian model using uniform priors ($O_{\bullet}$; Eqn 1.4).

Table 3 Source of information for input data, with priors and their associated distributions for estimated parameters

Symbol	**Input data**	**Distribution**	**Source**
$s_{y,m}$	Number of whales seen entangled in WRLF gear by year (2000 to 2017)	Data	Cetacean Stranding and Entanglement Database (Dept. Biodiversity, Conservation and Attractions; Parks and Wildlife Service Western Australia)
$E_{y,m,z}$	Fishing effort (rope days) by year, month and depth stratum (2000 to 2017)	Data	Dept. Primary Industries and Regional Development Catch and Effort databases
$\hat{\mu}_{y,d}$ $\hat{\sigma}_{d,y}$ $\hat{\sigma}_{d}$	Sightings data from whale-watching vessels at four locations in Western Australia	Data	Parameter estimates derived from linear model from whale-watching industry data
Symbol	**Priors**	**Distribution**	**Source**
W_0 $\hat{k}_W$	Population abundance in 2000. Coefficient of variation for abundance estimate fixed - derived from confidence interval	Log-normal (12042; CV 0.131)	Derived from abundance estimate for 2008 (28830; 95%CI: 23710,40100) from population model*
Φ	Overdispersion parameter for Dirichlet/multinomial	Uniform(1, 10000)	Uninformative (10000 is large enough to give approximate multinomial)
ρ	Rate of exponential population increase per year	Uniform(0.02, 0.125)	Bounded above at maximum demographic feasibility#
$\mu_{y,d}$	Annual mean migration dates (Julian day) and standard errors	Multi-normal ($\hat{\mu}_{d,y}, \hat{\sigma}_{d,y}$)	Estimates from linear model of whale-watching sightings data with year as categorical variable
O_N	Day offset for northern migration	Uniform (-120, -50)	Informed by distribution of migrating whales at each whale-watching location
O_S	Day offset for southern migration	Uniform (-20, 70)	
$q_{y,m}$	Mitigation Effect due to gear modifications	Uniform(0.01, 2)	Ranges from a 100-fold reduction in entanglement risk to doubling the risk
q_s	Hazard of entangled whale being sighted per unit sightings effort	Uniform($1x10^{-6}$, 1)	Ranges from very low sightings probability to every entangled whale is sighted
q_z	Hazard of entanglement per 1000 rope days for each depth stratum (z = 1 to 5)	1: Uniform ($9.14x10^{-7}$, $9.14x10^{-4}$) 2: Uniform ($2.11x10^{-6}$, $2.11x10^{-3}$) 3: Uniform ($1.27x10^{-6}$, $1.27x10^{-3}$) 4: Uniform ($5.59x10^{-6}$, $5.59x10^{-3}$) 5: Uniform ($1.69x10^{-6}$, $1.69x10^{-3}$)	Bounded so that proportion of population in each stratum in each month entangled is in the range [0.001 … $\leq$1].
ψ	Apparent survival of entangled whales	Uniform(0, 1)	Uninformative
ϖ ϕ	Sightings effort by non-fishery vessels (intercept and slope)	Uniform(0.01, 5); Uniform($1x10^{-12}$, 0.1)	Uninformative for intercept, assumed upper bound of 0.1 per year on linear rate of increase in general vessel traffic.

Table 4 Values of the model parameters corresponding with the median value of the mitigation, the correlations of each parameter with the mitigation effect. The 95% credible intervals are for the marginal distributions of each parameter.

Parameter	Value at median effect	Correlation with mitigation effect	95% credible interval
Abundance	12414	-0.0188	9290 - 15506
Overdispersion	8823.2	-0.1741	100 - 9619
Rate of increase	0.0790	-0.2250	0.0807 - 0.1246
North migration offset	-91.46	-0.2787	-110.82 - -81.20
South migration offset	22.47	0.1643	-9.81 - 63.47
Mitigation effect	0.416	1	0.169 - 0.982
Sighting coefficient	0.807	0.0019	0.027 - 0.974
Depth stratum 1 hazard	0.000264	0.1173	0.000012 - 0.000693
Depth stratum 2 hazard	0.001479	0.0055	0.000087 - 0.002077
Depth stratum 3 hazard	0.001103	-0.0137	0.000108 - 0.001252
Depth stratum 4 hazard	0.000058	-0.0256	0.000100 - 0.005340
Depth stratum 5 hazard	0.000254	-0.0323	0.000053 - 0.001649
Proportion remained entangled	0.2011	0.0940	0.0997 - 0.5290
Sightings effort intercept	1.2980	0.1062	0.1540 - 4.7175
Sightings effort trend	0.0960	-0.1679	0.0090 - 0.0986
Mean migration date in 2000	246.78	0.0230	240.27 - 247.14
Mean migration date in 2001	249.44	-0.0122	246.80 - 254.14
Mean migration date in 2002	241.88	0.0069	240.78 - 247.18
Mean migration date in 2003	245.13	-0.0091	238.77 - 246.04
Mean migration date in 2004	244.15	-0.0050	241.07 - 247.15
Mean migration date in 2005	242.47	-0.0030	240.93 - 248.01
Mean migration date in 2006	232.81	0.0066	227.22 - 235.78
Mean migration date in 2007	240.18	0.0033	238.12 - 246.64
Mean migration date in 2008	248.50	-0.0306	242.40 - 251.51
Mean migration date in 2009	240.72	0.0009	237.38 - 244.06
Mean migration date in 2010	242.44	0.0090	240.01 - 245.58
Mean migration date in 2011	243.19	0.0055	240.77 - 244.26
Mean migration date in 2012	236.99	0.0149	245.18 - 248.06
Mean migration date in 2013	231.08	0.0051	228.62 - 232.61
Mean migration date in 2014	235.34	0.0247	234.46 - 238.66
Mean migration date in 2015	239.06	0.0083	236.22 - 239.43
Mean migration date in 2016	240.58	-0.0134	237.76 - 241.04
Mean migration date in 2017	235.89	0.0068	233.27 - 238.01

4.3.1.3 Entanglement Records

Analyses of gear modification effectiveness were limited to only those records where the gear was confirmed to be from the WCRLMF and was obtained from the Department of Biodiversity, Conservation and Attractions; Parks and Wildlife Service, Western Australia cetacean standing database which also contains entanglement records (see Temporal Information: Cetacean Stranding Database).

Gear is attributed to a particular fishery through a range of means. As it is a statutory requirement that all commercial and recreational floats are marked with the fishers' unique identifier, gear retrieved during disentanglement operations can provide the fishers details and hence fishery involved. In some instances, these markings may be visible from video or photographs of the entanglement when a disentanglement is not possible / attempted. When the fisher cannot be identified, gear can still be attributed to a particular fishery. This is generally achieved through examination of photographs of the entanglement examined by experienced government staff with a detailed working knowledge of gear configurations of the state's fisheries or when the reporter of the entanglement has a similar background in the gear configuration of the state's fisheries (e.g. commercial fisher / commercial tour operator with previous fishing experience). Not all gear however can be attributed to a fishery and in these instances they are scored as "unknown" with a broad description e.g. ropes and floats, net or monofilament line. All new entanglement reports were compared with existing reports to ensure duplicate reports of an entangled whale were not counted as two separate entanglements.

4.3.1.4 West Coast Rock Lobster Managed Fishery – Fishing Effort

Commercial rock lobster fishers submit mandatory catch and effort statistics. Under the effort control system (pre-2011), this was in the form of a monthly report detailing retained catch and effort (no. pots) in 1 x 1 degree blocks. An additional voluntary logbook was completed by approximately 30% of the fleet (de Lestang et al. 2012) and captured more detailed information such as catch and effort by 18.3 m (10 fathom) depth categories for 10 minute latitude bands, as well as depth, soak time (time between setting and retrieving gear) and other discarded catch and environmental information. These data were used to apportion mandatory monthly effort information into the finer spatial scale captured by logbooks. Under the quota management regime (2011 onwards), fishers have been mandated to record catch and effort for each trip, explicitly stating the soak time (days) and depth range fished along with other variables. The spatial resolution of these data was scaled up to match that of the volunteer logbooks increased (de Lestang et al. 2012).

A metric was established from these effort data to describe the number of vertical lines that whales could encounter in each depth band and month. The number of pot retrievals was multiplied by the soak time to provide the total number of days when ropes and floats were present in the water column (rope days). The total number of rope days was determined for each 18.3 m (10 fathom) depth category, month and year combination. These effort data were used to inform the Bayesian model (Eqn 1.5).

4.3.2 Acoustic Alarms

Due to the nature of pot and line fishing, such as occurs in the WCRLMF and OIMF, acoustic alarms would be deployed in a vertical orientation. As alarms are rarely omnidirectional and minor attachment variations may exist, these variations have been included in the assessment. Two acoustic alarm types that are described by their manufacturers as being suitable to use in relation to humpback whales were tested. These were the Future Oceans F3, and a product from Fishtek that was not commercially available. Previous detailed characterisation of Future Oceans F3 alarms highlighted the need to characterise individual alarms to be used in the experiments for this project (Erbe et al. 2011a, 2011b, 2011c).

4.3.2.1 Initial Testing

The testing methodology was based upon Erbe et al. (2011a, 2011b, 2011c), and comparable to methods provided to and published by the International Whaling Commission, Woods Hole Oceanographic Institution, and National Marine Fisheries Service.

Acoustic recordings of alarms were made in open water non-reverberant conditions with minimal background noise in a freshwater and saltwater lake in Queensland and NSW respectively. These locations were chosen for their relatively low ambient levels however, they are still natural environments with ambient contributors, which influences the resulting broadband SPL measurements. Measurements inside a specialised acoustic tank would have been preferred, but was not feasible within the scope of the project. Alarms were recorded at 2 m range with calibrated system which included a HighTech HTI-96-MIN hydrophone (30 kHz frequency response) and portable field data recorder. Recordings were sampled at 96 kHz. with acoustic measurements standardised to a @ 1 m reference where Sound Pressure Level (SPL) was equivalent to Source Level (SL) at the reference @ 1 m.

Gear deployment recommendations from industry indicated that alarms are suspended vertically and acoustic output at these orientations must be biologically meaningful. Therefore, alarms were supported in the water in a manner appropriate to manufacturer's recommendations. The Fishtek alarm was measured within its banana case supported by a length of polyethylene rope, and the Future Oceans F3 supported by heavy chord developed by Western Australian fishermen as part of initial gear trials (How et al. 2015).

A total of four measurements were taken around the vertical axis, the device circumference (at 0º, 90º, 180º and 270º orientations, labelled #1, #2, #3 and #4), and four measurements along the horizontal axis from the transducer end to the non-transducer end (at 0º, 45º, 135º and 180º labelled #5, #6, #7 and #8), as shown in Figure 6. These measurement orientations were selected to examine the directionality aspects of each alarm.

A total of at least 30 tone bursts were measured at each orientation (six positions in total) for each alarm. For the Future Oceans F3, this was for each individual ping, and for the Fishtek this considered each grouping of four 50 ms tone bursts to be a single ping. Signals were analysed for broadband SPL, and narrowband SPL measurements of each major contributing tone.

Initial testing examined one of Future Oceans F3 and Fishtek whale alarms. With a higher SPL, subsequent testing was limited to Future Oceans F3 alarms. A total of 41 Future Oceans F3 alarms, destined for use in the whale behavioural response experiment (see below) were examined.

4.3.2.2 Testing at Geographe Bay

Due to poor results from the initial testing, a further 17 Future Ocean F3 alarms were recorded for testing purposes at the study site (Figure 7) using a TC-4033 hydrophone attached to a Sound Devices 722T recorder, recording at 96 kHz and 24-bit resolution. During these trials the alarms were not rotated, but measured at a single orientation while suspended vertically in the water column.

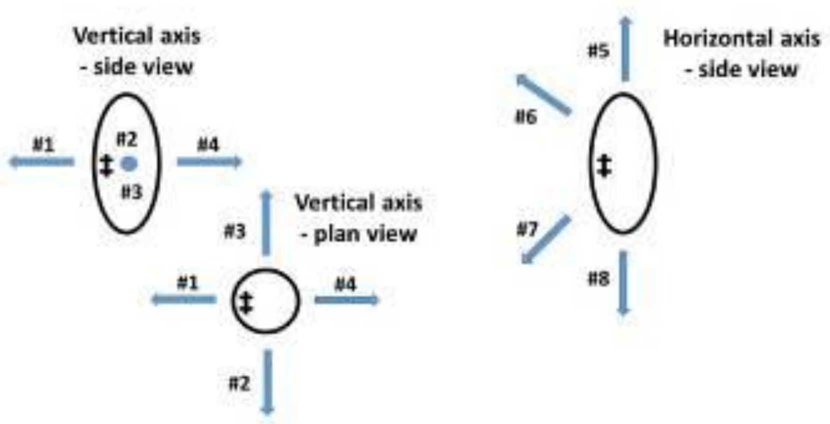


Figure 6 Schematic showing alarm measurement orientations, 4 from the vertical axis (at 90^o angles) and 4 from longitudinal axis (at 45^o angles)

4.3.2.3 Analysis

There is no data on the absolute hearing thresholds for humpback whales and only relative frequency-dependent sensitivities can be predicted. Their best hearing range is likely between 20 Hz and 6 kHz, with the highest sensitivity at approximately 885 Hz (Houser et al. 2001, Clark and Ellison 2004, Tubelli et al. 2012, Cranford and Krysl 2015). The lowest frequency signal from any of the alarms tested was above 2 kHz, therefore signals below this were not considered during the analysis. Considering this, and the hearing of humpback whales, outputs from the acoustic alarms in the frequency range 2-6 kHz were considered.

Recordings were analysed using propriety JASCO Applied Sciences acoustic software and Matlab routines. Results included both broadband and narrowband (tonal) analysis. Broadband analysis provided source level in SPL re 1µPa @ 1 m for all energy within the 2-6 kHz frequency band. Broadband is the system of energy metrics usually presented by acoustic alarm manufacturers. Narrowband or tonal analysis, which has more relevance to animal perception, and therefore localisation capability, provided source level in SPL re 1µPa^2/Hz @ 1 m for the energy structured into frequency tones within the 2-6 kHz frequency band. Both alarms were analysed over a 400 ms period, which is the signal time for the Future Oceans F3. However, this is also in line with Erbe et al. (2016) who recommend that when predicting an animal's ability to detect a signal of interest in quiet conditions, the tone level (SPL) should be computed over a fixed window of a few 100 ms length, rather than then any potentially shorter pulse duration. The same method was applied to both types of alarm tested. Initial acceptance testing was conducted, prior to detailed analysis occurring.

4.3.2.4 Modelling of acoustic alarms

JASCO's Marine Operations Noise Model (MONM-BELLHOP) was used to model the sound field of a Future Oceans alarm. This model computes sound propagation from highly-directional, high-frequency acoustic sources via the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994). To determine the detection footprint of the alarm above ambient, the fundamental (2785 Hz) and the first harmonic (5569.5 Hz) frequencies of the alarm were modelled on a lobster float line (mid-water column) in a typical sound speed environment in Geographe Bay. Source levels of the modelled source frequencies were calculated from field measurements.

There are various ways in which to conceptualise an optimal alarm spacing along a net, or a line of traps. As discussed in Erbe et al. (2011) assuming good intensity discrimination capabilities in humpback whales as well, alarms at greater distances will be heard at quieter levels, and alarms in series will thus highlight the location and direction of the trap line. . In the case of an animal swimming straight at a trap line, where the animal is in between two alarms, hence farthest away from any one alarm. If the animal swims towards the net at a speed v, and if it is just outside the detection radius when the alarms ping, then one would want the next ping to occur before the animal hits the net. This scenario determines a maximum alarm spacing.

The maximum alarm spacing d can be computed via:

$$d = 2\sqrt{r^2 - v^2T^2}$$

where d = maximum alarm spacing [m]

r = detection radius [m].

v = swim speed [m/s]

T = quiet time in between two pings [s]

4.3.2.5 Whale behavioural response to acoustic alarms

The effectiveness of acoustic alarms to alert whales to the location of pot lines was conducted in Geographe Bay in November 2014. Whales were tracked from a theodolite station located 50 m above Pt. Piquet in Geographe Bay. Tracking techniques followed that of previous tracking studies which occurred at the same location (Salgado et al. 2014). Humpback whales were tracked from the east, west/nor-westerly through the study site as they rounded Cape Naturaliste on their southern migration.

The Future Oceans F3 whale alarm was selected after initial testing, and all alarms used were tested to determine their source level. Four arrays were deployed within the study site consisting of two 10 alarm arrays, and two three alarm arrays (Figure 7). An array consisted of a series of vertical lines spaced 80 m from each other. The gear to which acoustic alarms were attached consisted of a single Polyform ™ LD1 float with 5 to 10 m of sisal biodegradable rope, connected to 10 mm polypropylene ropes and a concrete weight on the bottom. The sisal rope is negatively buoyant in water reducing any surface floating rope which would have increased the complexity or likelihood of an entanglement. In addition, through using sisal rope, if a whale became entangled, the rope would degrade resulting the whale freeing itself of the entanglement. The gear remained in place for the duration of the study, with the acoustic alarms attached to the gear by a shark clip 5m below the surface. While the position of the array of gear was evident to persons undertaking whale tracking, they were unaware if whale alarms were attached to the gear on any given day

The arrays were in place for 20 days, with tracking occurring on 17 days. A day was required to deploy and retrieve the array with a further day lost due to poor weather conditions. Days when alarms were present were randomly assigned resulting in alarms being present for nine when tracking occurred. Observers and those involved in tracking were "blind" to the presence of the alarms. When present the alarms were placed 5 m below the surface attached to the sisal rope with a shark clip.

Variation in SL between individual F3 alarms (Results: Alarm Performance) resulted in the alarms placed into three groups based on their SL. The mean SL of each of the three groups was then modelled to determine their detection distances. Transmission loss was modelled in 3-D for three frequencies: the fundamental and the first two harmonics of the F3 alarm (2785 and 5569 Hz). In the absence of hearing thresholds for humpback whales, humpback hearing was assumed to be ambient noise limited. Ambient noise levels at the study site varying between 60-65 dB re 1 μPa depending on wind condition (Salgado et al. 2014). Critical ratios in other mammals range between 16-24 dB re 1 Hz (Richardson et al. 1995), and as such a critical ratio of 20 dB was added to model alarm tone detection in broadband ambient noise (Erbe et al. 2016). Modelling was then used to determine the distance at which humpback whales could detect the alarms at 85 dB re 1 μPa.

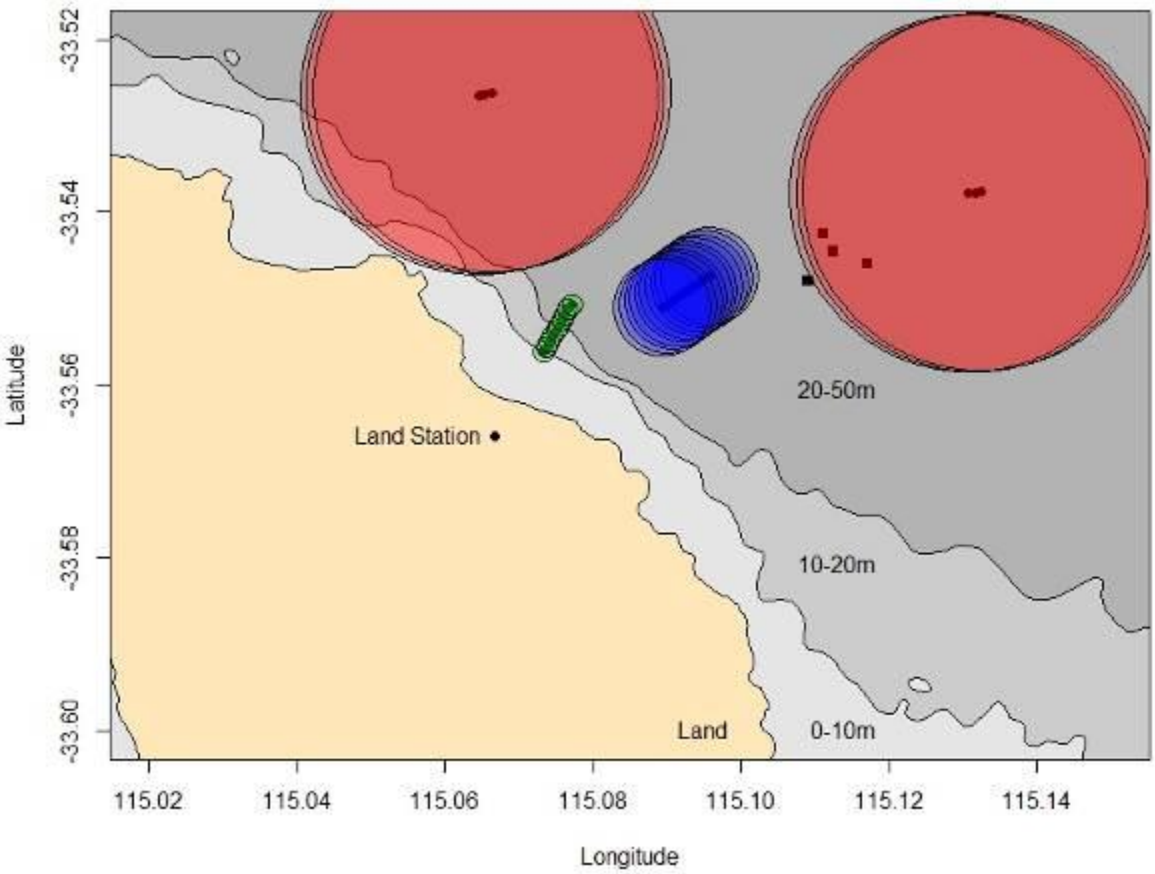


Figure 7 Location of array of whale alarms (black dots), acoustic loggers (black squares), theodolite location (“Land Station”) and the maximum alarm spacing based on signal strength of low (green), moderate (blue) and high (red) source levels.

5. Results

5.1.1 Entanglement Records

There have been 154 entanglements reported off the Western Australian coast between 1990 and 2017: 146 (95%) involved humpback whales, six (4%) involved southern right whales (*Eubalena australis*) and single entanglements of a Bryde's (*Balaenoptera brydei*) and minke (*Balaenoptera acutorostrata*) whale.

Total entanglements (all fisheries) rose from between zero and eight in the period 1990 to 2010 to a peak of 31 entanglements in 2013. Total entanglements declined to 13, eight, four and ten in 2014 to 2017, respectively (Figure 8). Over half of all entanglements (*n*=81) were associated with WCRLMF gear, though gear from a number of other sources including, octopus, deep sea crustacean and crab fisheries, as well as aquaculture activities has been involved in whale entanglements off Western Australia (Figure 8a). Approximately 33% (*n*=51) of all entanglements could not be ascribed to a particular fishery, although 50 of these entanglements involved ropes with or without floats that were similar to those used in the WCRLMF, and also octopus and crab fisheries, but lacked identifying marks or configurations. Entanglements in 'unknown ropes and floats' followed a similar pattern to entanglements in WCRLMF gear, peaking with ten entanglements in 2013, and three, five, zero and three entanglements in 2014 to 2017, respectively (Figure 8a).

Between 1990 and the introduction of quota management in 2011, entanglements in WCRLMF gear averaged 1.3 (range 0-6) per year, with an average during the pre-quota modelling period (2000-2010) of two entanglements per year (Figure 8b). In 2010, where there were no reported entanglements in identified WCRLMF gear, this was likely due to the season closing in May due to the early attainment of the quota. Entanglements rose to five in 2011, 12 in 2012 and peaked at 17 in 2013 (Figure 8b). Recent seasons have seen a decline with seven reported entanglements linked to the WCRLMF in 2014 (five before the introduction of gear modifications and two after their introduction), two in 2015, four in 2016 and six in 2017. In 2017, two of the six entanglements occurred in gear with no modifications as they likely occurred prior to the modification season period (before 1 May) based on gear inspection and fishers' records. There have been very few entanglements reported before May each year, with the majority of entanglements occurring during May – July. These months of peak whale entanglement reports occur within the gear modification period (May – October). The temporal pattern of entanglement reporting has remained relatively consistent despite differing season length or requirement for gear modifications in the WCRLMF (Figure 9).

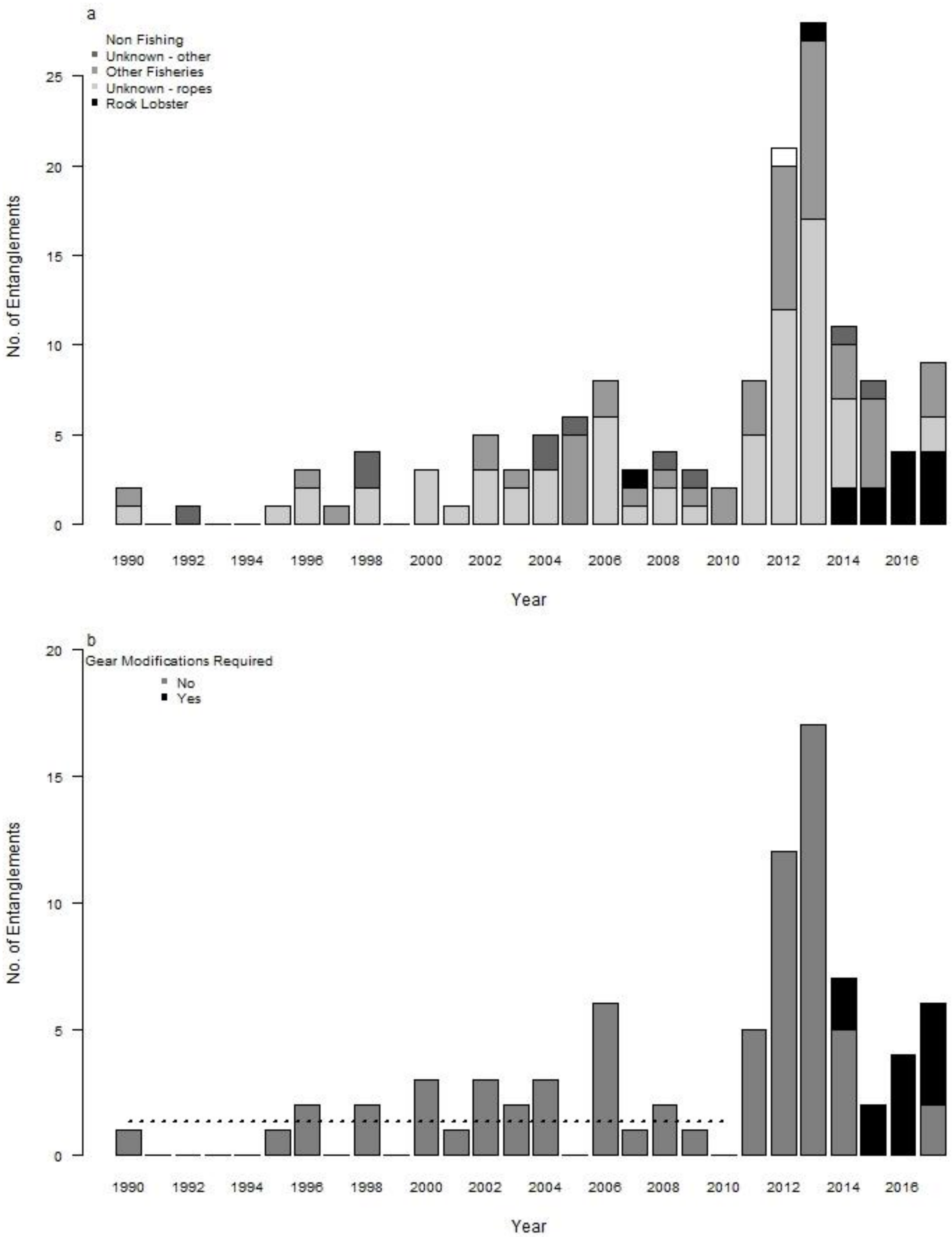


Figure 8 Annual whale entanglement numbers a) all gear and b) in West Coast Rock Lobster Managed Fishery gear. Black and grey bars represent when gear modifications were or were not required respectively. Dotted horizontal line represents the long term average number of entanglements in western rock lobster gear until 2010

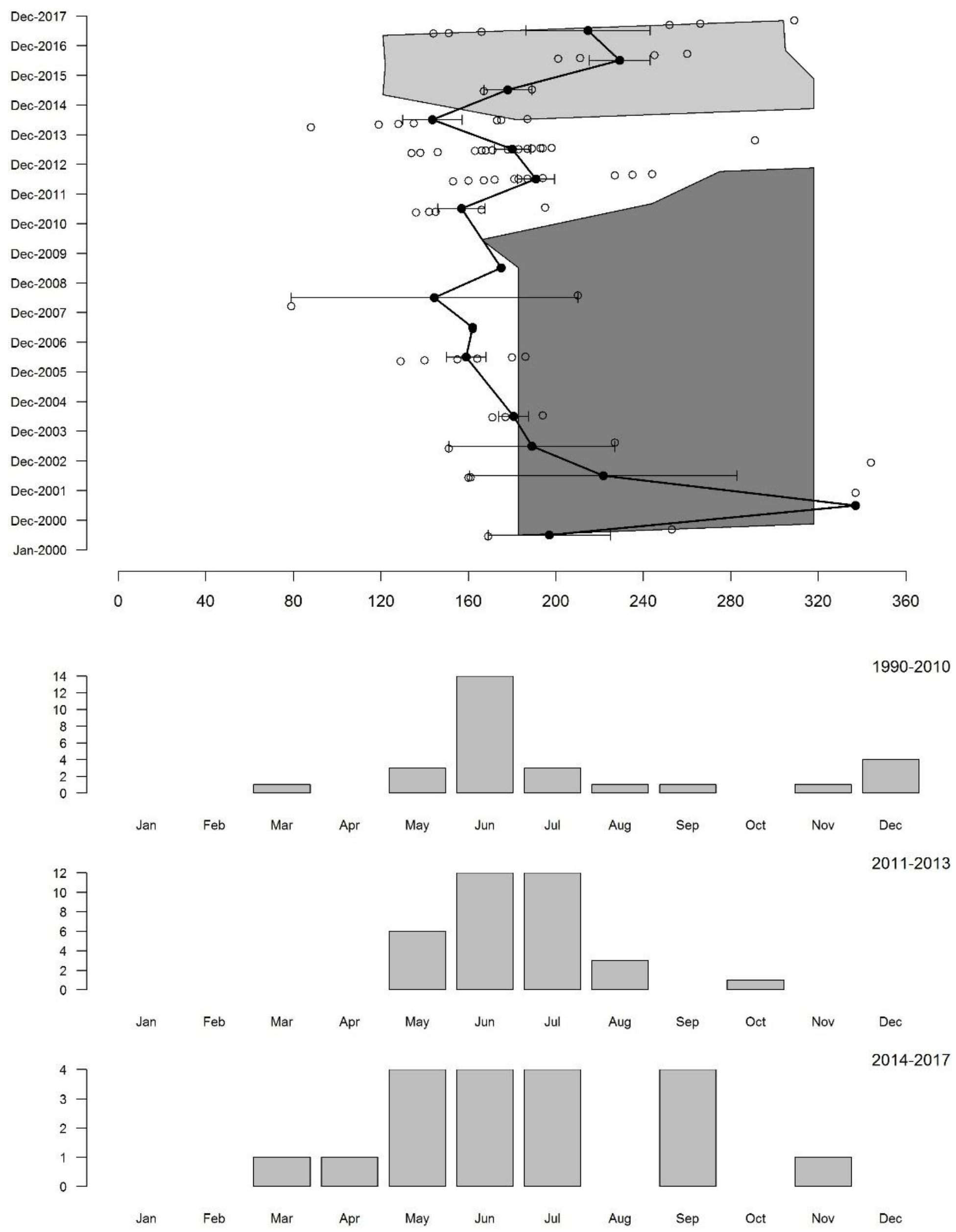


Figure 9 Date and day of the year of whale entanglement report in West Coast Rock Lobster Managed Fishery gear (open circles) and the annual mean (±SE) day of the year (filled circle and line). Time of closed season (dark grey polygon) and gear modification season (light grey polygon). All entanglement prior to 2000 are summarised and presented as 1999. Number of reported entanglements per month during the effort management (1990-2010), transitioning to quota management and year-round fishing (2011-2013) and year-round fishing with gear modifications (2014-2017)

Survey data from commercial western rock lobster fishers also indicated a decline in entanglements from 2013 to 2014. Fishers noted a reduction in the number of pots either lost (39%) or moved (63%) (assumed to be related to whale interactions) during the 2014 whale migration period when compared to the corresponding period in 2013 (Figure 10).

Gear modifications were well adopted by industry. Compliance checks highlight the high level of compliance with gear modifications by commercial fishers since their introduction part way through the 2014 migration season (Table 5).

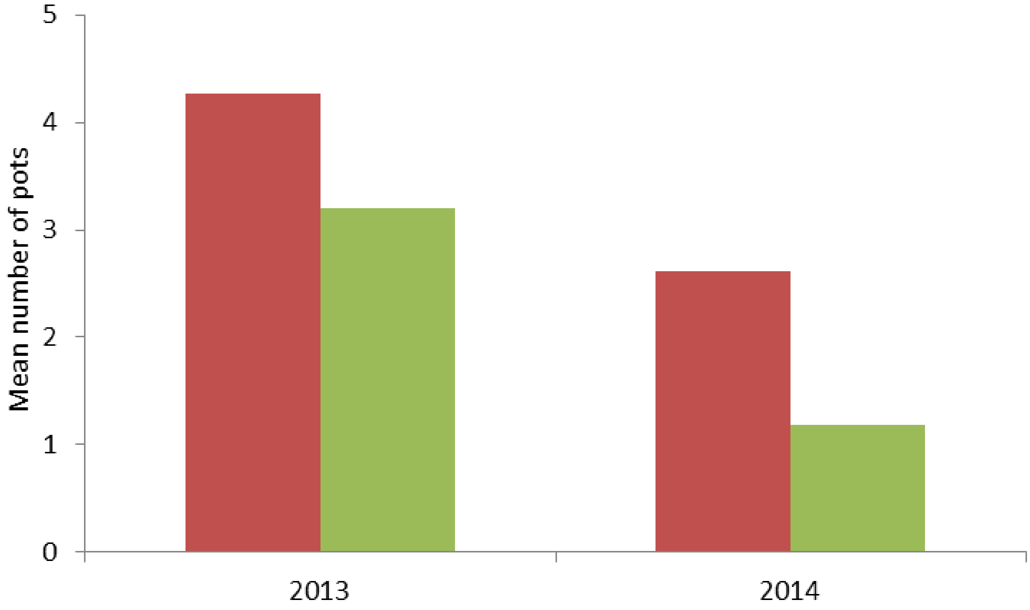


Figure 10 Mean number of pots lost (red) and moved (green) in 2013 and 2014

Table 5 Compliance statistics relating to whale mitigation regulations by season

Season	No. Gear Checks	Warnings	Infringements
2014	80	13	0
2015	456	9	3
2016	194	14	0
2017	279	3	0

5.2 Produce fine-spatial and temporal information on whale migrations along the west coast of Western Australia necessary for a tailored spatio-temporal closures and/or areas for gear modifications.

5.2.1 Temporal Information

5.2.1.1.1 Commercial Whale Watching Logbooks

There was clear temporal separation between the northern and southern migrations of humpback whales from commercial whale watching data (Figure 11). Albany and Augusta (Figure 4) interact with the northern migration which peaks in July, while Perth and Geographe Bay (Figure 4) interact with the southern migration in October / November (Figure 11). The northern most region, Kimberley, is believed to be the main calving and mating grounds (Jenner et al. 2001a) and interacts with the middle of the migration. Regions between Perth and Kimberley interact with both the northern and southern migration to varying extents (Figure 11).

Calves appear on the states nor-west and north coasts (Figure 11) from July with peaks in the Kimberley in early September. Peak calf abundances recorded by commercial whale watching vessels at Ningaloo peaks about 1 month earlier than the Kimberleys in early August. Shark Bay, which is further south again than Ningaloo (Figure 4) saw good numbers of calves recorded in a number of years as early as mid-July. Calves are regularly recorded on their southern migration off Perth and Geographe Bay, though they tend to be sighted later than the bulk of the whales migrating through these regions (Figure 11).

Examination of the inter-annual changes in the timing of migration was limited to Albany / Augusta and Perth / Geographe Bay which access the northern and southern respectively. These regions have a consistently high effort (number of trips) across years (Table 6). The numbers of whales sighted each week in a region was well described by a normal distribution (Figure 12). The notable exception was for Geographe Bay in 2013 where whales were sighted for a number of months before the traditional peak in whale abundance later in the season (Figure 12).

The timing of migration of humpback whales along the Western Australian coast is temporally consistent. Prior to 2013, nine of the 13 seasons saw the median estimate of the migration occur in a one-week period from 29 August to 4 September. Those years when peak abundances were outside the one week band were in 2001, 2006, 2008 and 2012 (Figure 13). In 2001, 2008 and 2012, peak abundance were later than normal, occurring five, one and one day later, respectively, than the upper end of the "normal band" (4 September), while in 2006 whales arrived nine days earlier than the lower end of the "normal band" (29 August; Figure 13).

There was a clear distinction in the general timing of migrations after 2012, with more recent years occurring generally a week earlier than pre 2013 migrations. Despite this apparent temporal shift, the 2013 migration was considerably earlier again, with the median migration estimate of 21 August, 16 days earlier than whales which migrated in 2012 (Figure 13).

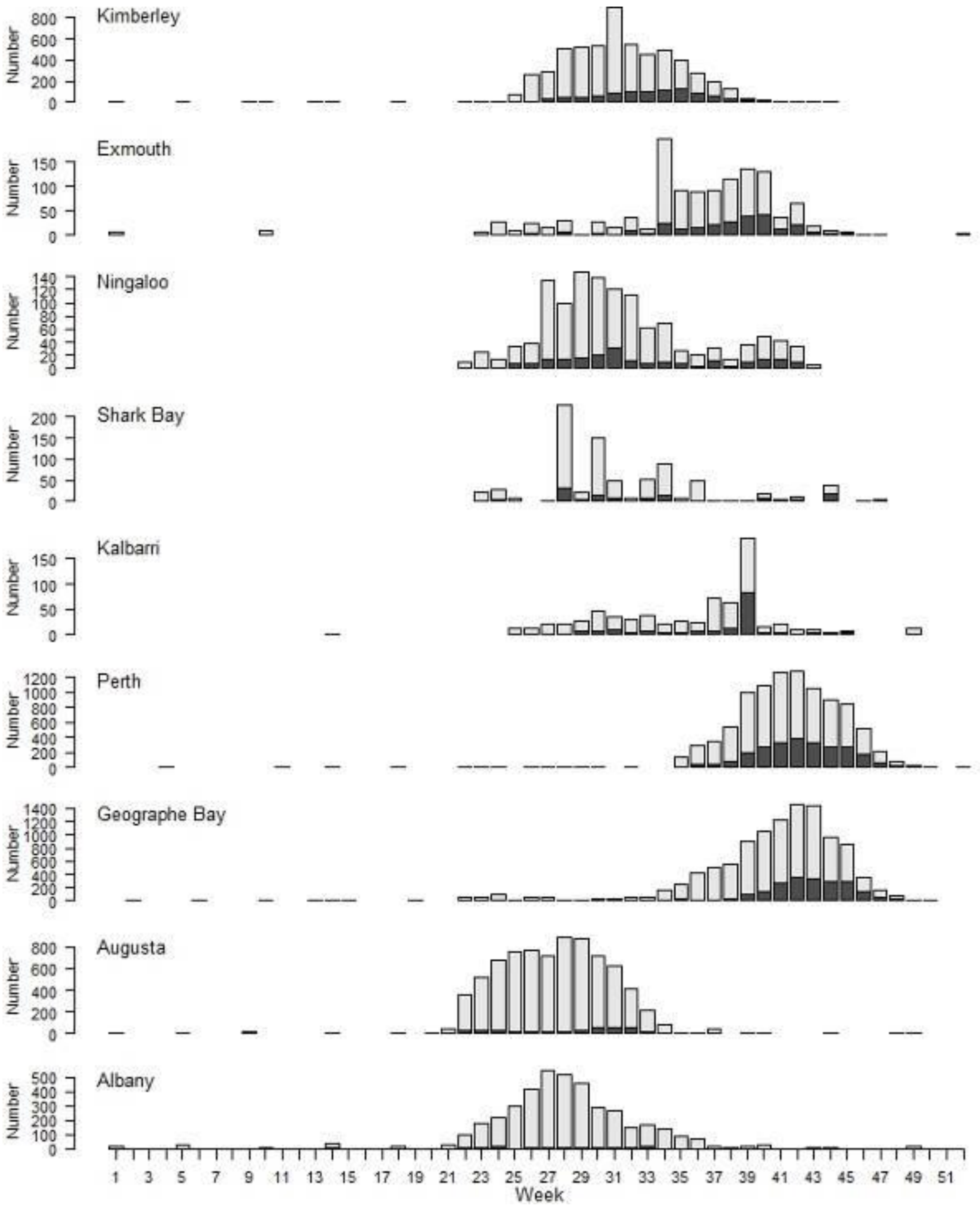


Figure 11 Number of adult (light grey) and calves (dark grey) recorded weekly (all years pooled) in regions where more than 500 were recorded

Table 6 Number of trips conducted by commercial whale watching vessels by region and year

Year	Kimberley	Dampier	Exmouth	Ningaloo	Shark Bay	Kalbarri	Mid West	Perth	Cape Naturalist	Augusta	Albany	Esperance
2000	2	4	2	24	8	30	9	230				
2001	17	1	154	5	3		4	208			2	
2002	57	52	7		33			177	86	133	34	
2003	56			100	8			136	99	104		
2004	39			60				197	101	109		5
2005	23		43		7			180	57	107		3
2006	29		29		14	23		75	41	40	15	
2007	22		10	9	5	12	1	72	1	44	37	3
2008	137		28		11	25		86			48	
2009	59		22		2	6		56			105	
2010	72		10	15				76	102	48	62	3
2011	96		26	30				156	268	156	111	
2012	54			17				73	236	182	176	
2013	97		1	27				77	359	75	48	
2014			1		5	33		164	236	96	56	
2015	143		42					214	364	167	94	
2016	106			22		38		204	252	209	57	
2017	51							70	143	139	1	

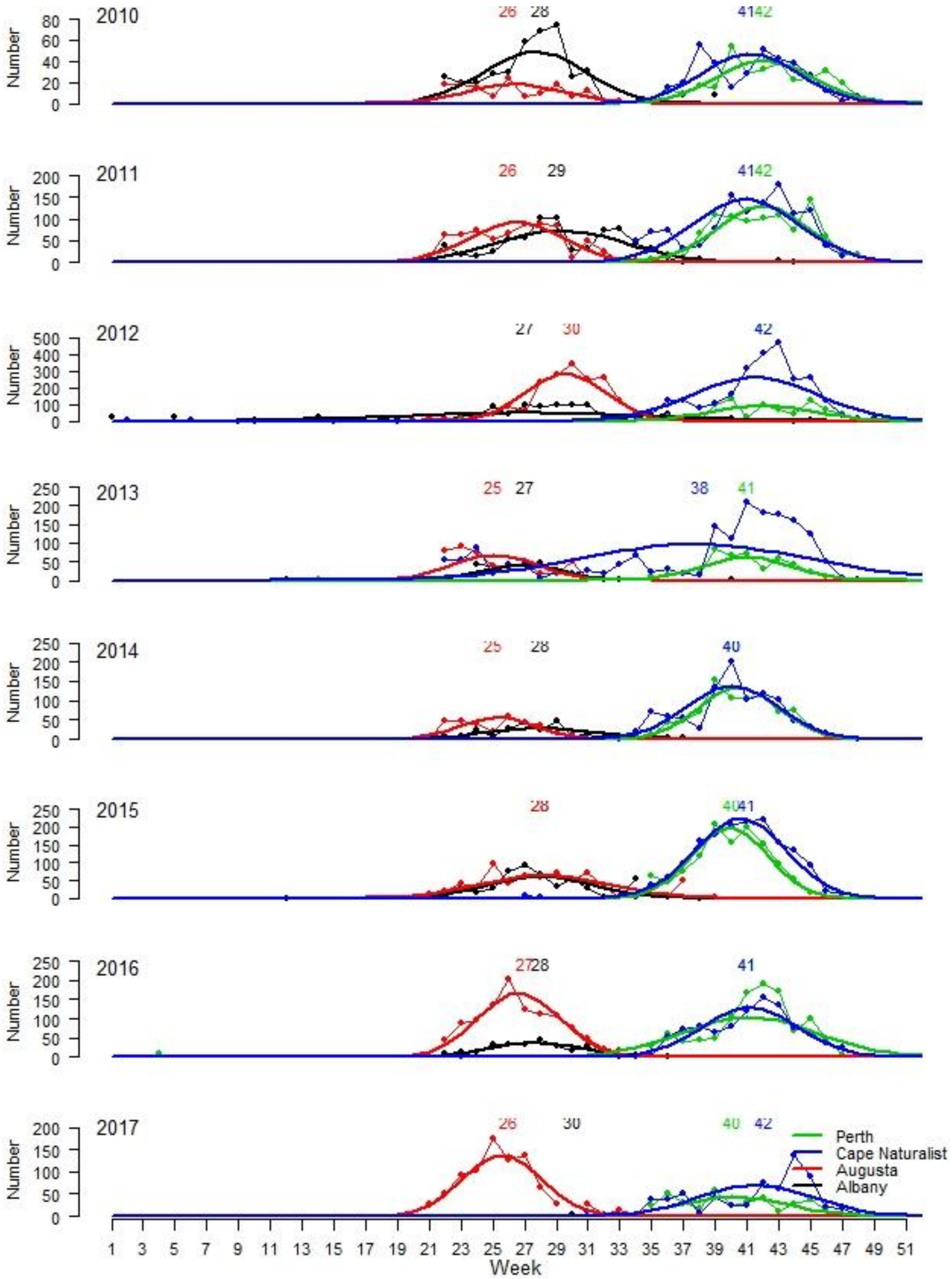


Figure 12 Annual fitted distribution (thick line) and the actual number of whale (thin line with dots) encountered by commercial whale watching vessels by week of the year at Perth (green), Cape Naturalist (blue), Augusta (red) and Albany (black).

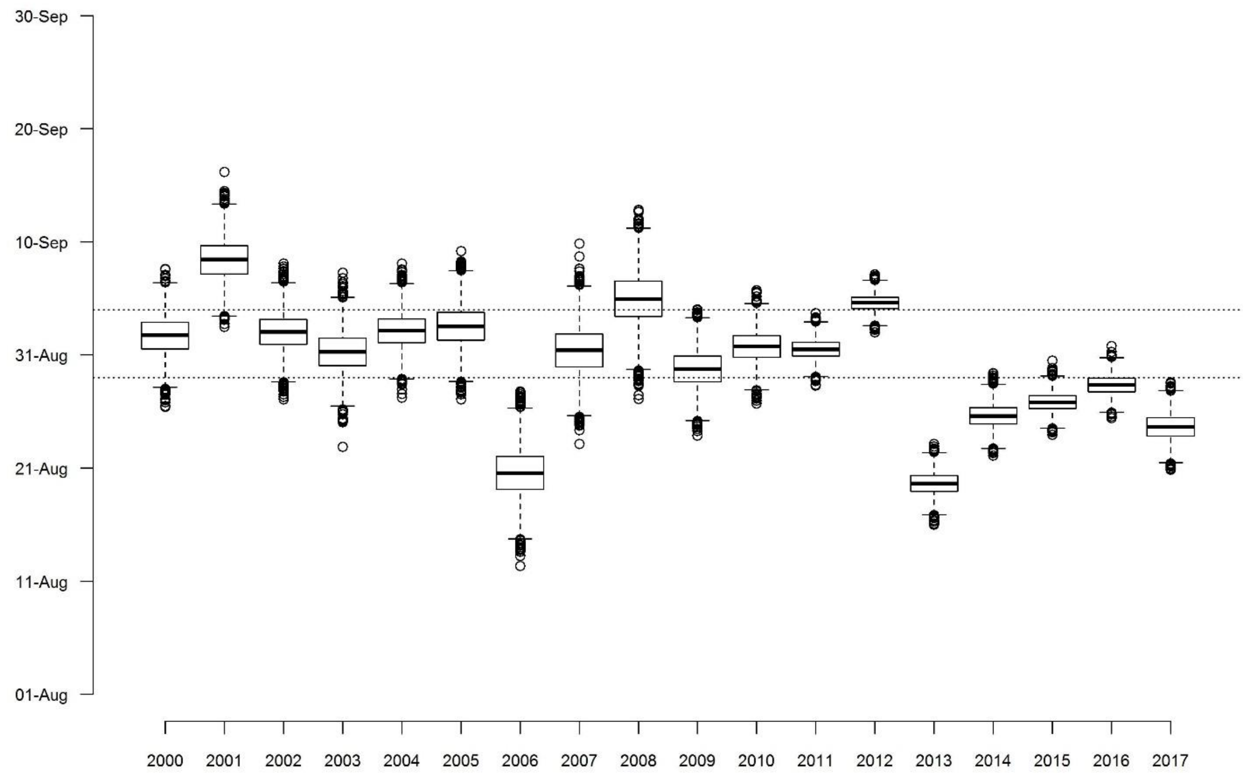


Figure 13 Boxplot of annual model estimated migration dates (dotted line represents band of 'normal' migration timing, 29 August – 4 September)

5.2.1.1.2 Whale Sightings

For the three migration seasons that the WhaleSightingsWA app was used, 685 reports were submitted by 74 observers reporting a total of 1853 whales. The overwhelming majority of these were humpback whales (1736), with southern right whales (77) and unknown (20) being the next two abundant species recorded. Twenty-two Commercial lobster fishers also provided sighting (or nil reports) via their catch disposal records (CDR) during the 2013-2016 seasons.

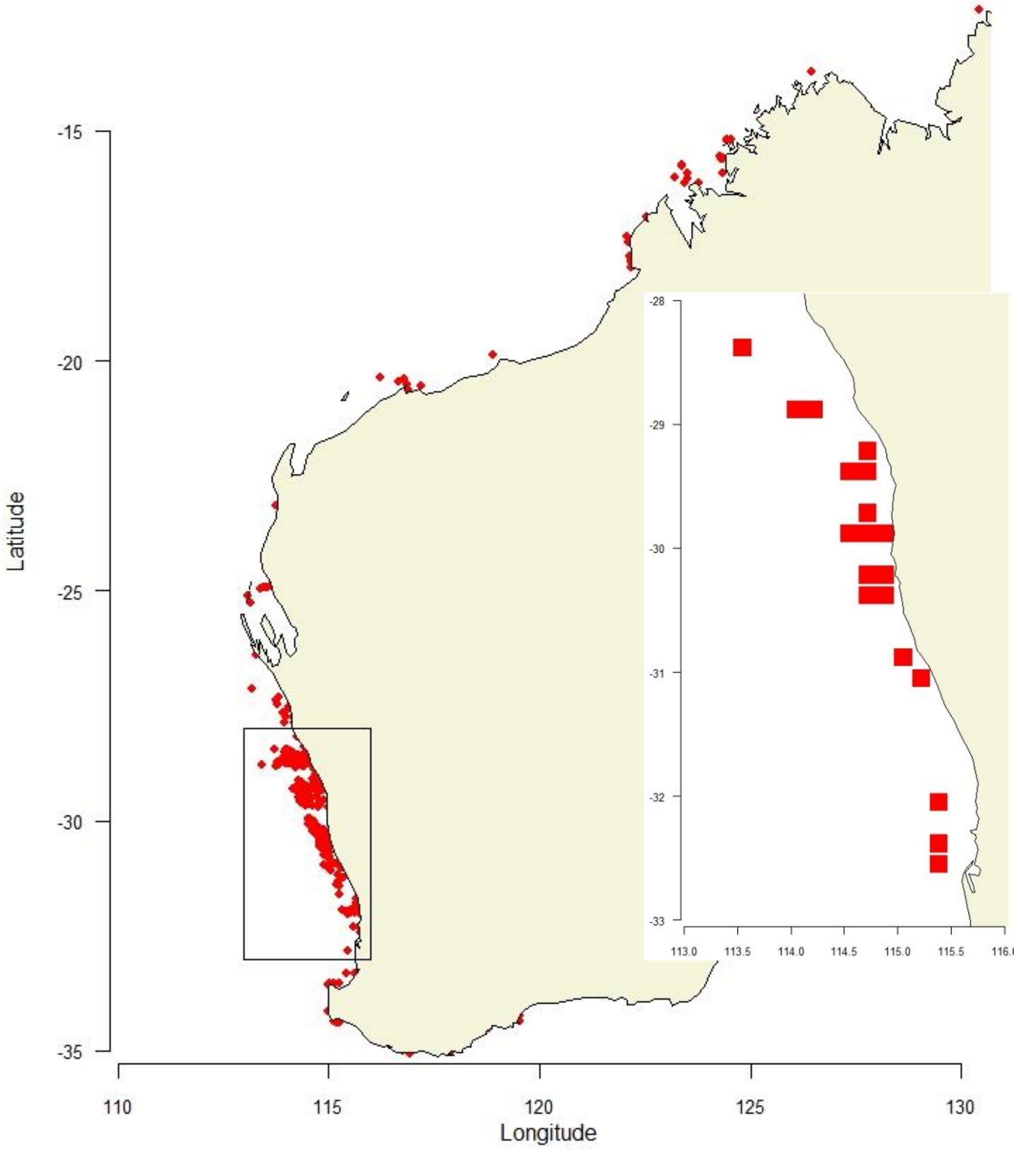


Figure 14 Location of whale sightings as recorded through the WhaleSightingsWA app (red dots). Inset: 10x10 minute blocks where whales were recorded by commercial rock lobster fishers on the catch disposal records

The vast majority of whale sightings which were recorded were obtained through the WhaleSightingsWA app. The app was released in July 2014 with August 2014 recording the highest number of sightings. They decline in subsequent months during 2014 as the whales migrated off the Western Australian coast. In 2015 and 2016, peak records of whale sightings occurred in September and October respectively. These correspond to the southerly humpback migrating, with few sightings recorded on their northerly migration. There were few records from CDRs compared to those from the WhaleSightingsWA app.

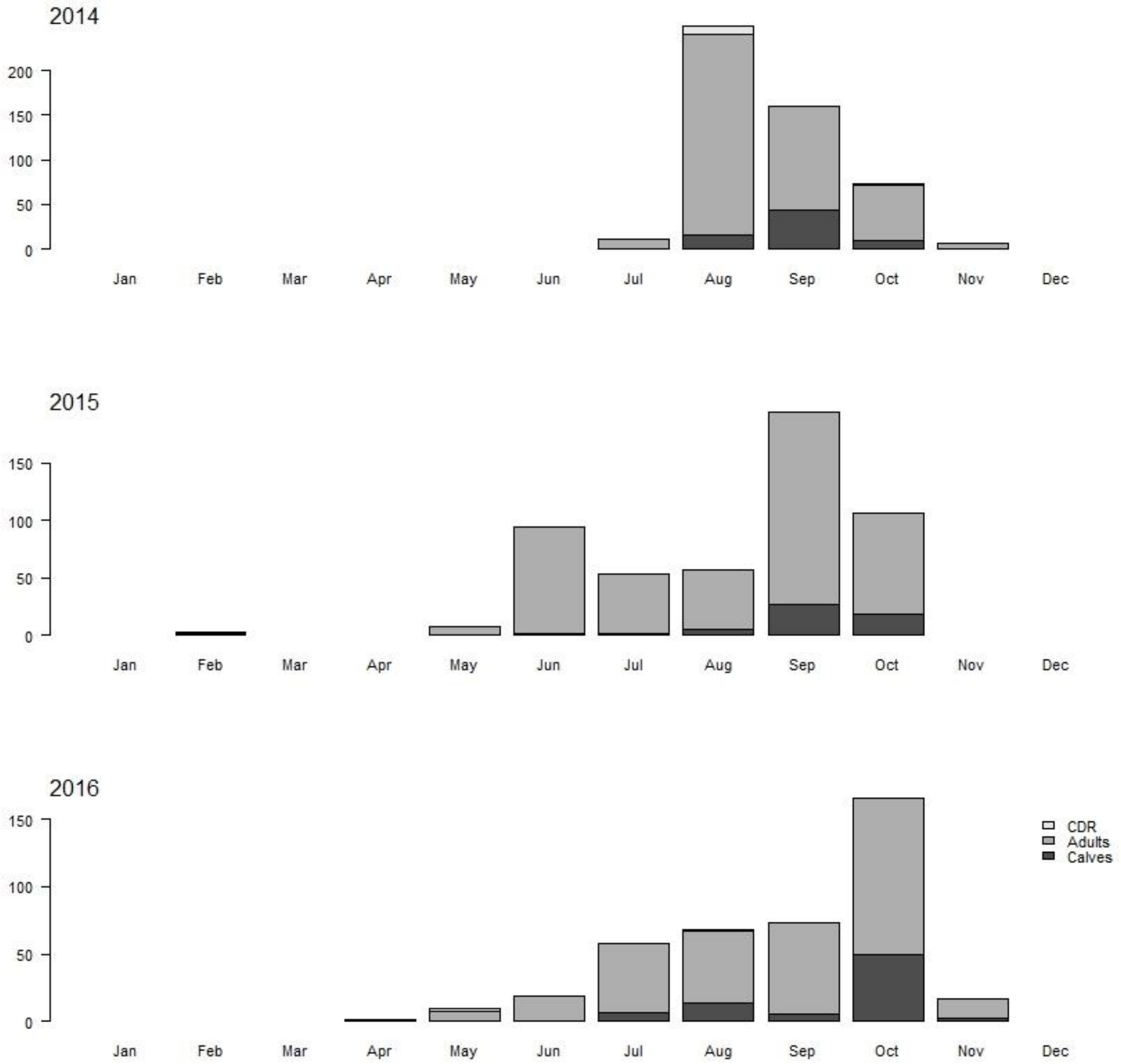


Figure 15 Number by month and year of humpback adults (grey) and calves (dark grey) recorded using WhaleSightingsWA and whales (light grey) recorded on catch disposal records.

Activity data that was recorded as part of the WhaleSightingsWA app showed most of the whales which were sighted were surface active or milling. For those that were observed migrating, north bound whales were most common from May to July inclusive, while southbound whales were observed progressively more frequently from August through to November (Figure 16).

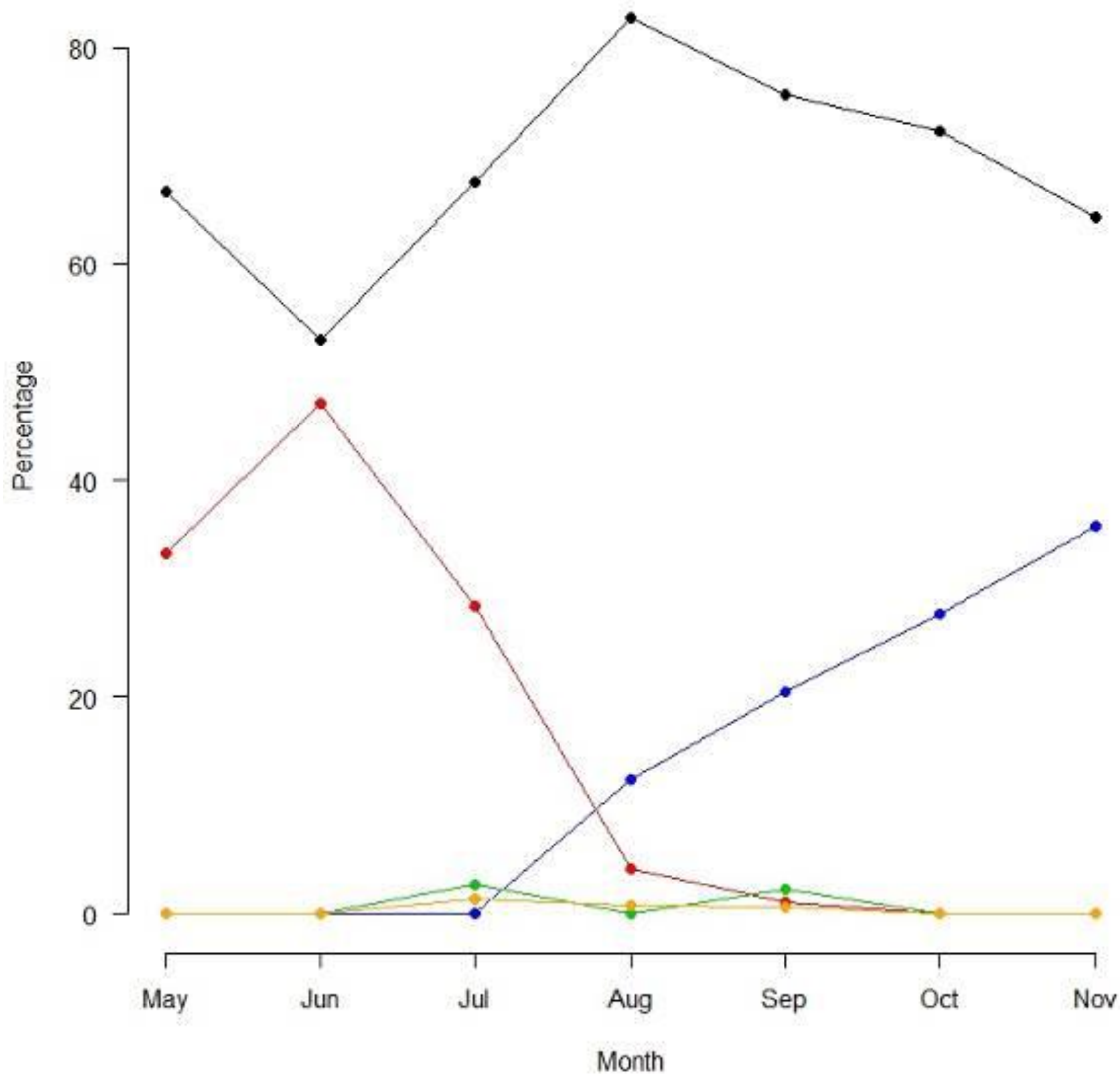


Figure 16 Percentage of humpback whales milling / surface active (black), migrating north (red), south (blue), east (green) and west (orange) by month from whale sightings.

Depth information associated with sightings from CDRs showed that the majority of whales were sighted in the 20-29 (36.6-54.4 m), with no sighting recorded in waters less than 10 fathoms (18.3 m) (Figure 17).

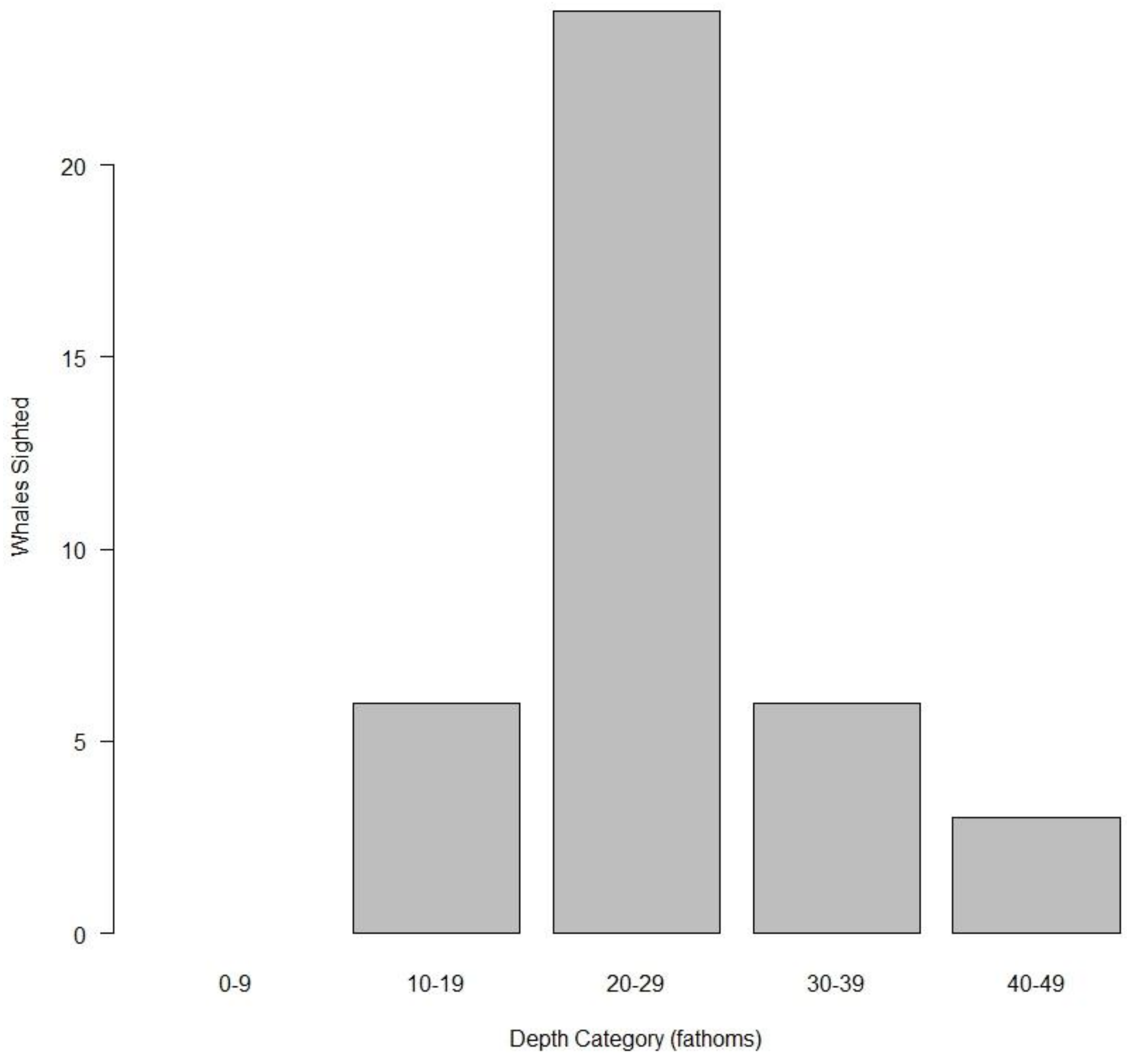


Figure 17 Number of whale sightings recorded on catch disposal records by 10 fathom (18.3 m) depth categories

5.2.2 Spatial Information – Satellite Tracking

A total of 62 satellite transmitters were successfully deployed over four tagging trips from 2014-2016 (Table 7), with 11 and 18 deployments in Carnarvon in 2014 and 2016 respectively, and 14 and 19 deployments in Augusta in 2015 and 2016 respectively. The majority of whale tagged were considered adults (*n*= 57) with 5 sub-adults tagged. Biopsies permitted the sexing of 43 whales, with 23 males and 20 females tagged.

Longer tracking durations (Figure 18a), resulting in more locations (Figure 18b) and greater tracked distance (Figure 18c) occurred for whales which were tagged in 2016. For the 2014 southern and 2015 northern migrations, whales were tracked up to 50 and 60 days respectively. However, these same migrations in 2016 resulted in maximum durations of 151 days for the northern migration and 197 days for the southern migration. This permitted over 8,500 location detections for some individuals as they were tracked for almost 16,000 km.

A more detailed examination of the impact of tag placement, migration direction, sex and deployment pressure on data transmission success and transmitted longevity will be undertaken to better inform future tagging studies (see Section Further development; Factors affecting transmission success and deployment longevity of implantable satellite tags).

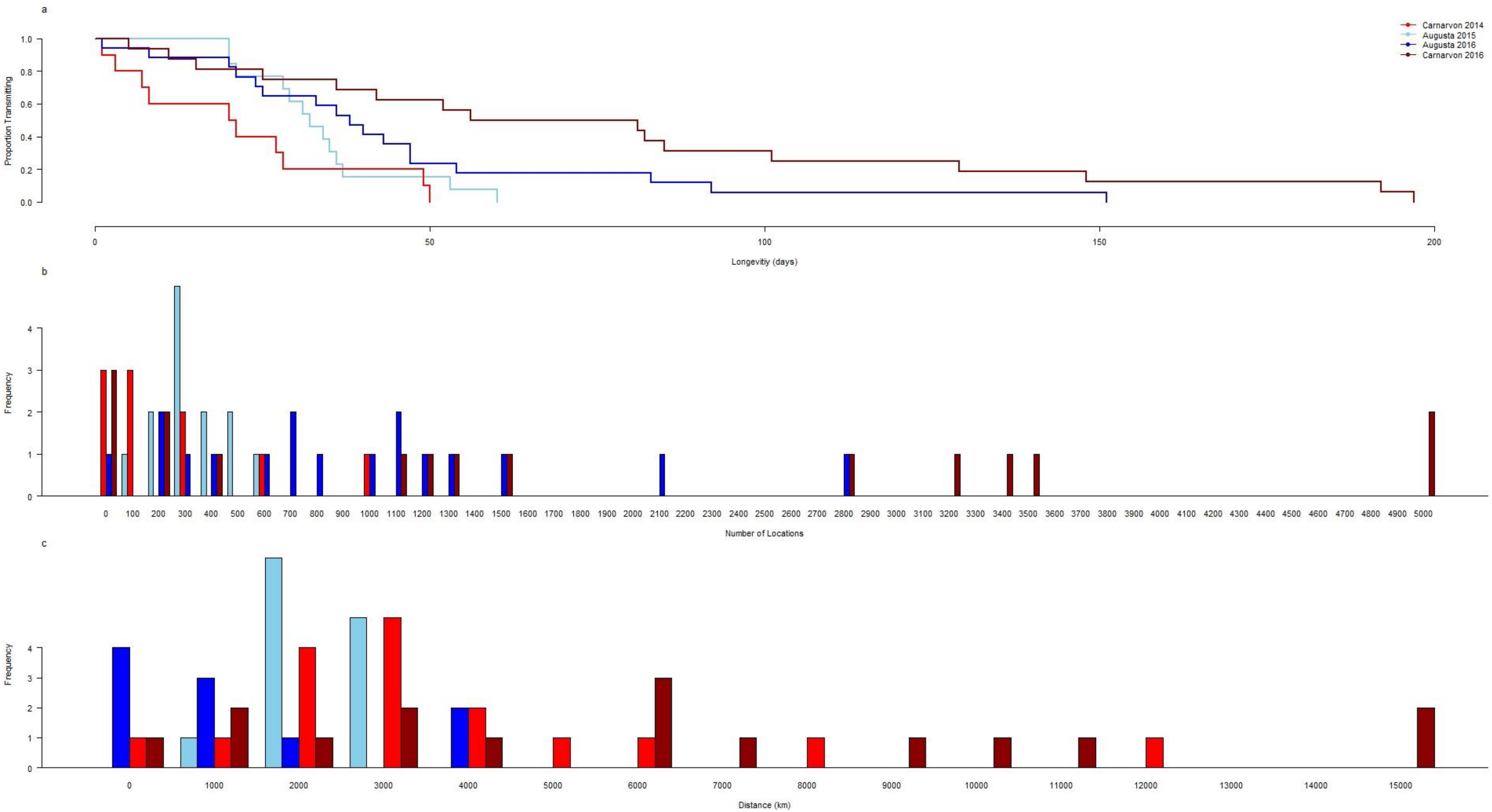


Figure 18 Summary details for a) longevity, b) number of locations and c) distance tracked by deployment trip for tagged humpback whales.

Table 7 Tagging, biological and tracking data of humpback whales tagged during the four deployment trips

Trip	Tag	Maturity	Sex	Tag Date	Last Date	Longevity	Locations	Distance	Argos					
									3	2	1	0	A	B
Carnarvon 2014	112743	Adult	Male	2014-09-01	2014-09-08	7	115	704	0	7	8	4	22	74
Carnarvon 2014	112739	Adult	Female	2014-09-01	2014-09-21	20	322	1880	4	24	33	14	57	190
Carnarvon 2014	112735	Adult	Male	2014-09-01	2014-09-02	1	17	80	1	1	1	0	2	12
Carnarvon 2014	112740	Adult		2014-09-02										
Carnarvon 2014	120941	Adult	Female	2014-09-02	2014-09-29	27	342	2193	0	6	6	7	39	284
Carnarvon 2014	121196	Adult	Male	2014-09-02	2014-10-22	50	695	4026	4	34	59	25	133	440
Carnarvon 2014	121190	Adult	Female	2014-09-03	2014-09-11	8	156	935	6	13	20	7	32	78
Carnarvon 2014	112720	Adult	Female	2014-09-03	2014-09-06	3	49	445	2	2	6	2	10	27
Carnarvon 2014	121204	Adult		2014-09-04	2014-10-02	28	23	1709	0	0	0	0	1	22
Carnarvon 2014	112744	Adult		2014-09-05	2014-10-24	49	1010	4610	45	112	135	63	201	454
Carnarvon 2014	120939	Adult	Negative	2014-09-05	2014-09-26	21	147	1806	3	9	2	3	26	104
Augusta 2015	131160	Subadult		2015-06-23										
Augusta 2015	131150	Adult	Male	2015-06-26	2015-08-02	37	138	1101	2	7	3	2	20	104
Augusta 2015	131161	Adult	Female	2015-06-27	2015-08-02	36	435	3103	9	17	16	8	63	322
Augusta 2015	131157	Adult		2015-06-27										
Augusta 2015	131168	Adult	Female	2015-06-28	2015-07-29	31	368	2621	4	9	9	4	54	288
Augusta 2015	131166	Adult		2015-06-28	2015-08-02	35	332	3020	0	2	3	2	23	302
Augusta 2015	131164	Adult	Male	2015-06-28	2015-07-18	20	273	2425	7	18	22	8	40	178
Augusta 2015	131163	Subadult	Female	2015-06-29	2015-08-02	34	547	2935	20	32	27	11	96	361
Augusta 2015	131152	Adult	Male	2015-06-29	2015-07-27	28	255	2517	0	3	1	1	18	232
Augusta 2015	131169	Adult	Female	2015-06-30	2015-08-29	60	380	3907	1	2	3	1	27	346
Augusta 2015	131165	Adult	Male	2015-06-30	2015-07-29	29	321	3179	2	6	7	3	28	275
Augusta 2015	131170	Adult		2015-06-30	2015-07-21	21	402	2025	14	30	40	16	56	246
Augusta 2015	131148	Adult	Male	2015-06-30	2015-08-01	32	605	2704	54	86	65	13	117	270
Augusta 2015	131167	Adult		2015-06-30	2015-08-22	53	591	3779	14	38	41	14	120	364
Augusta 2015	112742	Subadult	Male	2015-07-01	2015-07-21	20	375	2207	10	23	38	14	66	224

Trip	Tag	Maturity	Sex	Tag Date	Last Date	Longevity	Locations	Distance	Argos					
									3	2	1	0	A	B
Augusta 2016	154856	Adult	Female	2016-06-23	2016-07-29	36	740	2919	32	76	27	26	106	473
Augusta 2016	154863	Adult		2016-06-23										
Augusta 2016	154857	Adult	Female	2016-06-23	2016-09-14	83	1389	6832	73	108	93	45	279	791
Augusta 2016	154861	Adult	Male	2016-06-23	2016-06-24	1	51	122	11	10	8	13	3	6
Augusta 2016	154858	Adult	Male	2016-06-23	2016-07-18	25	1139	2160	83	170	217	80	209	380
Augusta 2016	154864	Adult		2016-06-24										
Augusta 2016	154851	Adult	Female	2016-06-24	2016-08-06	43	2135	3460	290	419	398	122	414	492
Augusta 2016	154850	Adult	Female	2016-06-24	2016-07-18	24	1042	3499	192	163	157	64	171	295
Augusta 2016	154854			2016-06-26										
Augusta 2016	154859	Adult	Female	2016-06-30	2016-11-28	151	1555	12391	9	23	24	13	199	1287
Augusta 2016	154860	Adult	Female	2016-06-30	2016-08-16	47	381	3673	17	23	40	20	62	219
Augusta 2016	154853	Adult	Male	2016-06-30	2016-08-07	38	654	3820	14	13	13	10	121	483
Augusta 2016	154855	Adult	Male	2016-06-30	2016-08-23	54	805	4392	8	23	22	19	142	591
Augusta 2016	154874	Adult	Female	2016-07-02	2016-10-02	92	2874	8954	178	389	557	191	577	982
Augusta 2016	154868	Adult	Male	2016-07-02	2016-08-18	47	1283	5114	55	117	146	73	317	575
Augusta 2016	154870	Adult	Female	2016-07-02	2016-07-10	8	291	1244	3	9	13	26	80	160
Augusta 2016	154869	Adult	Male	2016-07-02	2016-08-04	33	403	3247	12	20	32	8	102	229
Augusta 2016	154873	Adult	Male	2016-07-02	2016-07-22	20	255	2003	0	12	32	28	72	111
Augusta 2016	154871	Adult	Male	2016-07-02	2016-07-23	21	717	2396	23	55	91	51	180	316
Augusta 2016	154872	Adult	Female	2016-07-02	2016-08-11	40	1113	4664	102	180	192	64	215	360
Carnarvon 2016	154862	Sub-adult		2016-09-06	2016-10-18	42	1569	4641	40	132	195	69	323	810
Carnarvon 2016	154865	Adult		2016-09-06										
Carnarvon 2016	154849	Adult		2016-09-06	2016-10-12	36	1389	3747	64	117	189	70	343	606
Carnarvon 2016	154852	Sub-adult		2016-09-06	2016-12-16	101	5553	10782	234	519	712	298	1361	2429
Carnarvon 2016	154866	Adult		2016-09-06										
Carnarvon 2016	154867	Adult		2016-09-06	2017-01-13	129	3526	11192	89	200	339	173	705	2020
Carnarvon 2016	154876	Adult		2016-09-12	2016-12-06	85	76	3783	0	0	11	3	15	47
Carnarvon 2016	154877	Adult	Male	2016-09-12	2016-09-17	5	95	466	0	10	10	3	27	45

Trip	Tag	Maturity	Sex	Tag Date	Last Date	Longevity	Locations	Distance	Argos					
									3	2	1	0	A	B
Carnarvon 2016	131181	Adult		2016-09-12	2016-10-07	25	298	2365	6	13	11	8	57	203
Carnarvon 2016	113215	Adult	Male	2016-09-13	2017-03-29	197	3266	15885	131	346	444	189	542	1614
Carnarvon 2016	131183			2016-09-13										
Carnarvon 2016	154848	Adult	Male	2016-09-15	2016-12-05	81	1213	6830	18	64	90	53	294	694
Carnarvon 2016	154875	Adult	Female	2016-09-15	2016-11-10	56	1155	6912	18	33	92	69	220	723
Carnarvon 2016	113220	Adult	Female	2016-09-15	2017-03-26	192	3465	15133	128	350	524	255	660	1548
Carnarvon 2016	131140	Adult	Female	2016-09-15	2016-12-06	82	2860	6343	79	296	439	122	651	1273
Carnarvon 2016	113224	Adult		2016-09-20	2016-10-01	11	83	1017	2	1	3	6	16	55
Carnarvon 2016	113218	Adult	Male	2016-09-21	2016-11-12	52	430	7015	11	8	16	11	71	313
Carnarvon 2016	112693	Adult	Male	2016-09-21	2016-10-06	15	284	1671	0	4	39	16	35	190
Carnarvon 2016	112724	Adult	Male	2016-09-21	2017-02-16	148	8544	9780	625	1520	1742	655	1612	2390

5.2.2.1.1 Overall movement pattern

Whales tagged in Augusta all moved in a northerly direction along the West Australian coast and remained almost exclusively on the continental shelf (< 200 m), with only a couple of whales moving off the shelf on their northerly migration around Perth (Figure 19). Whales were generally tracked moving to the states north coast, with one whale tracked to the states north most point. The majority of tracking ceased for whales when they were between Exmouth and Broome. However, after reaching the states north coast 12 (*n*=5 2015; *n*=7 2016) northbound whales were also tracked returning south. All whales, with the exception of one, turned on the states north coast, generally between Exmouth and Broome, from late July to mid-August.

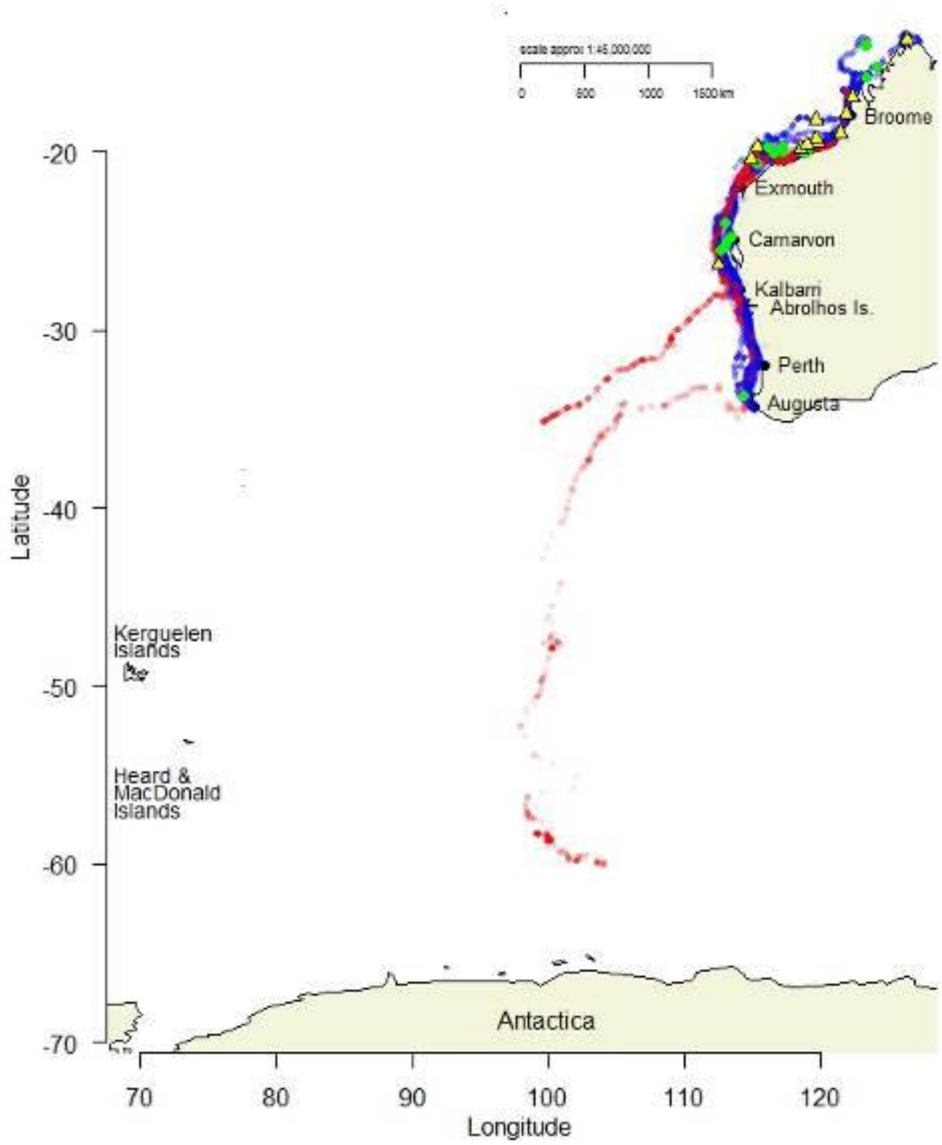


Figure 19 Northerly (blue) and southerly (red) movement of humpback whales tagged in Augusta in 2015 and 2016. The final detection location of northern migrating whales (green) and locations where movements changed from northerly to southerly movements (yellow triangles).

Whales tagged specifically on their southern migration moved offshore to 71.6º W in the eastern Indian Ocean and were tracked as far south as 65.3º S (Figure 20). While a number of whales did move south along the continental shelf, a significant number whales moved of offshore on-route to Antarctic feeding grounds (Figure 19 and Figure 20). Eleven whales were tracked south to Kerguelen Island or lower latitudes. At this point there was a change in their movement patterns, likely more reflective of feeding than migratory movements. These will be examined further in future analyses (see Section Further development: Offshore and feeding associated movements of humpback whales in Antarctic waters)

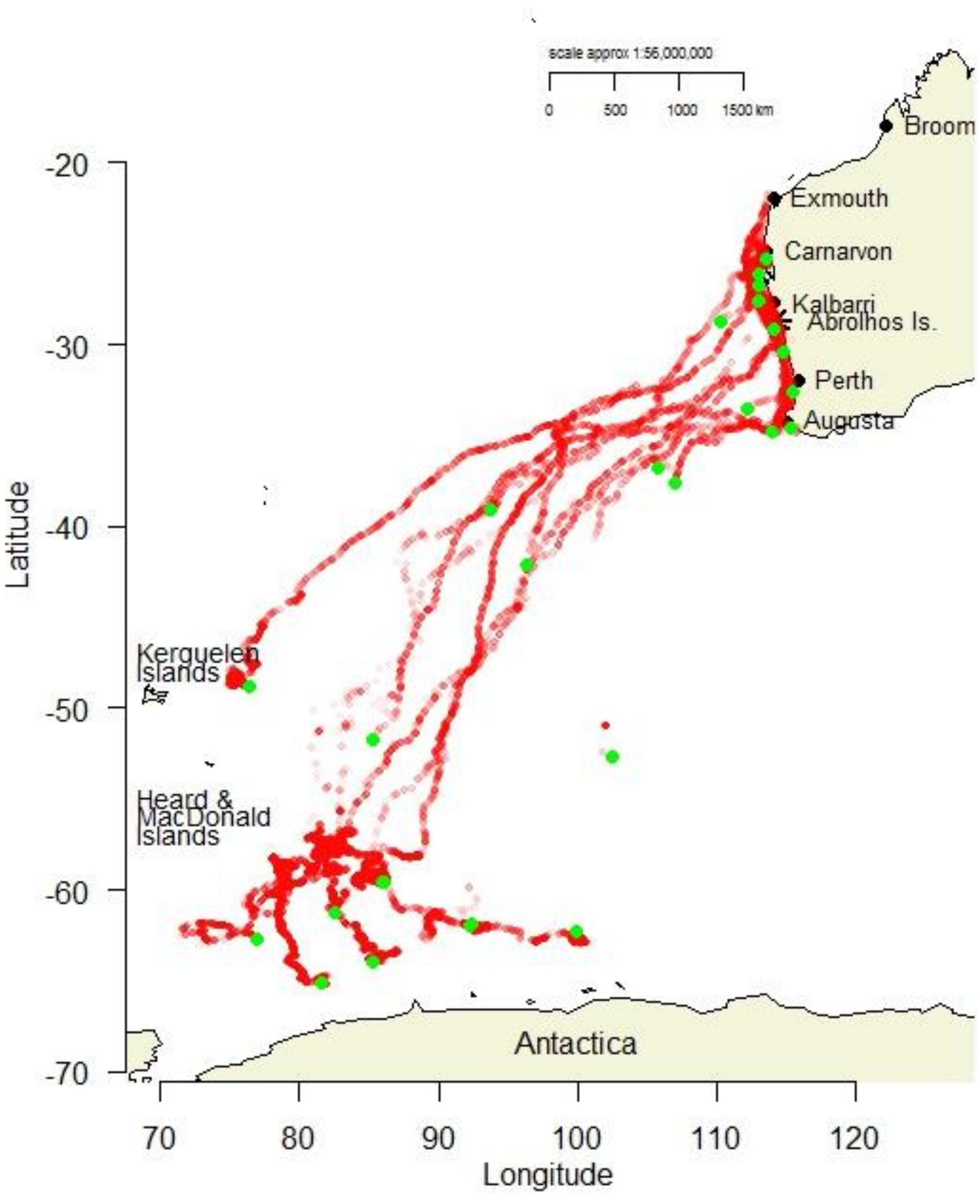


Figure 20 Southerly (red) movements of humpback whales tagged in Carnarvon in 2015 and Carnarvon and Exmouth in 2016 with the final detection location (green).

5.2.2.1.2 Sex related movement patterns

Males and females followed generally similar migration patterns, though there were a few noticeable deviations. Females tended to remain further offshore in a number of regions off the Western Australia coast (Figure 21). The two whales that were tracked moving off the continental shelf in the lower-west coast were both females. Similarly, on the states north coast, females appeared to remain further offshore until they reached Broome (Figure 21). Six whales (3♀, 3♂), whales were tracked north of Broome (18^{o} S), with four that made it to the latitude of the southern boundary of the Camden Sound Marine Park. Only one whale, a female was recorded in Camden Sound Marine Park, while two males remained offshore of the park and a second female transited further north outside of the park boundary (Figure 21).

5.2.2.1.3 Directionality of migration

Accounting for from the overall direction of migration (i.e. northern or southern), there were clear differences in the bearing of travel as whales migrated along the coast (>112^{o} E) (Figure 22). The Western Australian coastline was divided into five regions where the coastline follows a similar general orientation (Figure 22). In most regions for both the northern and southern migration, the orientation of the coastline in these regions corresponded the modal bearing of the humpback migration in that region (Figure 22). Whales traveling north through the lower-west moved in a more easterly direction than the general northern orientation of the coastline in the region and moved in a considerably more westerly direction in their southern migration in this region. The most notable deviation away from the orientation of the coastline were southerly migrating whales in the Capes, which showed a strong westerly movement despite the southerly orientation of the coastline (Figure 22).

There was also a clear distinction in the variance of bearings between the northern and southern migrations as well as between the various coastal regions. Whales in higher latitudes had a smaller variance than those at lower latitudes, with variances being larger in each region on the southern migration compared to the northern migration (Table 8).

Table 8 Circular variance for whales migrating north or south through the five regions off the Western Australian coast (>112^{o} E)

Coastal Region	Migration Direction	
	North	South
Capes	0.434	0.514
Lower west	0.303	0.519
Mid west	0.462	0.626
North west	0.617	0.749
North	0.622	0.687

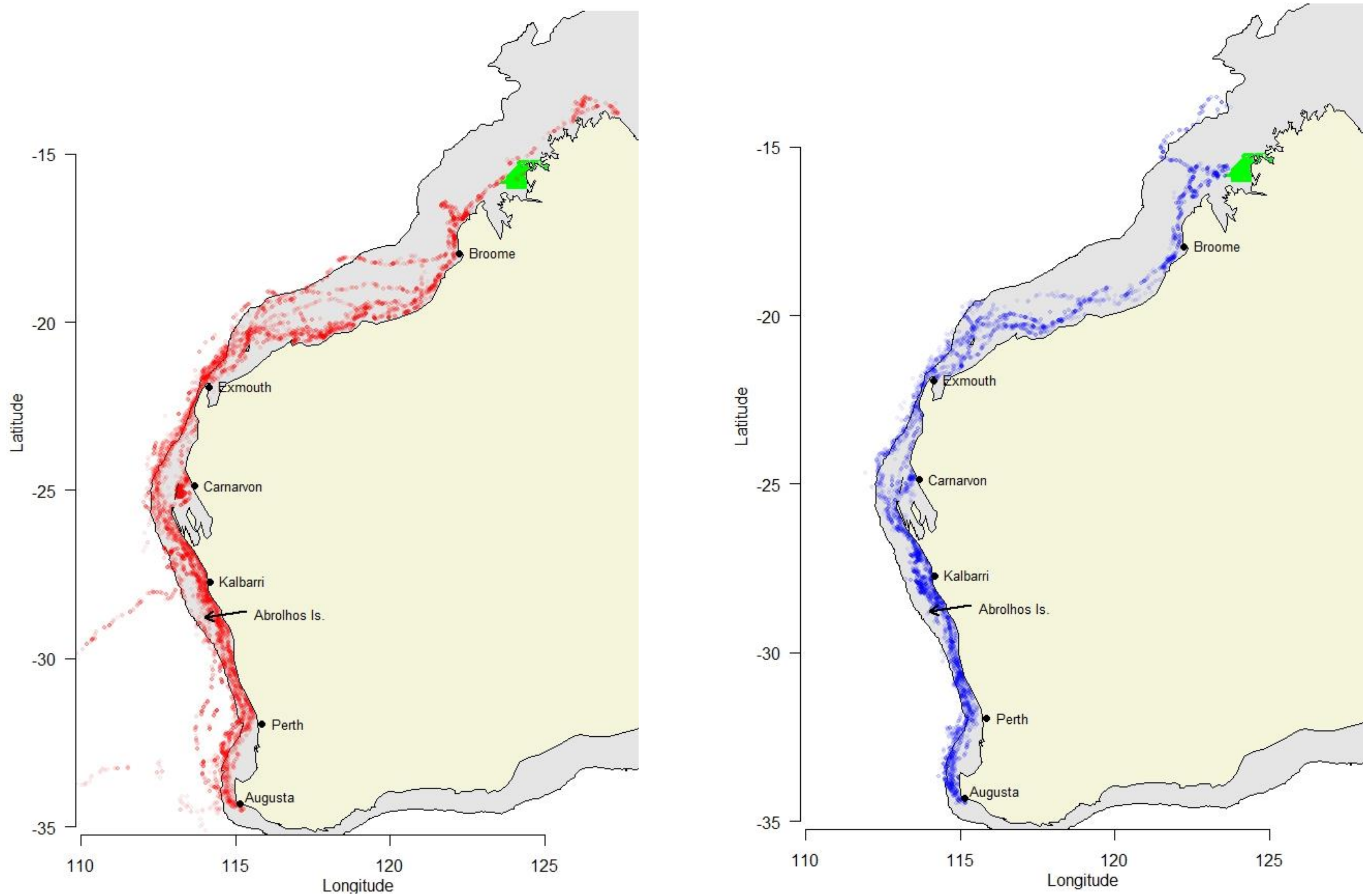


Figure 21 Movements of females (red) and male (blue) satellite tagged humpback whales off the Western Australian coast and the location of the Camden Sound Marine Park (green)

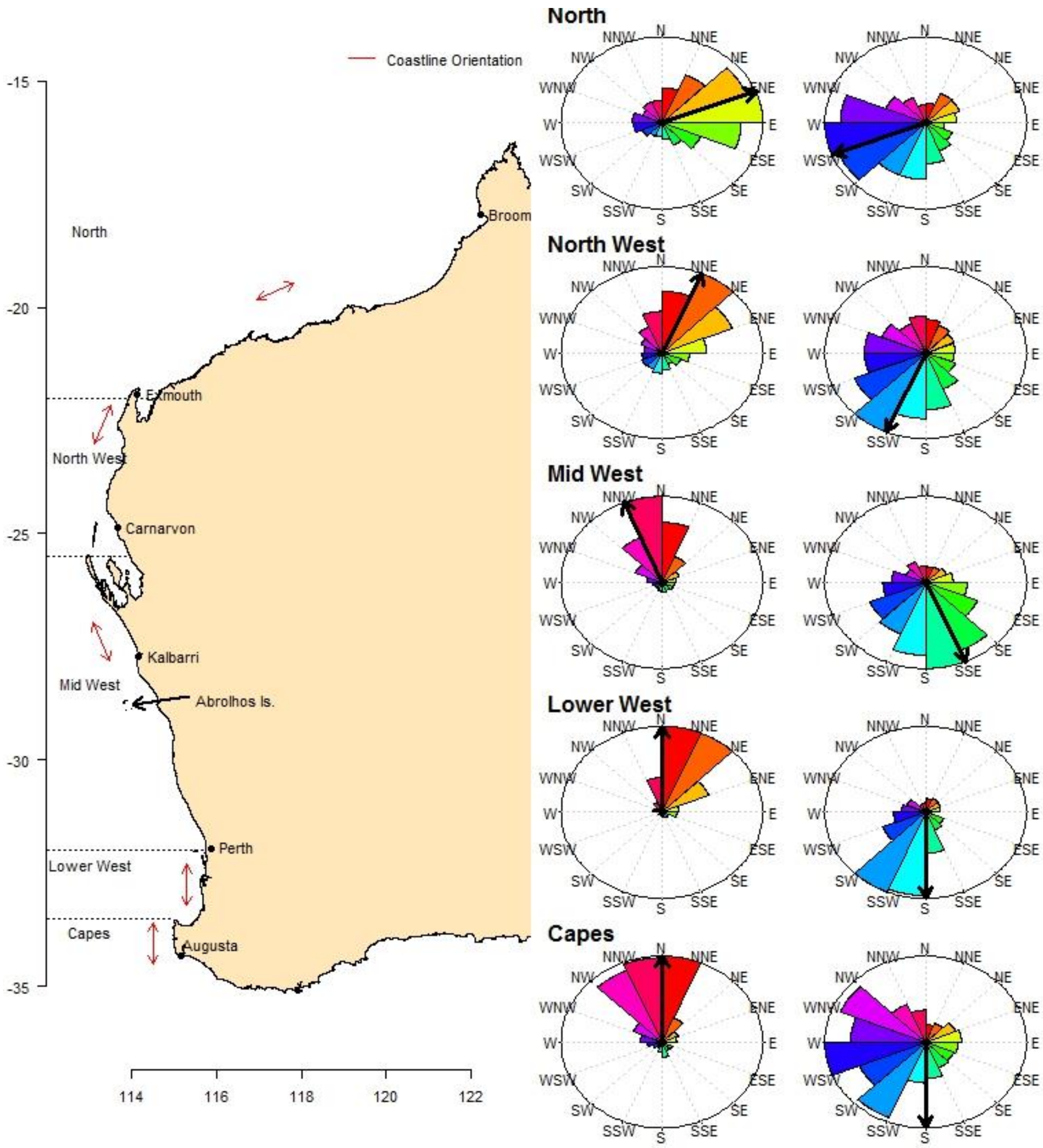


Figure 22 a) Map of Western Australia with the regional bands where the coastline runs in a similar orientation as indicated by the red arrows, b) frequency of whale movement bearings within a regional band (>112 ^{o}E) for whales on their northern (left) and southern migration (right). Bold arrow indicates the coastal orientation in that region

5.2.2.1.4 Movements relevant to spatial management

The West Coast Rock Lobster Managed Fishery (WCRMLF) extends from Cape Leeuwin (34^{o} 24' S) to North West Cape (21^{o} 44' S), though the majority of fishing effort occurs between Kalbarri and Fremantle (Figure 23). Fishers operating in Zones 1 and 2 of the Octopus Interim Managed Fishery require gear modifications. These zones extend from 26^{o} 30'S to 30^{o} S (Zone 1) and 30^{o} S to 34^{o} 24' S (Zone 2) (Figure 23). The Cockburn Sound Line and Pot Fishery operates in Cockburn Sound and Owen Anchorage which form a large embayment just south of Perth (Figure 23). Therefore, analysis relating applicable to gear modifications or spatial closures was restricted to those whales which moved between Cape Leeuwin (Augusta) and the Steep Point near Carnarvon (Figure 23).

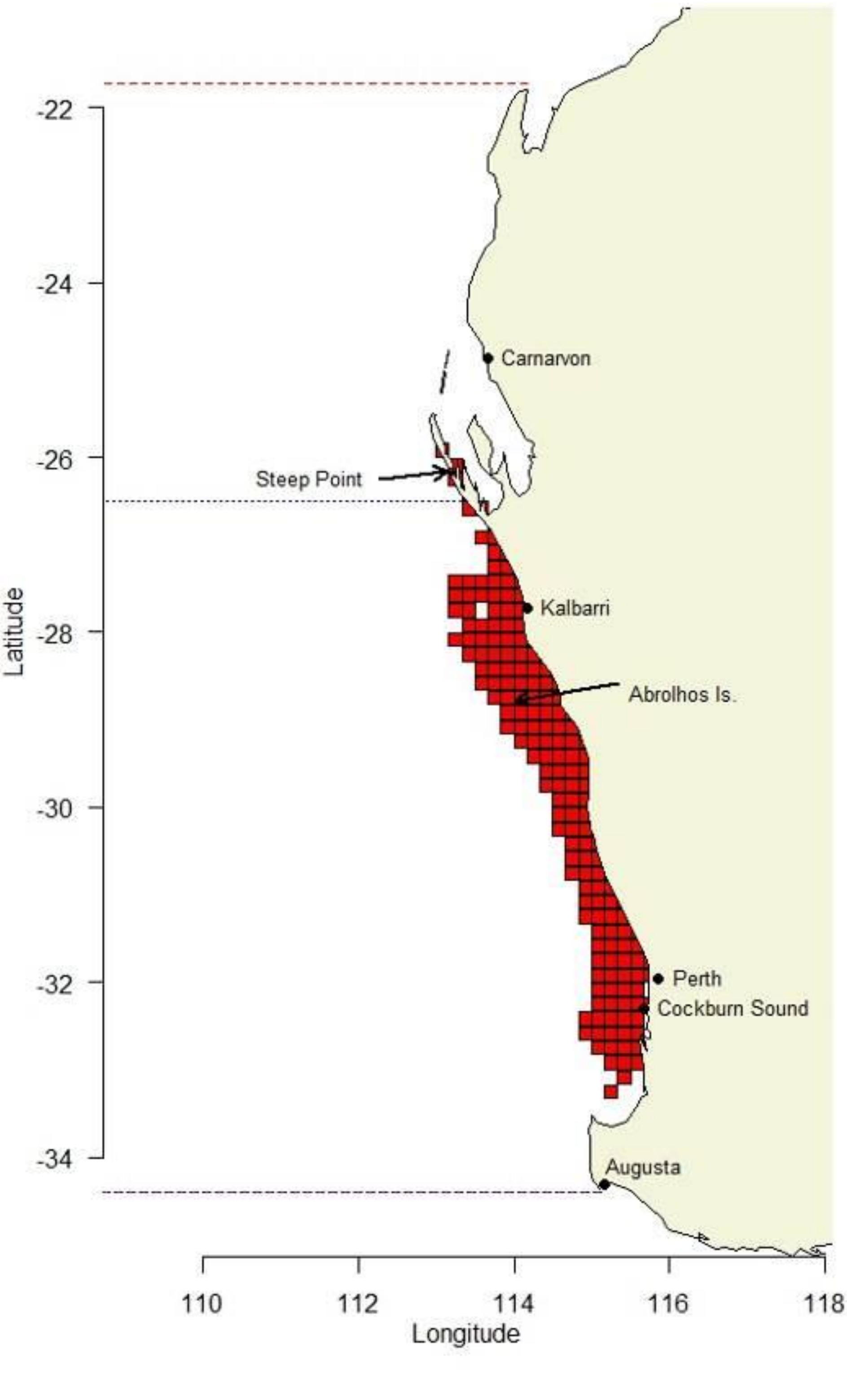


Figure 23 Blocks fished during the 2010-2013 seasons to show the "active" West Coast Rock Lobster Managed Fishery (WCRMLF). Northern boundaries of the WCRMLF (red) and Octopus Interim Managed Fishery (Zone 1; blue line) with their shared boundary (red and blue line; Zone 2).

5.2.2.1.4.1.1.1 Speed of travel

There were differences in the speeds travelled by whales depending on the year and their direction of travel. In 2016 was there a direct comparison on the northern and southern migration, with the southern migration speed being slightly slower than that of the northern migration. However, the northern migration in 2016 was on average almost 1 km/h faster than in 2015 (Figure 24).

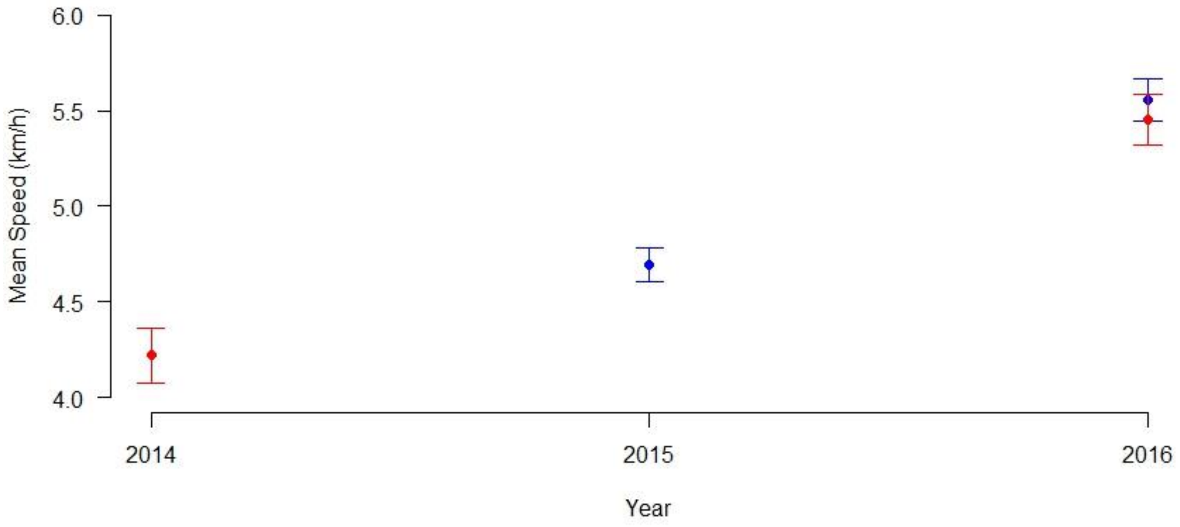


Figure 24 Mean speed (±SE) of humpback whales by year and migration direction (north = blue, south – red)

5.2.2.1.4.1.1.2 Coastal movements and the Leeuwin Current

The warm water, southward flowing Leeuwin Current's strength can be determined by the mean Fremantle sea level. Peak flow generally occurs in May and eases throughout the migration period of the humpback whales until reaching an annual minimum during the austral summer (Figure 25a). The average mean Fremantle sea level during the northern (May – July) and southern (August – October) components of the migration varies annually (Figure 25b). Over the last 17 years the strongest Leeuwin Current recorded was in 2013 for both the northerly and southerly migration periods. Since then the strength of the Leeuwin Current for both components of the migration has declined, though 2017 returned to just above average (Figure 25b).

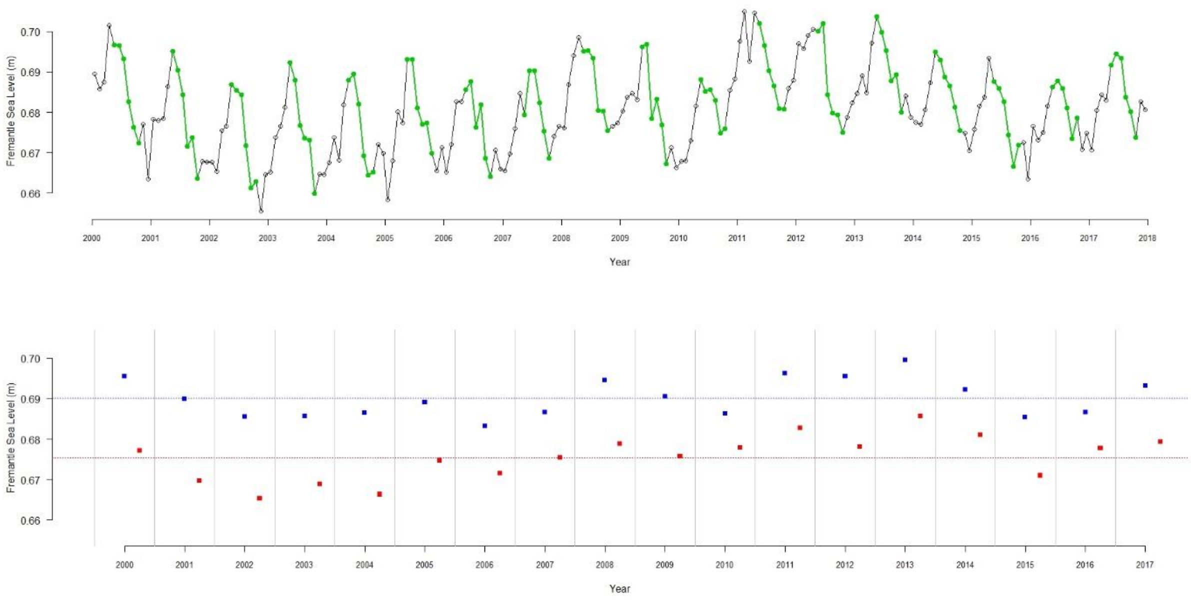


Figure 25 a) Monthly Fremantle sea level (m) recordings from 2000 to 2017 with the months from May to October (inclusive) in green; b) mean of May – July (blue) and August – October (red) monthly Fremantle sea level records, with dotted lines representing the average value from 2000 – 2016 for May – July (blue) and August – October (red).

A total of 29 (13 in 2015, 16 in 2016) humpback whales were tagged out of Augusta on their northern migration. They generally remained inshore of the Leeuwin Current along the west coast of Australia though in 2016 two whales moved offshore of the Leeuwin Current before utilising a cyclonic eddy to move back onto the coast (Figure 26). Northbound humpback whales remained offshore until north of Perth before becoming far more coastally associated in both years.

There were 22 (seven in 2014 and 15 in 2016) humpback whales which moved south along the continental shelf of the west coast of Western Australia. This number is smaller than northbound whales as several whales moved offshore prior to reaching the mid-west coast, and less southbound whales were initially tagged (Table 7). Those that remained on the shelf appeared to utilise the warm southbound Leeuwin Current to assist in their southern migration (Figure 27).

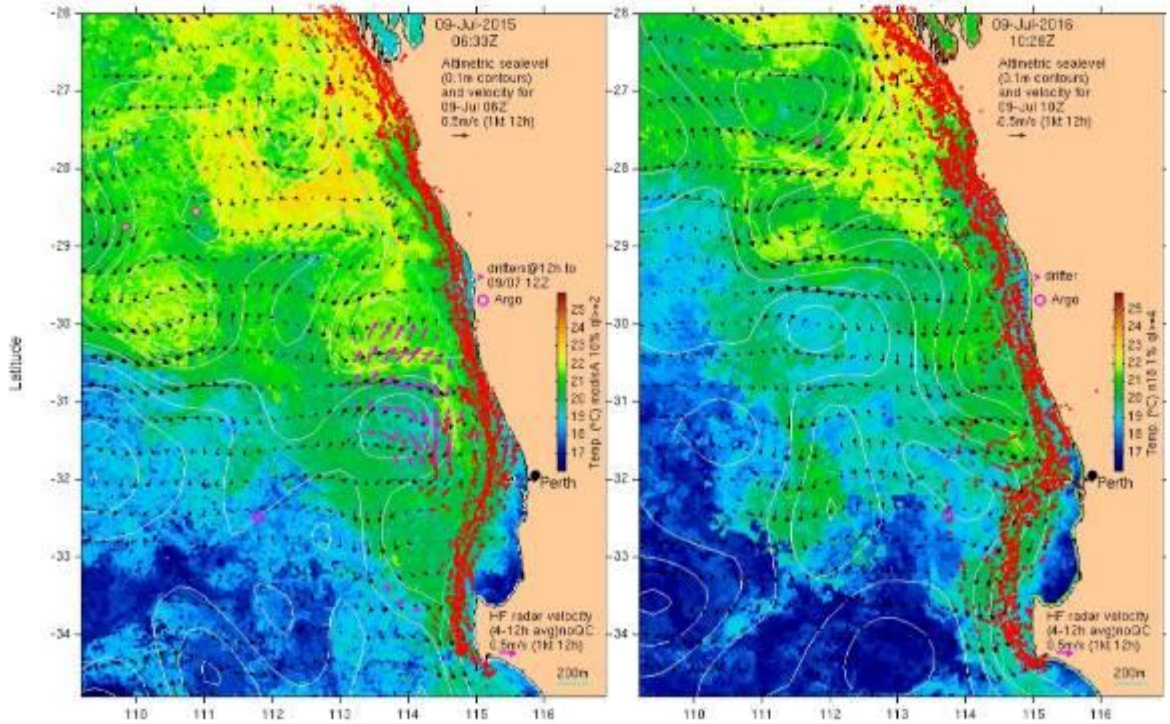


Figure 26 Location of northbound humpback whales (red dots) in 2015 (right) and 2016 (left) plotted on sea-surface temperatures (SST) with direction and strength of the Leeuwin Current (black arrows). SST and current image from http://oceancurrent.imos.org.au/sst.php

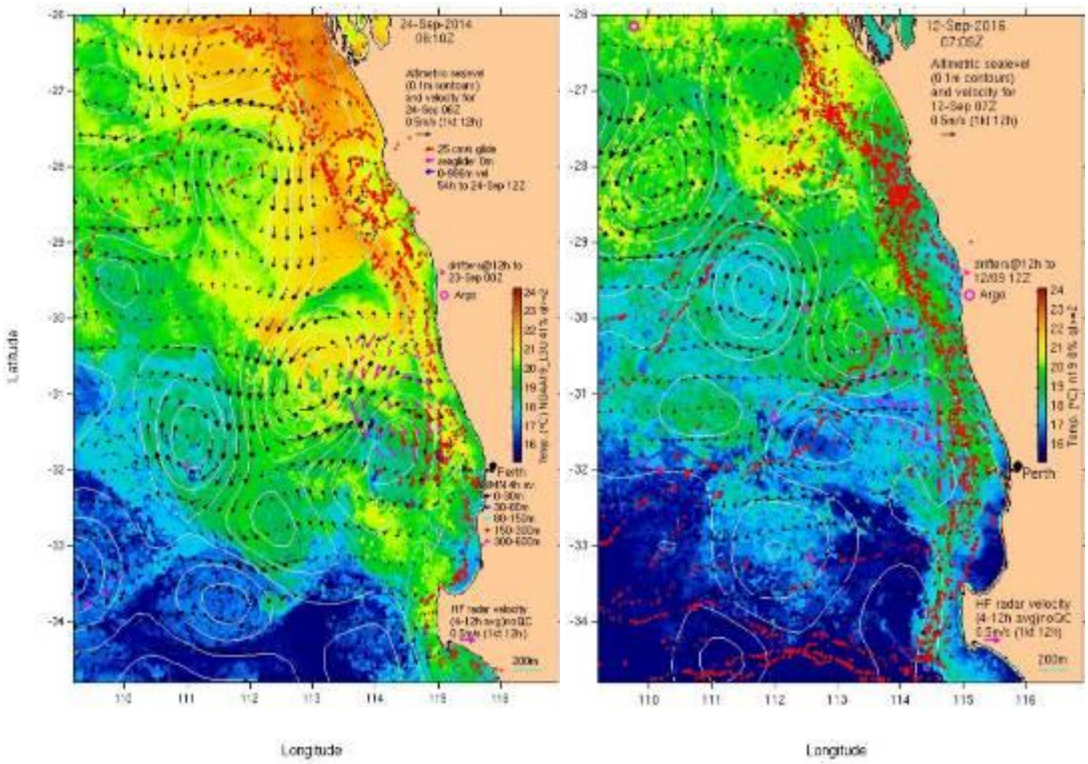


Figure 27 Location of southbound humpback whales (red dots) in 2014 (right) and 2016 (left) plotted on sea-surface temperatures (SST) with direction and strength of the Leeuwin Current (black arrows). SST and current image from http://oceancurrent.imos.org.au/sst.php

The inter-annual differences in the Leeuwin Current strength (Figure 25) correspond to differences in the longitudinal location of whale detections. Whales migrating north against the relatively stronger (Figure 28) Leeuwin Current in 2015 were further inshore in a more concentrated region than in 2016 in the lower west and southern mid-west (Figure 28). There was little differences in the location of migratory whales between the 2015 and 2016 in the northern mid-west coast (27° S).

However, in this the northern mid-west coast, there was a clear separation of the northern and southern migrations, with the northern migration clearly inshore of the southern migration (Figure 28). The 2016 southern migration was slightly inshore of that in 2014 the northern mid-west coast, though was offshore for the lower west and southern mid-west. The 2014 southern migration progressed relatively closer to shore while the 2016 southern migration became more diffuse with a number of whales moving offshore on-route to Antarctic feeding grounds (Figure 28).

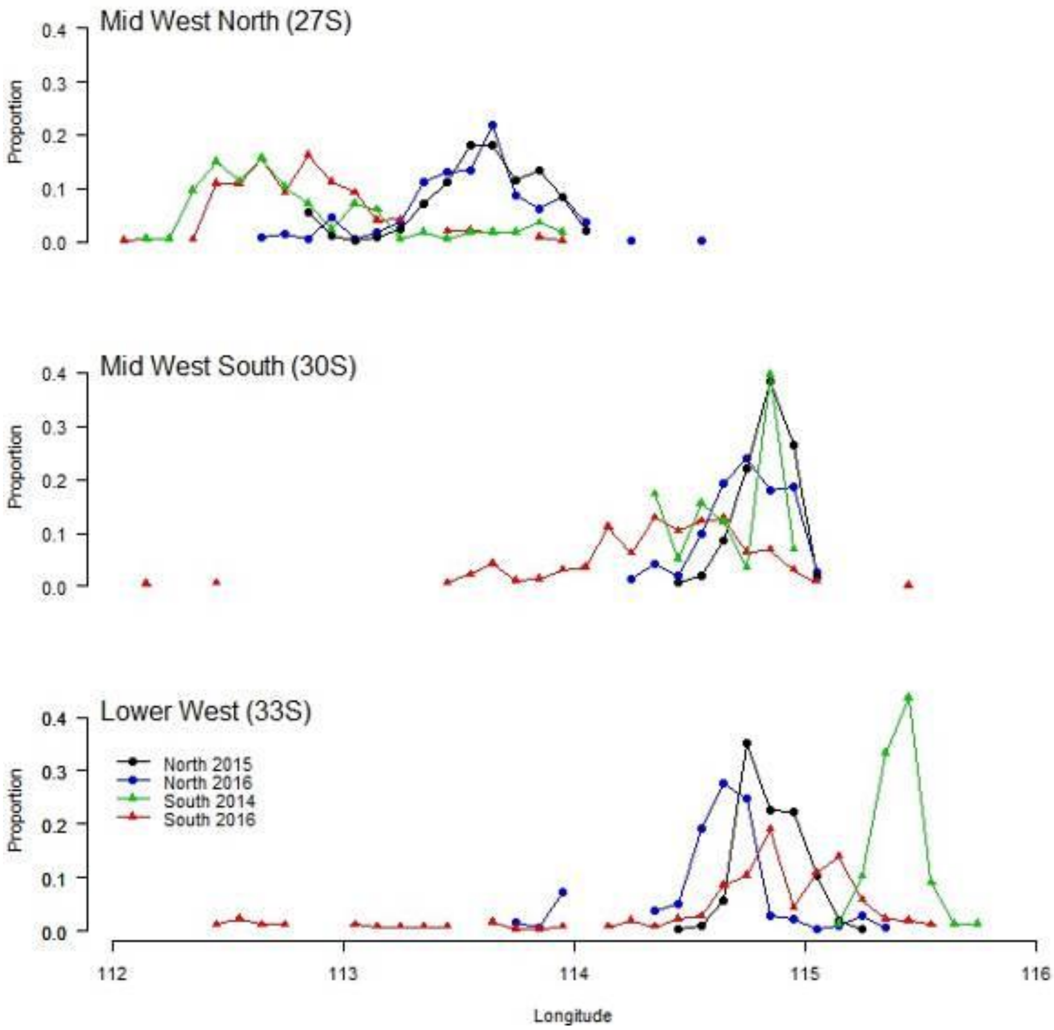


Figure 28 Proportion of satellite locations in 0.1° longitude bands for humpback whales migrating north in 2015 (black) and 2016 (blue) and south in 2014 (green) and 2016 (red) within 1° latitude bands centred on -27° (top), -30° (middle) and -33° (bottom)

5.2.2.1.4.1.1.3 Migration depth through the West Coast Rock Lobster Managed Fishery

The more inshore movement of northbound humpback whales in 2015 compared with 2016 (Figure 28) resulted a slightly greater proportion of detections of tagged whales in shallower water (Figure 29). However, in the mid-west region, approximately half of all detections were recorded between 20-59 m for both the northern and southern migration, with very few detections (<10 %) being recorded in waters less than 20 m (Figure 29). The detections in this region declined with increasing depth from 60 m for the northern migrating whales and were generally less than 5% for the southern migrating whales with the exception of waters > 200 m where around 20 % of detections occurred.

In the lower west region migration depths tended to be deeper than was recorded in the mid-west region (Figure 29). Northern migrating whales had very few detections in waters less than 40 m (<2%; Figure 29). For this component of the migration whales were detected across a range of depths with a large proportion in deep water (>200 m). Similarly, in 2016 for the southern migration, there were few detections (7%) in waters less than 40 m with detections generally spread through the remaining depths with a peak again in deeper water (>200 m). However, in that year there was around ⅓ of detections reported in the 40-59 m depth range. The southern migration in 2014 saw a peak in detections (80%) in the 20-39 m depth category (Figure 29).

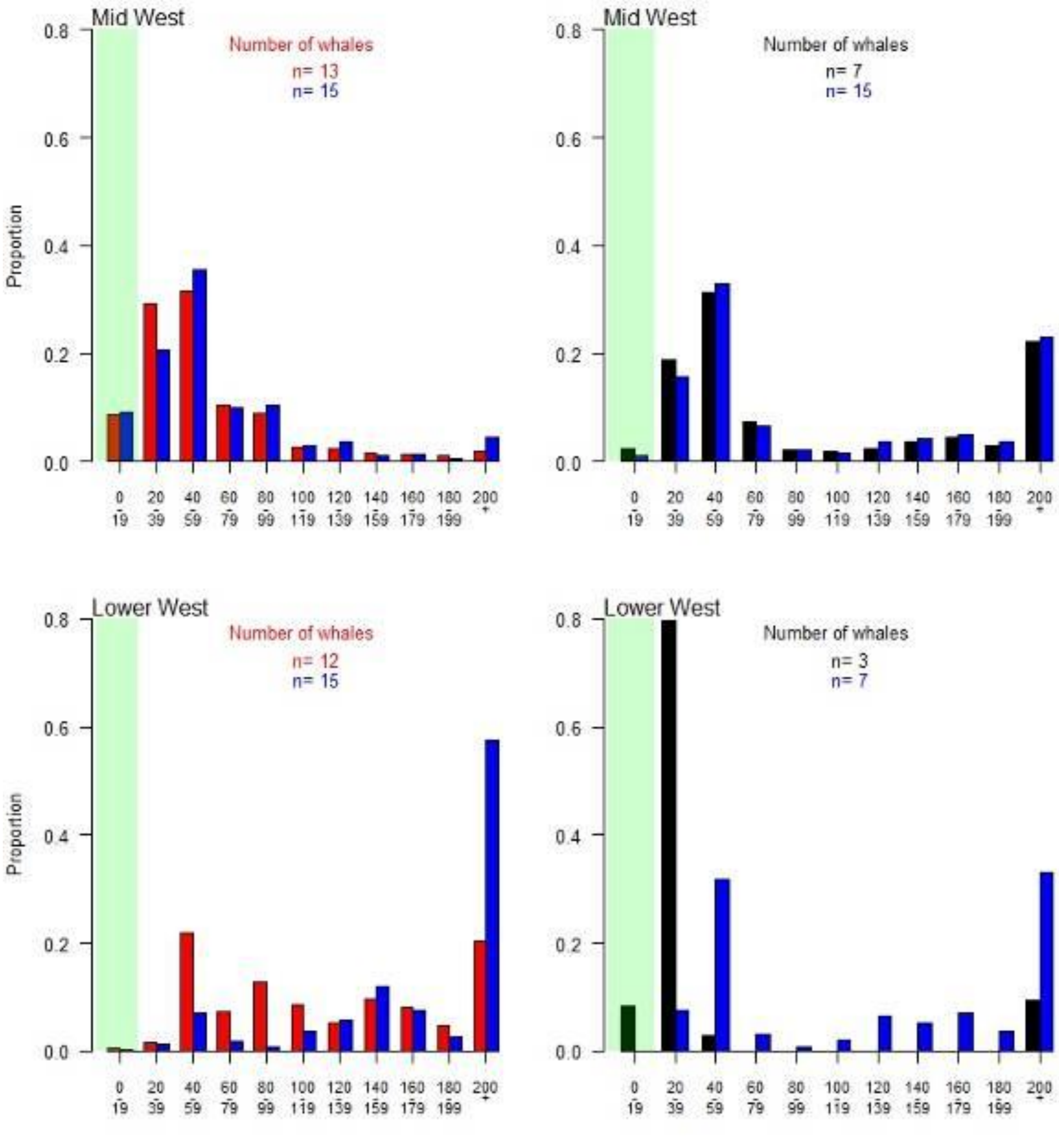


Figure 29 Proportion of detections by 20 m depth categories for the northern (left) and southern (right) migrating whales off the west coast of Western Australia (left) by year (2014-black, 2015-red and 2016-blue) for the two major latitude categories in which the West Coast Rock Lobster Fishery operates. Green area represents depth range where gear modifications are not required.

5.2.3 Spatial Information – Spatial Model

A total of 13,030 whale locations from 45 individuals (average 290 locations / individual) were used to develop spatial models of humpback whale distribution throughout the WRLF. There were 7578 locations from 25 individuals that were used for the northern migration and 5452 locations from 20 individuals were used for the southern migration spatial model. The average test cross-validated AUC scores for the replicate runs for the northern and southern migration were 0.886 (SD=0.004) and 0.851 (SD=0.003) respectively, indicating the model has very good discrimination at predicting random presence sites from random background sites. Both the northward and southward migration models predicted a range in suitable habitats (>0.5 probability of occurrence [Figure 30, Figure 31: yellow and red colours]) throughout the modelled fishery area. Core areas of higher habitat suitability, in which there was a greater than 70% probability of occurrence identified in the northern migration model, occurred in inshore areas around Kalbarri, between Jurien south to Lancelin, along the Cape Range near Exmouth and in areas offshore of Perth and Fremantle (Figure 30). There was a slight difference for the southern migration, which exhibited a wider area offshore along the latitudinal length of the fishery indicating a potentially more diffuse movement of whales on their southern migration. Core areas of higher habitat suitability occurred in the northern parts of Shark Bay, inshore waters of Kalbarri and Geographe Bay (Figure 31).

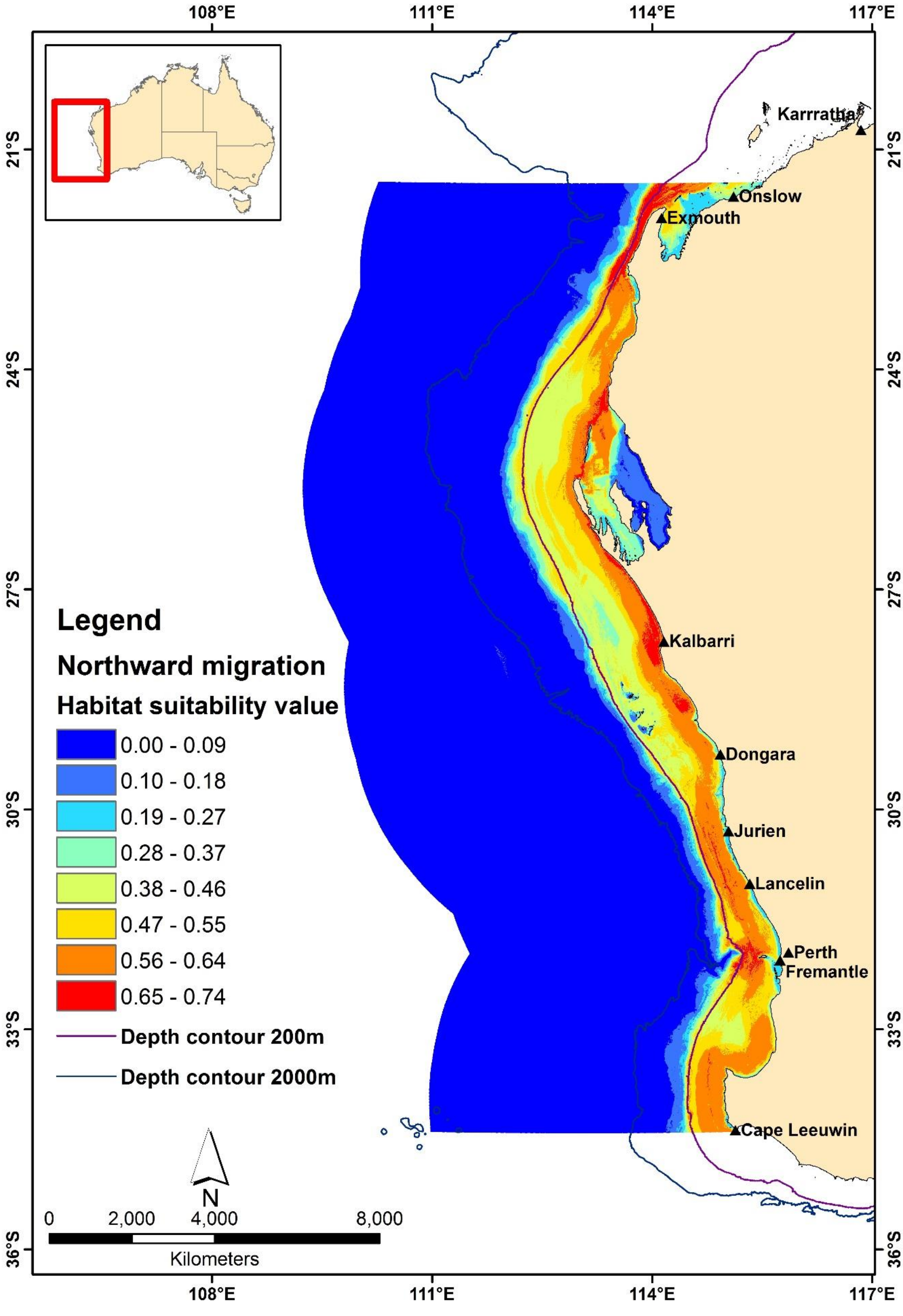


Figure 30 Predictive spatial habitat model for humpback whales migrating north through the West Coast Rock Lobster Managed Fishery

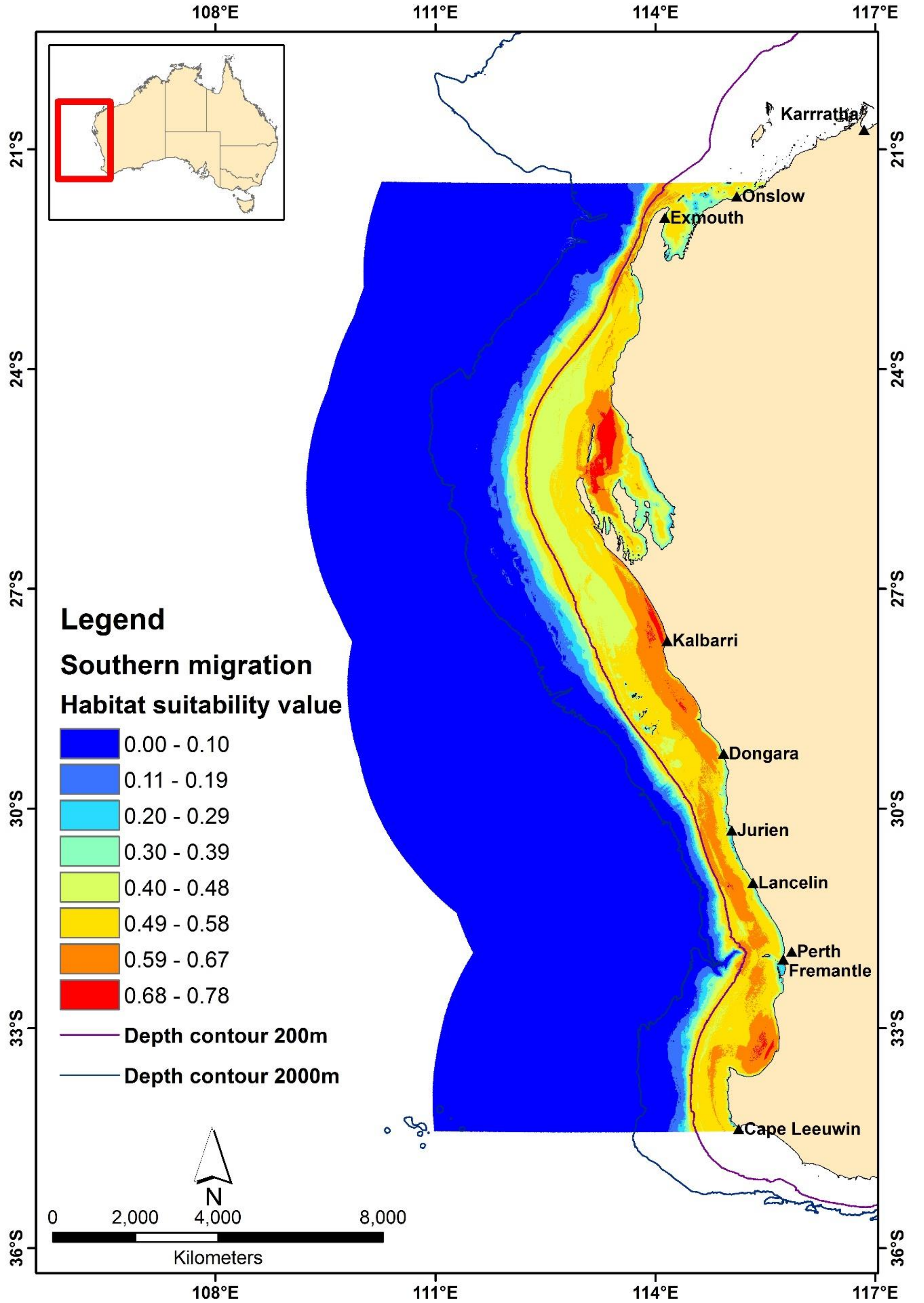


Figure 31 Predictive spatial habitat model for humpback whales migrating south through the West Coast Rock Lobster Managed Fishery

A very strong signal in the data was the restriction of humpback whale movement predominantly within the 200m depth contour. The key environmental predictors for migrating humpback whales were bathymetry (73.1% northward migration, 88.3% southward migration) and distance to the coast (23% northward migration, 7.6% southward migration), based on the jack knife results and their relative contributions to the Maxent model. The remaining environmental variables of seafloor rugosity, seafloor slope and distance to the 200 m contour line combined contributed less than five percent to explaining the movement of whales.

Response curves characterising the relationship between probability of occurrence and environmental variables indicate that humpback whales area a coastal (<100 km) shallow water (< 500m) species (Figure 32). For water depth there is a bi-modal distribution in the habitat suitability response curves for values > 0.5 (values of 0.5 and higher represent a greater than random chance that a species will be present). Habitat suitability for northern and southern migration peaked at 33m and 19 m respectively before secondary lower peaks at 187 m and 203 m respectively (Figure 33a). Response curves for distances from the coast indicate a preference between 8 and 25 km from the coast peaking at approximately 20 km for northern migrating whales (Figure 33b). Response curves for the southward migration indicate preference between 4.6 and 36 km from the coast peaking at approximately 18 km from the coast; Figure 33b).

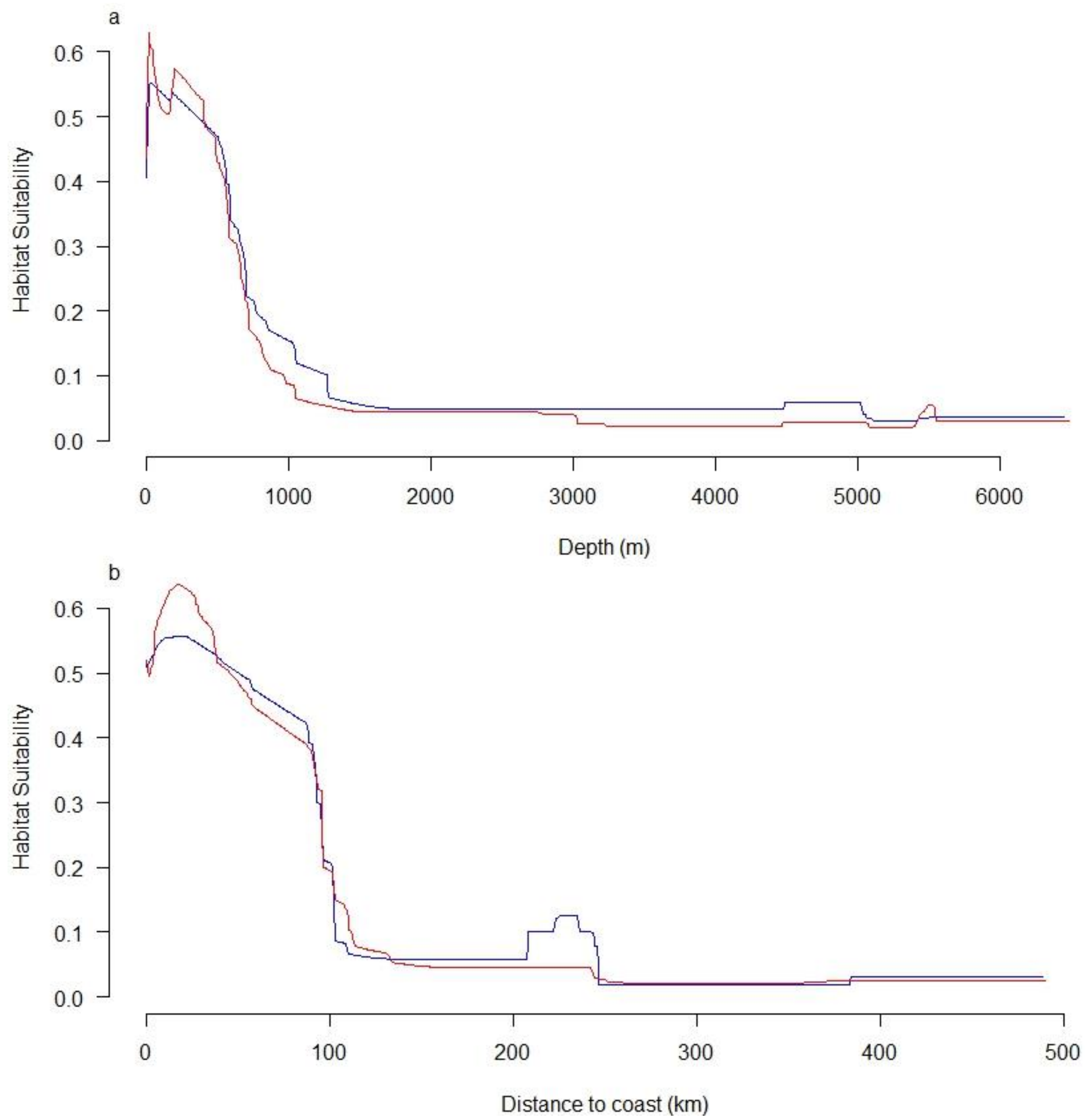


Figure 32 Response curves (probability of occurrence) for environmental variables a) water depth and b) distance from the coast for northward (blue) and southward (red) migrating humpback whales

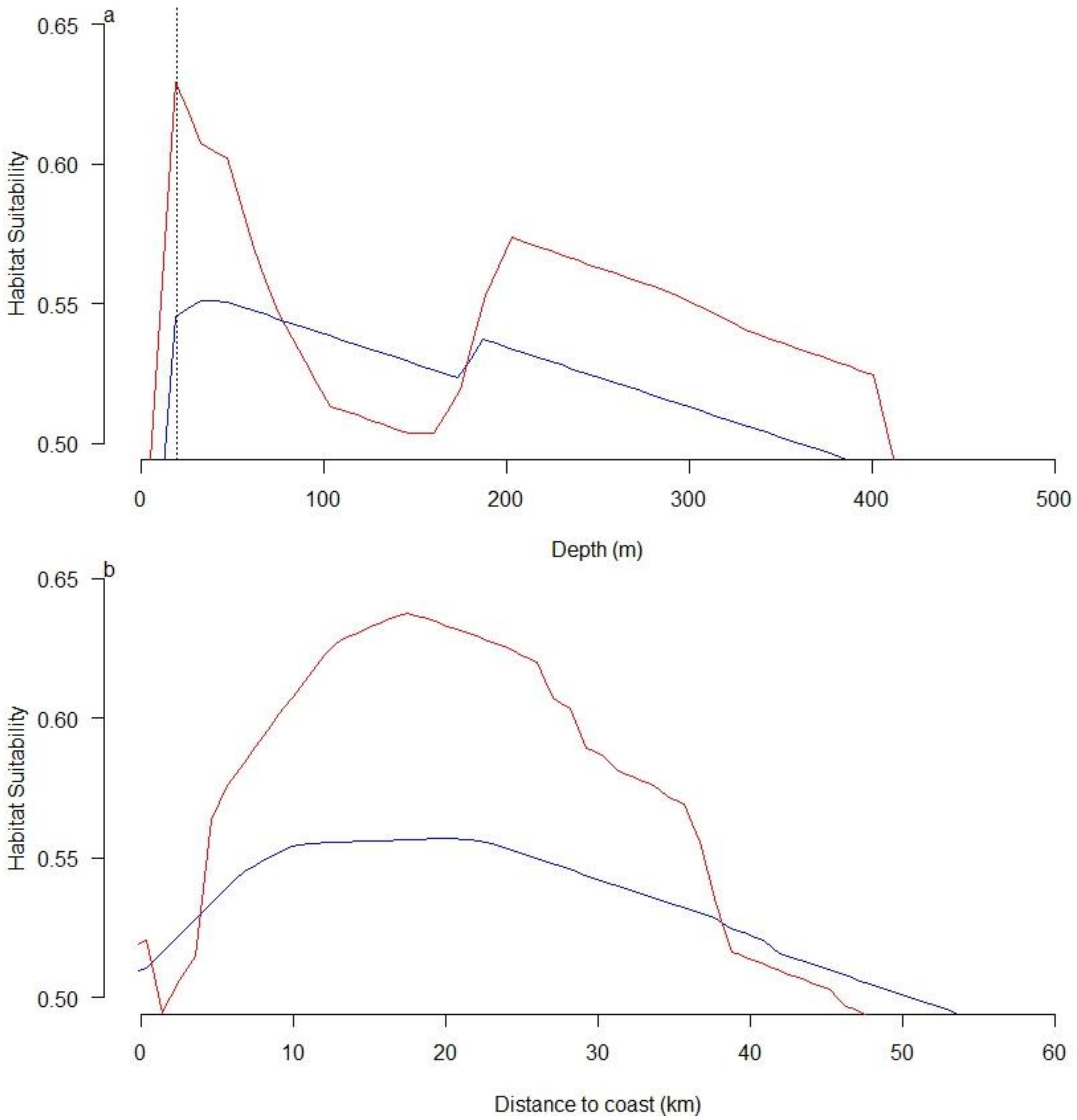


Figure 33 Response curves when the probability of occurrence is >0.5 (values of 0.5 and higher represent a greater than random chance that a species will be present) for environmental variables a) water depth and b) distance from the coast for northward (blue) and southward (red) migrating humpback whales. Dotted vertical line denotes 20 m.

5.3 Provide clear scientific methods behind the testing of selected gear modifications to reduce whale entanglements

5.3.1 Rope Associated Modifications

5.3.1.1.1 West Coast Rock Lobster Managed Fishery – Fishing Effort

Annual rope days remained relatively constant at around 12 million until 2005 after which time they decreased gradually due to a series of effort control measures introduced into the fishery (Figure 34a). Rope days declined markedly in 2009 to around 6.2 million and have remained at this lower level in subsequent years resulting in the post quota period (2011+; average 4.6 million) having markedly less rope days than under the effort-control management system (2000 - 2009; average 11.2 million).

While there has been an overall reduction in rope days since 2008 the changes have not been uniform in relation to the depths fished during the gear modification period (May-October) (Figure 34 b). All depth categories less than 54.8 m (30 fathoms) had a reduction in rope days prior to the introduction of quota in 2011, while rope days in deeper water remained consistently lower than other depth categories. The reduction in rope days was most noticeable in shallow water (<18.3 m, <10 fathoms), where the quota-management average (2011+; 490 000 rope days) was around ¼ of that under effort management (2000 - 2009; average 1.9 million). Rope days in the 18.3-36.5 m (10-19 fathom) and 36.6-54.8 m (20-29 fathom) averaged 497 000 and 543 000 pot days respectively under effort management (2000 – 2009) before dropping to a minima in 2010 before increasing over the next 2 years, before gradually declining from their peak in 2012 of 789 000 and 943 000 pot days respectively (Figure 34b). Changes in fishers' behaviour since the introduction of gear modifications in 2014 has resulted in the proportion of effort declining in depths < 36.5 m while it has increased in the 36.6-54.8 m strata, and it is currently at an all-time high. There has been a slight increase in the deep water fishing (>54.9 m; Figure 34b).

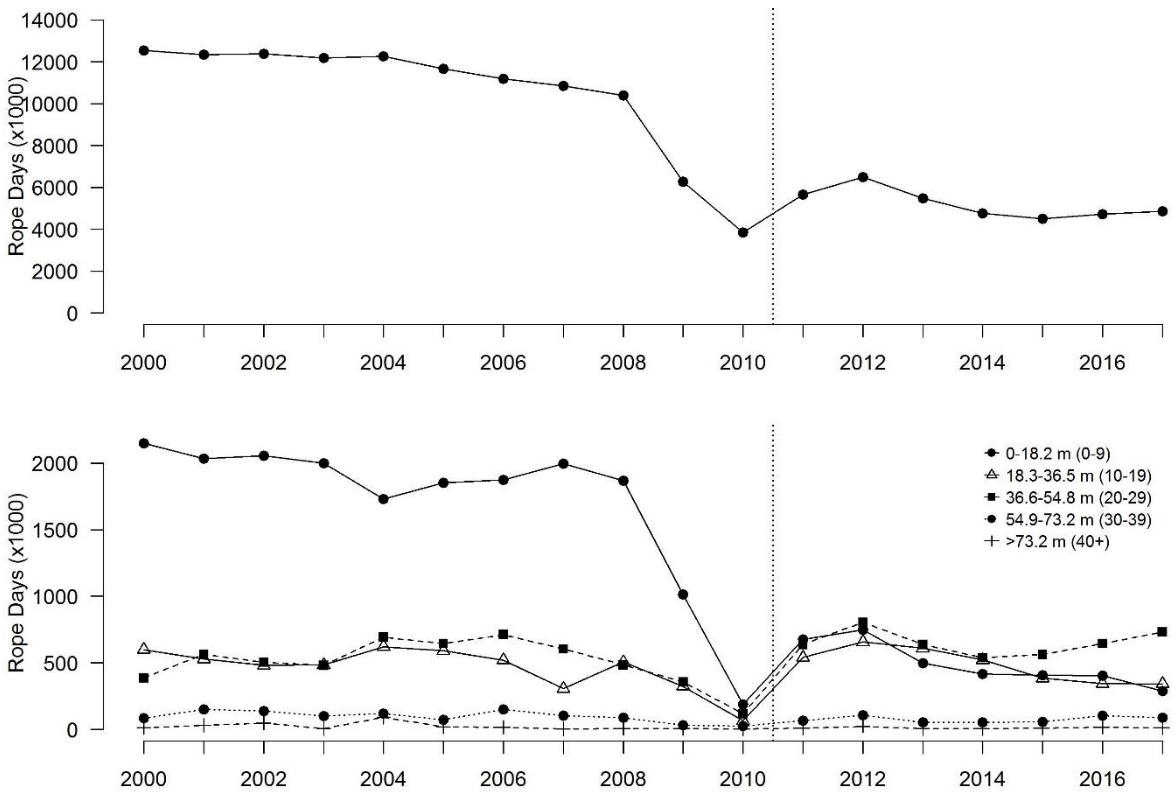


Figure 34 a) Annual rope days (x1000) for the West Coast Rock Lobster Managed Fishery (WCRLMF), and b) rope days by 10 fathom depth category during the gear modification period (May-October). Vertical dashed line represents when the WCRMLF transitioned to a quota management system

5.3.1.1.2 Fisher Surveys

The similarity in effort between 2014 and 2013 was also evident from fisher's survey responses. Most fishes didn't change their location of fishing, with a few moving shallower and less moving deep. It was of note, that the gear modifications which were introduced had minimal effect on fishers being unable to fish during this time (Figure 35).

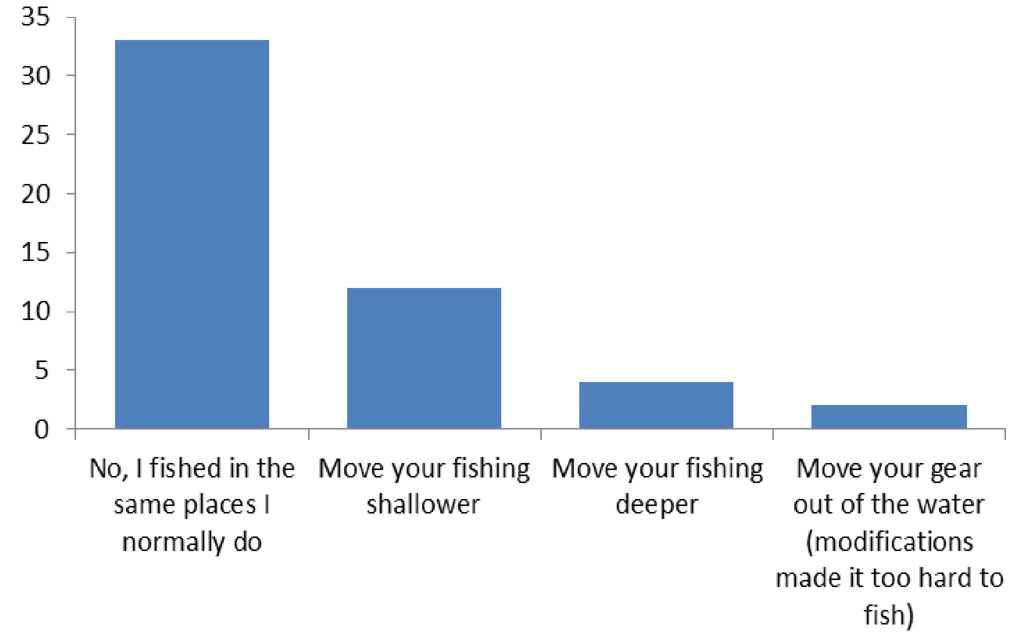


Figure 35 Number of fishers and their response to the effect of gear modifications on their fishing practices

5.3.1.1.3 Model Outputs

As expected the data did not greatly inform the distribution of some parameters with the posterior distributions being very similar to their respective priors. However, by including these parameters in the model we can be assured that the uncertainty arising from the influence of these parameters is integrated in the posterior distribution of the parameter of greatest interest – the mitigation effect of gear modifications (Figure 36a). The median estimate for the proportional reduction in entanglements due to gear modifications (i.e. 1. - mitigation effect) was 0.584 (95% credible interval: 0.018 – 0. 831; Figure 37). It is unlikely the gear modifications had no effect or increased the risk of whale entanglement (effect <0; Figure 36a). The chance of a whale becoming entangled in western rock lobster gear is very low, approximately 0.2 entanglements recorded per million rope days (Figure 36b). The relative catchability of a whale was higher in the 54.9-73.2 m (30-39 fathom) depth range, and was very low in the shallow water (0-18.2 m; 0-9 fathoms) (Figure 36c). There was a clear separation between the timing of northern and southern migrations with a model estimated peak northern migration peaking in late May, compared to a more dispersed southern migration which peaked in late September (Figure 36d). The reported entanglements peaked just after the northern migration in June, with relatively few entanglements reported from September to December (Figure 36d). The availability of an entanglement to be re-sighted (Figure 37e), showed a marked decline in each subsequent month (Figure 36d).

The available data did, inform the posterior distributions for several parameters including, over-dispersion (Figure 37a), the rate of population increase per year (median=0.12; Figure 37b), the number of days required to offset the north and south migrations from the mean migration date (medians -93.7 and 26.6, respectively; Figure 37c & d), the proportion of entangled whales surviving (available to sight) after one month (median = 0.28 Figure 37e) and the slope and intercept of non-fisheries sighting effort over the 18 years of this study (medians = 0.78 and 0.07 respectively; Figure 37e & f).

The model replicated the time series of entanglements well (Figure 38a) with eight of the 16 estimates (predictions of the number of entanglements in years with zero observed entanglements are not defined because such years are excluded in the calculation of the log-likelihood) within one plus rounding (i.e. <1.5) of the actual entanglement number recorded during a season. Of those years which were considerably outside this range, 2006-2008 had less (2 – 3.5) entanglements than were predicted, while 2012, 2013 and 2016 had considerably more (3.8, 6.2 and 2.1, respectively) than estimated by the model (Figure 38c). When the posterior parameter distributions were used to calculate entanglements with a mean effort distribution of 2000-2004 applied throughout the time series without gear modifications, model estimates again did not replicate the high entanglement numbers recorded in 2012 and 2013 (Figure 38b). However, modelling this effort distribution from 2014-2017 resulted in model estimates of 3.4, 6.4, 0.5 and 4.6 more entanglements respectively, than were actually recorded (Figure 38c).

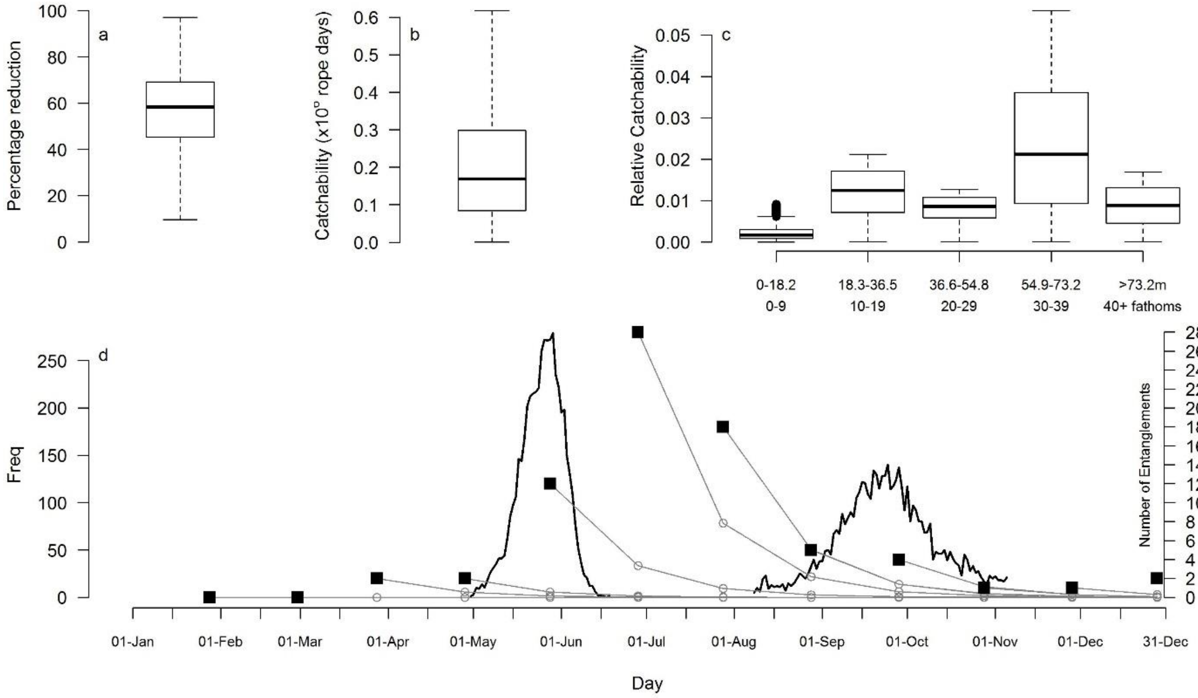


Figure 36 a) Effect of gear modification of whale entanglements, b) catchability of whales in western rock lobsters gear, c) relative catchability of whales in western rock lobster gear by depth category and d) frequency of model estimates of the northern and southern migrations (lines), the number of reported entanglements by month (squares) with their respective availability to be re-sighted in subsequent months (grey line open circle) based on the median modelled survival parameters (0.279).

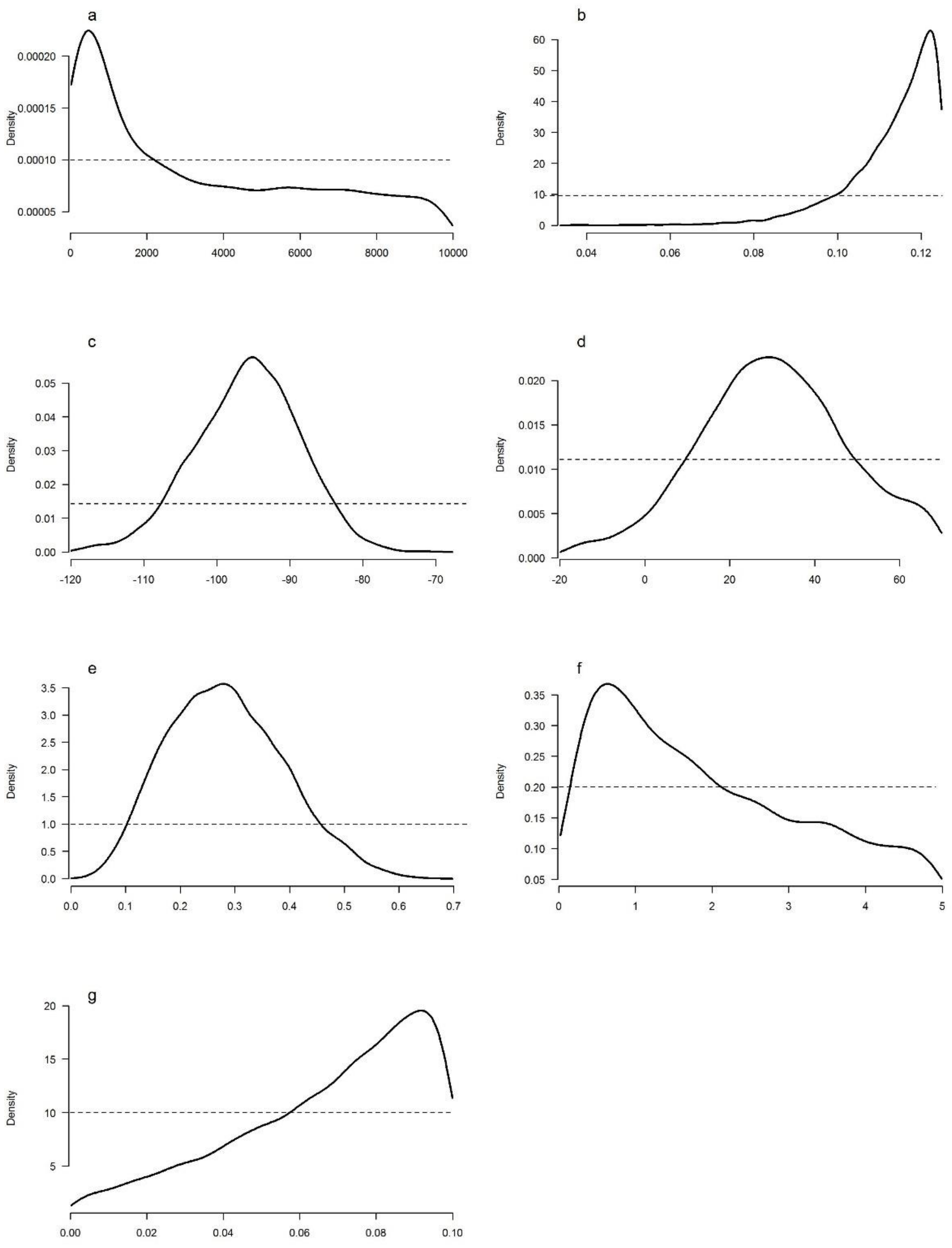


Figure 37 Additional plots of the prior (dashed line) and posterior distributions (solid line) a) over-dispersion, b) rate of population increase, c) north migration offset, d) south migration offset, e) survival of entangled whale, f) sightings effort (non-fishery) intercept and g) sightings effort (non-fishery) slope

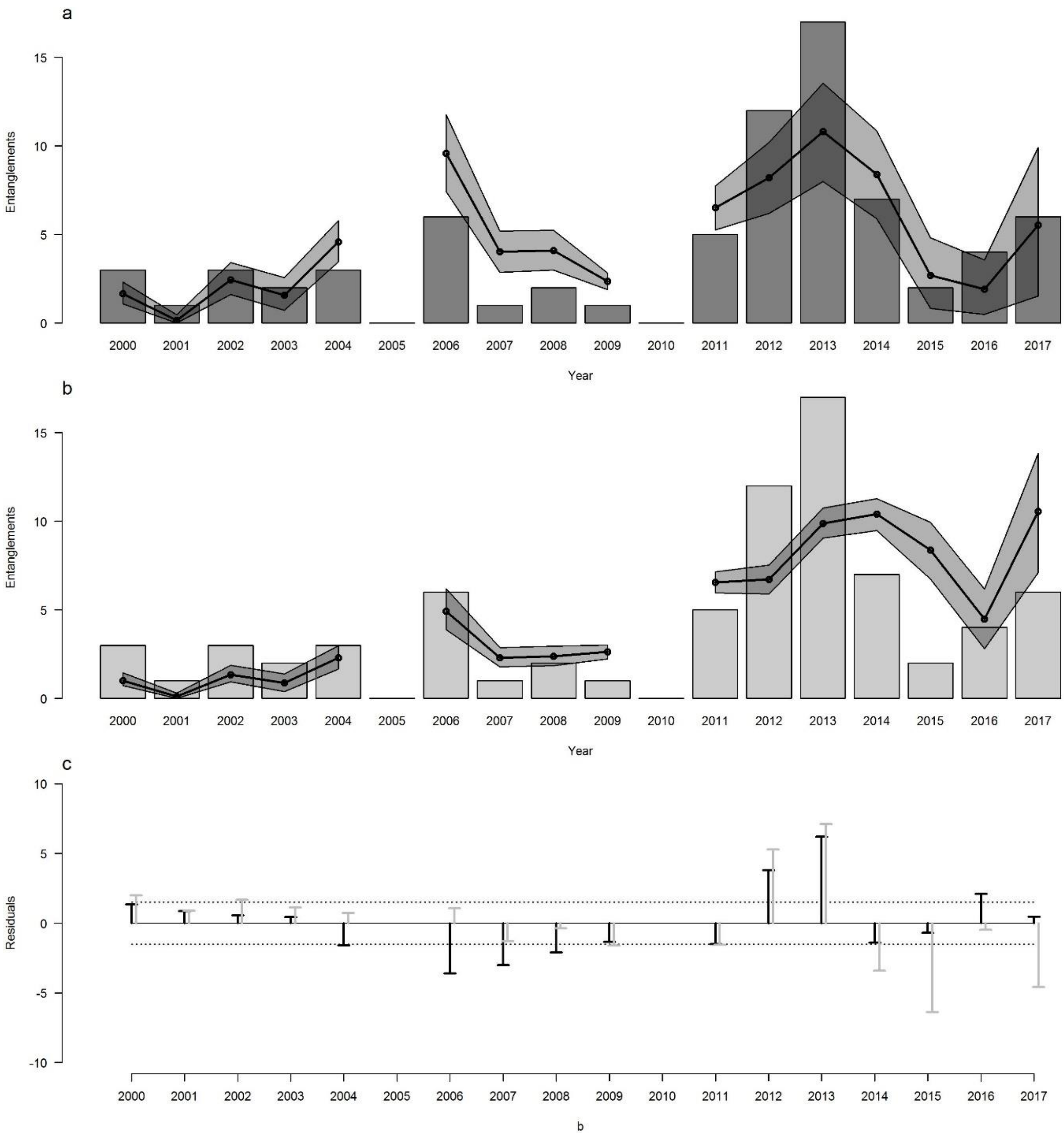


Figure 38 Annual reported entanglements in western rock lobster gear (bars), with median estimated entanglements (circles and line) with 95% CI (heavy grey shading) from a) modelling incorporating actual inter-annual effort distribution variation and b) estimated entanglements with no gear modifications and no inter-annual effort distribution variation from 2004, and c) the residuals from panels a (black) and b (grey)

5.3.2 Acoustic Alarms

5.3.2.1.1 Alarm Selection

5.3.2.1.1.1 Alarm Characterisation

The F3 signal is a single tone burst in the order of 400 ms duration, with the majority of energy at the fundamental frequency of approximately 2.7 kHz, with significant harmonics present up to the maximum recorded frequency of 48 kHz.

The fundamental centred at 3 kHz had a source level of 111 dB re 1µPa^2/Hz @ 1m, while the fundamental centred at 4 kHz had a median level of 122.5 dB re 1µPa^2/Hz @ 1m. The first harmonics were produced at approximately 8 kHz and above 9 kHz, and therefore were excluded from the analysis.

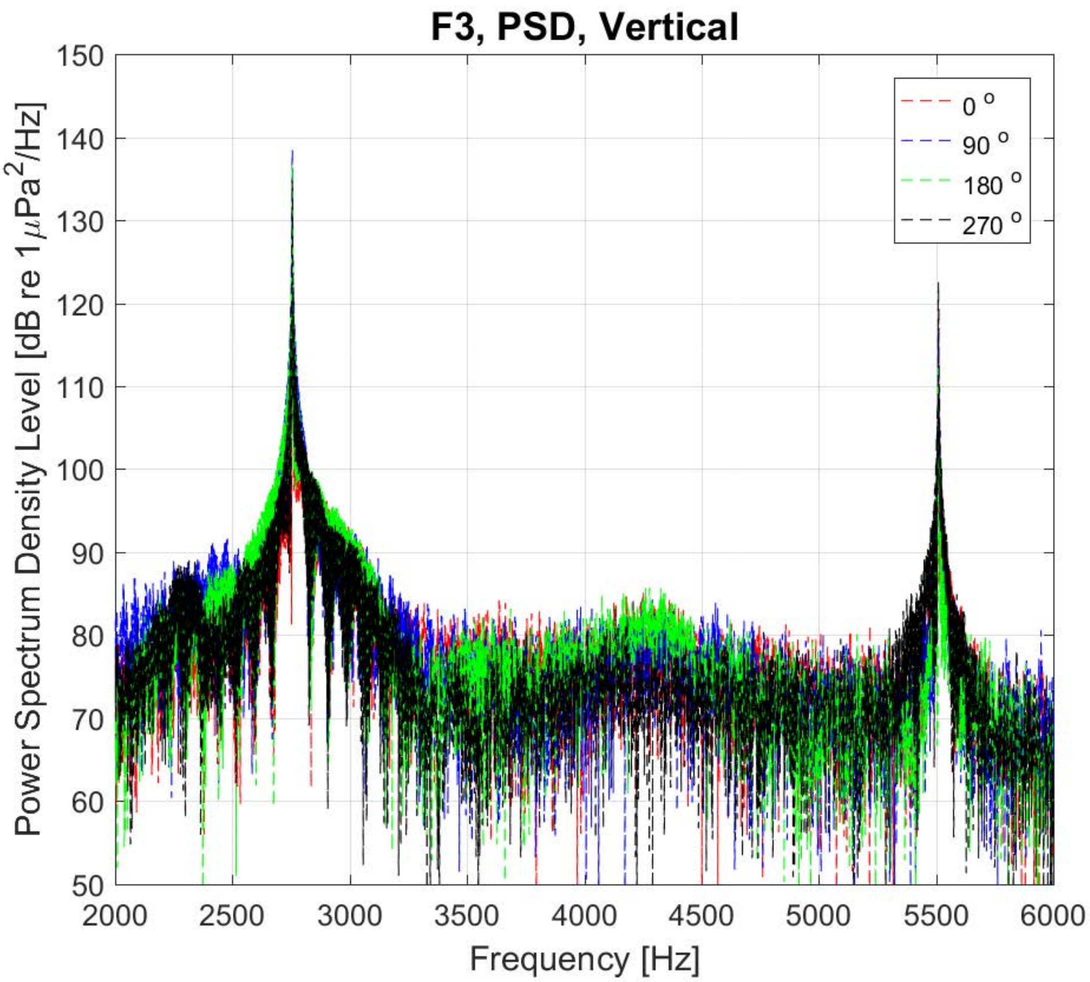


Figure 39 Power spectral density plot for a single tone burst at each of the 4 vertical orientations for a single selected F3 alarm, recorded at 2 m.

The Fishtek whale alarm has four discrete 50-60 ms tones, with a gap of approximately 50 ms between each, in a repeating pattern with an approximately 100 ms gap between each set of tones. The fundamental frequency of each tone for the tested alarm alternated between approximately 3015 and 4025 Hz.

The fundamental centred at 3 kHz had a source level of 111 dB re 1µPa^2/Hz @ 1m, while the fundamental centred at 4 kHz had a median level of 122.5 dB re 1µPa^2/Hz @ 1m. The first harmonics were produced at approximately 8 kHz and above 9 kHz, and therefore were excluded from the analysis.

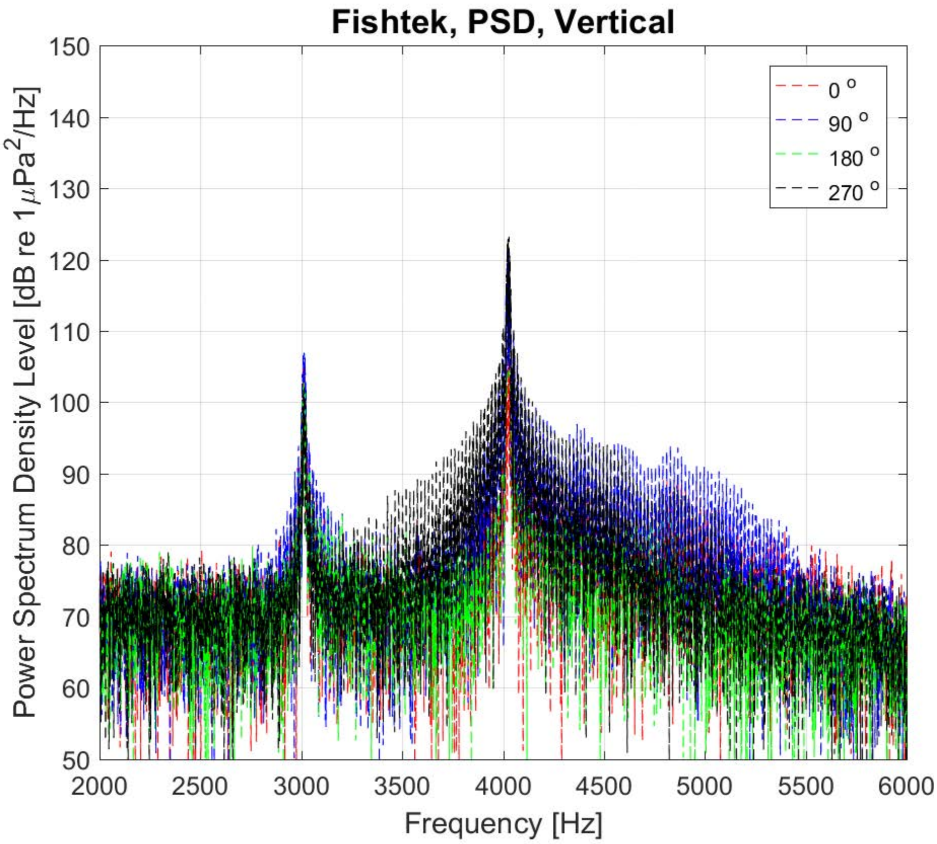


Figure 40 Power spectral density plot for a single tone burst at the four vertical orientations for the Fishtek alarm, at 2 m. 2 – 6 kHz.

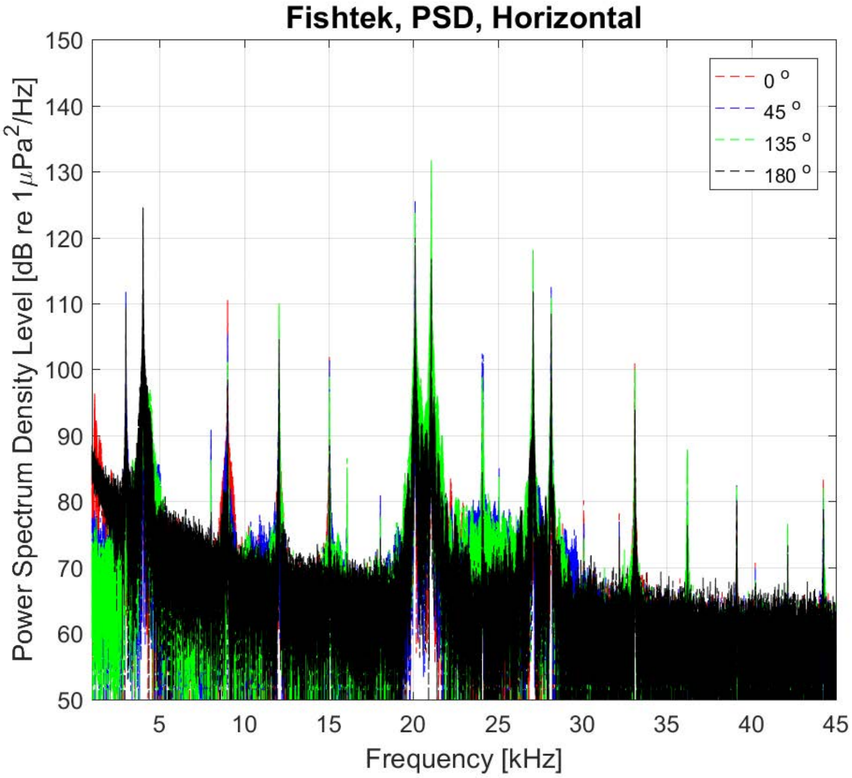


Figure 41 Power spectral density plot for a single tone burst at the four vertical orientations for the Fishtek alarm, at 2 m.

5.3.2.1.1.2 Whale alarm selection

The testing demonstrated that while the Fishtek has some signal energy within the whale hearing sensitivity range peak energy of <6 kHz, the majority of signal energy occurred above 20 kHz, which is likely not detectable by humpback whales. While similar to the F3 the Fishtek had a significant difference between the minimum and the mean (or medium) SPL, the minimum level from the Fishtek was below that of the F3. The shorter 50 ms intervals between the Fishtek tones are also less likely to be as biologically appropriate as the 400 ms alarm signals from the Future Oceans F3, which will provide a greater opportunity for the humpback whales to perceive their location. Therefore, with a greater signal energy within the theorised hearing range of humpback whales, and a longer signal to aid in alarm location, the Future Oceans' F3 whale alarm was used for whale behavioural assessments to the presence of alarms on fishing gear (see Method; Whale behavioural response to acoustic alarms).

5.3.2.1.2 Alarm Performance

There was considerable variation in the source level of the 53 Future Ocean F3 alarms (Figure 42) which were tested prior to field deployment in the whale behaviour study (Methods; Initial Testing). This variation required whale alarms to be grouped for the field trial into soft, medium and loud alarms (Figure 42), resulting in mean SL of each group was 115, 122 and 129 dB re 1 μPa respectively. Three alarms were unsuitable due to extensive electronic noise or bad tones and hence were not tested to determine their SL. These alarms were arbitrary ascribed a SL of

107 dB re 1µPa @1m. Therefore, the range is likely to be larger than the 107 – 144 dB re 1 µPa @ 1 m that is presented in Figure 42.

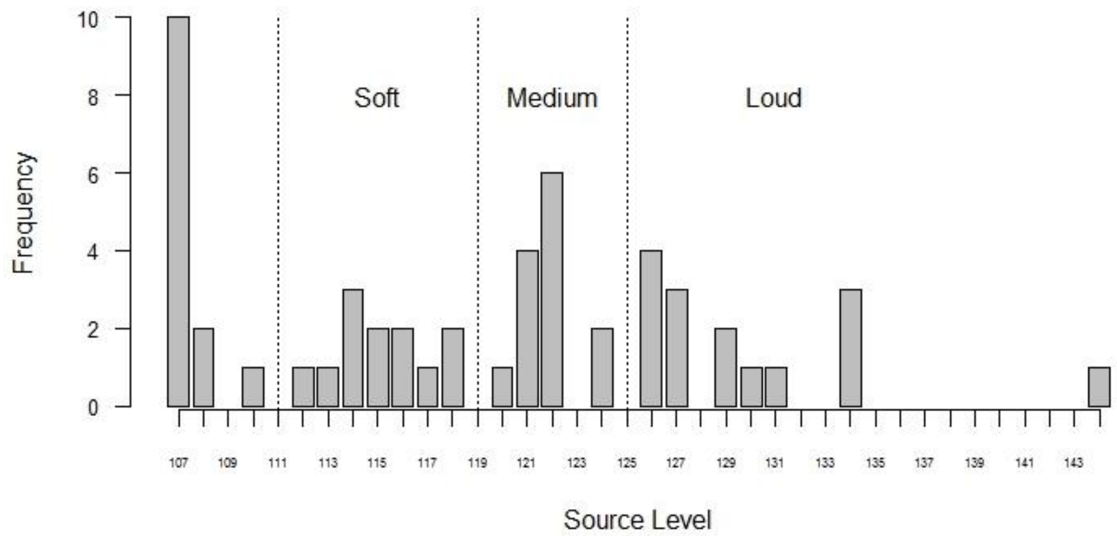


Figure 42 Frequency of Future Ocean F3 alarms by 1 Hz median source level (SL) categories (dB re 1µPa @1m) at 2785 Hz, and the groupings of alarm SL used in humpback behavioural trials

As well as source level variation between alarms, there was also variation in the signal frequencies for those alarms with a SL > 108 dB re 1µPa @1m. Median frequencies were used for modelling assessment, though the frequencies ranged by 182 and 363 Hz for the fundamental (2785 Hz) and first harmonic (5569.5 Hz) respectively.

5.3.2.1.3 Modelling results

The modelling results are presented to the 80 dB isopleth as this aligned with the likely detection level by the humpback whales. Modelling of the fundamental for each of the three alarm groups defined for the experiment was conducted to assist with the design of the field trial. Whale swimming speed was defined as 2.7 m/s, and the quiet time between two pings as 6 s, in line with Erbe et al. (2011). The 95% detection range was used to remove any influence of directionality.

Table 9. Horizontal distances in metres to SPL isopleths for each experimental group of Future Ocean F3's alarms.

Isopleth (dB re 1 µPa)	SL of 115 dB re 1 µPa @ 1 m		SL of 122 dB re 1 µPa @ 1 m		SL of 129 dB re 1 µPa @ 1 m	
	R_{max} (m)	$R_{95\%}$ (m)	R_{max} (m)	$R_{95\%}$ (m)	R_{max} (m)	$R_{95\%}$ (m)
100	—	—	—	—	47	47
95	—	—	31	31	181	165
90	31	31	101	95	484	448
85	72	72	335	313	1280	1140
80	224	211	899	802	4000	2780

5.3.2.1.4 Whale behavioural response to acoustic alarms

A total of 161 whale groups were tracked through the area with 18 groups tracked (focal followed) in detail (Table 10). Seven groups were tracked when the alarms were off, while 11 groups were tracked when the alarms were active (Table 10).

Table 10 Summary of groups observed and tracked (focal follow) of humpback whales (HW) and blue whales (BW) in Geographe Bay in November 2014. Affiliations or split of groups are not counted as new pods.

Date	#Groups	# Focal Follow HW	# Focal Follow BW	Alarm Status
Nov-03_2014	12	0	0	0
Nov-04_2014	22	2	1	0
Nov-05_2014	18	1	1	1
Nov-06_2014	11	0	1	0
Nov-08_2014	11	2	1	1
Nov-09_2014	10	1	1	1
Nov-10_2014	15	1	1	1
Nov-11_2014	0	0	0	0
Nov-12_2014	4	1	0	1
Nov-13_2014	0	0	0	1
Nov-14_2014	21	3	1	1
Nov-15_2014	11	2	0	0
Nov-16_2014	11	2	1	0
Nov-17_2014	4	1	1	0
Nov-18_2014	6	1	0	1
Nov-19_2014	5	1	1	1
Total	161	18	10	9 – 7 On-Off

Tracked humpback whales generally moved between the 10 – 20 m isobaths (Figure 43 and Figure 44), and as a result generally encountered the array of gear to which the 'low' powered alarms were attached. Multiple groups were tracked through and past this array when the alarms were attached (Figure 43) and absent (Figure 44). There was no evidence of whales interacting or avoiding with the gear at any stage during the trial, indicating they were capable of negotiating the gear without becoming entangled whether alarms were present or not.

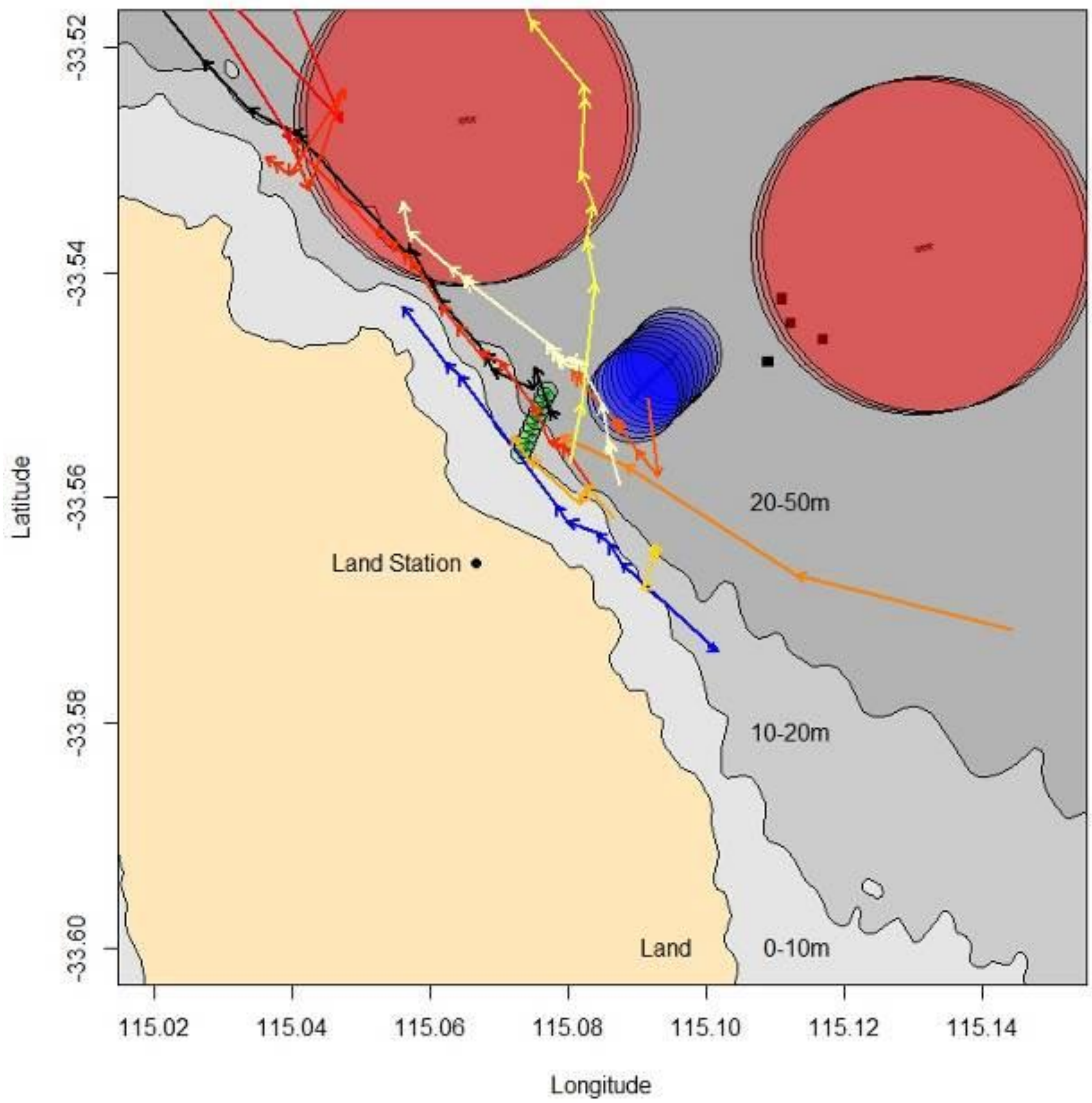


Figure 43 Tracks of focally followed humpback whales moving through the study area when the alarms were active. (Array description as per Figure 7)

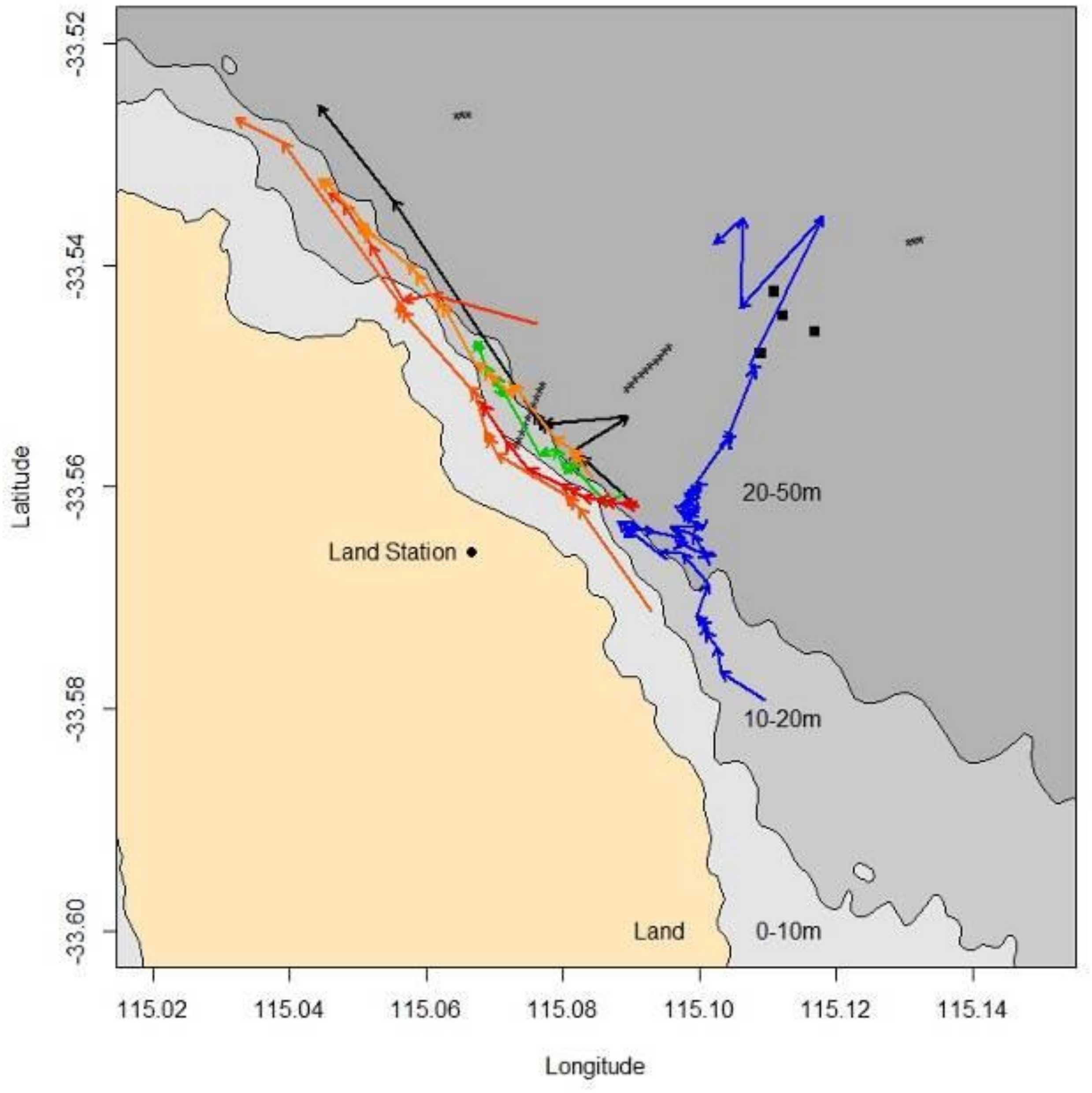


Figure 44 Tracks of focally followed humpback whales moving through the study area when the alarms were not present. (Array description as per Figure 7)

5.4 Incorporate any new practices that may reduce entanglements with migrating whales in the CoP for the fishery and ensure its extension and adoption

Surveys were conducted at the end of the 2013 (n= 17) and 2016 (n= 15) whale migration seasons of fishers from seven ports spanning the fishery. There was a marked improvement in fishers understanding of the code of practice (Figure 45a), the information it contained (Figure 45b) and what to do if they encountered an entangled whale (Figure 45 c).

By the end of the 2013 whale migration season over 80% of surveyed fishers were aware of the implications on the fishery that whale entanglements posed, with approximately 70% aware of the code of practice. While ⅔ of surveyed fishers knew where to get hold of the code, only about 40% were aware it had been updated since 2006. Through regular communication with industry through this project and its predecessor (FRDC 2013-037), over 90% of surveyed fishers were aware of the fishery issues and code of practice for whale entanglements. There was also a very clear improvement in the understanding of where to get hold of the code of practice and that it had been updated (Figure 45a).

While important to know of the code, and that it was updated, it was encouraging that fishers understood the major points of the code. By the end of 2013, between ¼ and ½ of fishers surveyed understood what was contained within the code. However, by the end of the 2016 season, this had increase to between ½ and all fishers surveyed. The most notable improvement was not to leave pots in the water for more than 7 days (Figure 45b).

The changes in understanding the required actions when encountering an entangled whale were not as marked, though they did improve (Figure 45c). Most surveyed fishers were already aware that they needed to report an entanglement, though this did increase slightly by the end of 2016. Around half of all fishers surveyed were aware that they should not cut the entanglement line, with the biggest improvement coming from their understanding of standing by the whale when they encountered an entanglement (Figure 45c).

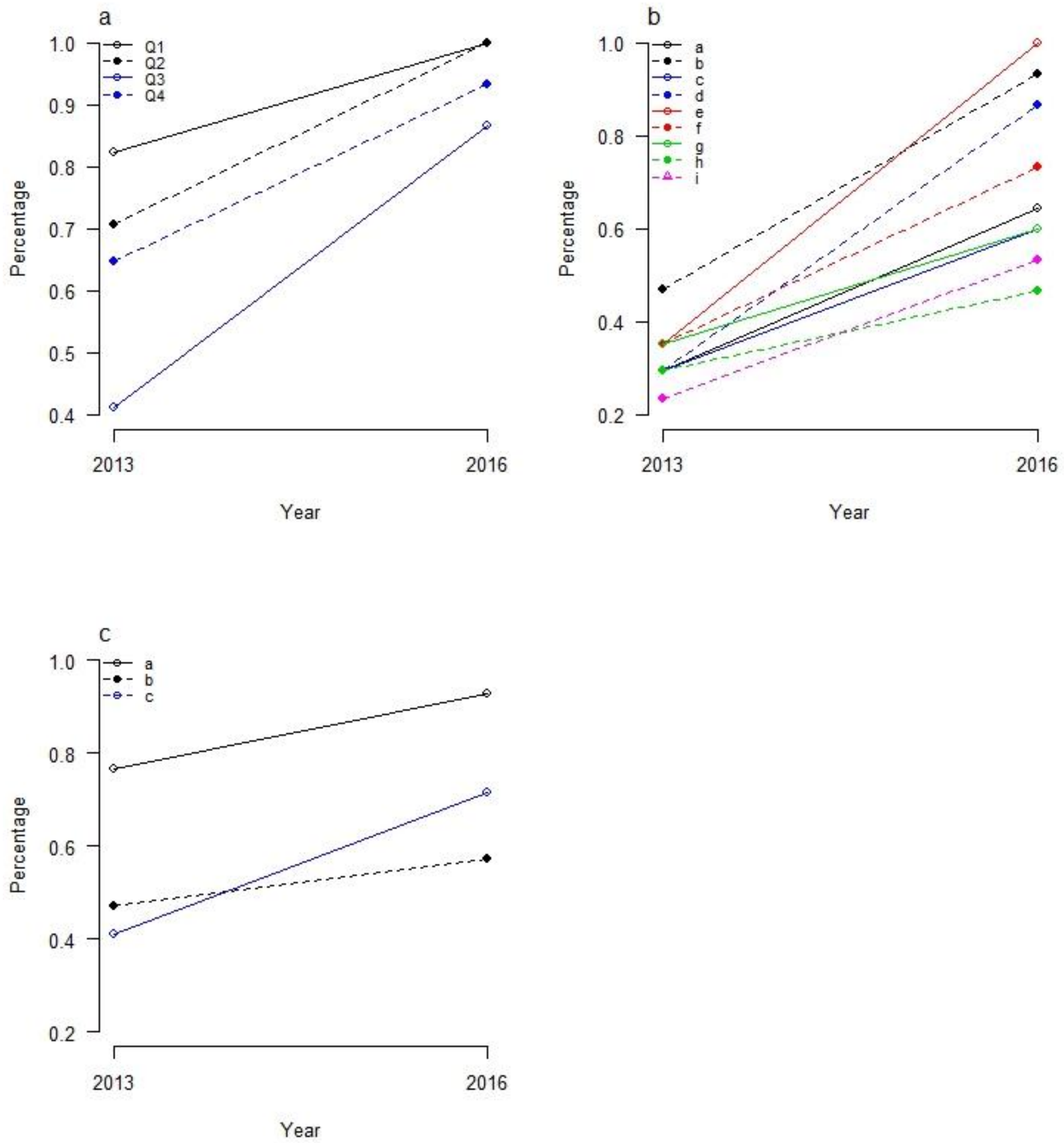


Figure 45 Outcomes of questionnaires (Appendix 6) of commercial rock lobster fishers regarding a) the code of practice (Questions 1-4), b) the information contained with the code (Question 5 a-i) and c) what to do if they encounter an entangled whale (Question 6 a-c) after the 2013 and 2016 whale migration seasons.

6. Discussion

Gear modifications, identified in How et al. (2015), were implemented for the West Coast Rock Lobster Managed Fishery (WCRLMF) and Octopus Interim Managed Fishery (OIMF) in July 2014. Since their introduction there has been a reduction in the entanglements with migrating humpback whales. The overall reduction in entanglements has fallen from a peak of 17 and three in WCRLMF and OIMF gear respectively in 2013 to six and one in WCRLMF and OIMF gear respectively in 2017. The number of entanglements recorded in unknown gear also declined from 10 in 2013 to only three in 2017. These declines have resulted in all entanglements falling from by ⅔ from the 31 entanglements recorded in 2013 to the 10 recorded in 2017.

The implementation of gear modifications were generally well received by fishers. Their introduction did not impact on the location of fishing activities, saw a reduced level of lost gear, which mirrored the reduction in entanglements, and there was good adherence to the regulations as demonstrated by the high level of compliance by fishers.

The empirical and anecdotal decline in entanglements which was coincident with the introduction of gear modifications indicates that the gear modifications and management changes were appropriate for reducing entanglements. However, the decline in entanglements was statistically assessed to determine the actual impact attributable to gear modifications, accounting for other factors which may impact the entanglement rate and their reporting.

6.1 Effectiveness of Gear Modifications

By including changes in fishing effort distribution, an increasing abundance of whales, inter-annual changes in migration timing, varying reporting probabilities and the introduction of gear modifications, our model was able to reasonably predict the time series of whale entanglements in the WCRLMF. The model's posterior distribution indicates that the gear modifications introduced in 2014 reduced the rate of whale entanglements in the WCRLMF by at least 16% with 95% probability, with a median reduction of almost 60%.

The rationale behind the legislated gear modifications focused on reducing the amount of slack rope at the surface and in the water column. It was thought loops of slack rope can form around the whale before any tension is exerted on the line. Through the inclusion of a weighted component to the top third of the rope length, this segment of rope will be always under tension and therefore potentially less likely to entangle a whale. Similarly, a reduction in the total rope used (maximum rope length of double the water depth) and a limit on float numbers, may also reduce the likelihood of entanglement or reduce the entanglement complexity.

Our model estimated the probability of entanglements was highest within the 54.9 – 73.2 m (30-39 fathoms) depth category. These depths were traditionally fished with two to three times the water depth of rope and three to four floats. Off Western Australia these depths are often exposed to strong ocean currents in autumn/winter (Leeuwin Current) which can cause ropes and floats to become submerged, which is why fishers historically used longer ropes and more floats to aid in their retrieval during these conditions. However, during calm periods (weak currents and light winds) the positively buoyant rope would float on the surface and potentially lead to the entanglement of migrating whales. It was the elimination of this slack surface rope that was the primary intent of the gear modifications, and appears to be the likely cause for the successful reduction in whale entanglements.

Another important component of the mitigation measures was their application to waters generally deeper than 20 m. This provided a region of the fishery where fishers could fish without gear modifications, providing a potential incentive through not having to modify their gear, to fish in shallower areas thereby removing effort from the main area of whale migration and higher entanglement risk. The model demonstrated that the shallower area of the fishery is very unlikely to contribute to overall entanglements. However, it does not appear that fishers have preferentially moved into this depth region with the proportion of rope days in the <18.3 m depth range remaining relatively constant or even declining slightly before and after the introduction of gear modifications in 2014, likely due to higher catch rates and larger, generally more valuable size grades being attained in deeper waters (de Lestang unpublished data).

6.2 Acoustic Alarms

There was considerable variation in the performance of whale alarms both between products (Future Oceans and Fishtek) as well as between individual alarms. For a whale to detect an acoustic alarm it must be loud enough to be detected above background noise, and within the hearing range of the species being alerted. The hearing sensitivity range of humpback whales is estimated to be 20 Hz and 6 kHz.

The ears of marine mammals are similar to an integrator which sums sound energy with a frequency-dependent time constant (Plomp and Bouman 1959). Tougaard et al. (2015) suggested a related “rms fast average” for underwater sound characterisation, using a time constant of 125 ms, to reflect the integration time of the marine mammalian ear (Madsen 2005, Tougaard et al. 2015). The length of the acoustic alarm signal should be considered in terms of this integration time. While echolocating animals such as dolphins and porpoise might be able to understand the short 50 ms tones from the Fishtek, it is hypothesised that these, combined with the 50 ms intervals between tones, would likely be more difficult to detect by humpback whales (Erbe et al. 2016). In this regard, the 400 ms long tones from the F3 are likely more biologically appropriate, particularly as the alarm signals need to provide the maximum opportunity for the humpback whales to perceive their location.

Initial testing of the two whale alarm products indicated that the F3 alarm was the most appropriate to test behavioural responses of humpback whales to fishing gear with alarms affixed. The F3 generated higher SPL tones within the presumed peak hearing sensitivity of humpback whales, with median levels of tones between orientations associated with a vertical alarm deployment varied <5 dB.

The Future Ocean F3 alarm used in the initial detailed assessment produced a much higher SL than most of the subsequent F3 alarms tested. Orientation testing of the F3 estimated a SL of 146-149 dB re 1μPa @1m, considerably higher than the strongest alarm (144 dB) of the 53 alarms which were subsequently tested. This results in a 20 dB range in output from the same whale alarm product and is independent of the variation in SL which exists depending on the alarms orientation.

Even small differences in the SL can have significant impacts on alarm detection. Due to the logarithmic nature of the scale, a drop of 3 dB, which is the half power point, would reduce potential whale detection from around 50 m to 35 m. Therefore the variation in the order of 20 dB as seen between various individual F3 alarms would have a profound impact on the distance at which the alarm would be detected by migrating whales.

The presence of whale alarms on the modified rock lobster gear deployed in their migratory pathway did not appear to impact their movement behaviour. Acoustic signals have impacted humpback whale movements previously, with some signals even having an attractive response (Todd 1991). The use of acoustic alarms has been demonstrated in a number of net fisheries to impact entanglement rates (Lien et al. 1992, Todd et al. 1992). However, for pot and line fisheries, due to the absence of a barrier, movement changes may not be pronounced enough to be detected remotely through tracking using a theodolite. The lack of a noticeable detection was also evident on migratory whales off the eastern coast of Australia (Harcourt et al. 2014, Pirotta et al. 2016) and west coast of Australia (How et al. 2015), though a reduction in swimming speed was noted when alarms were present (Harcourt et al. 2014).

This project did deploy an acoustic recorder as part of the field trial of alarm effectiveness (Method; Whale behavioural response to acoustic alarms). Analysis of this data was outside the scope of this project, however future analysis of it is planned. These data will be examined to determine if there is a change in the vocalisations of humpbacks in the presence of alarms, particularly at night where the visual cues provided by the gear are not as obvious.

6.3 Overall Movement

Stock D humpback whales, which breed on the northern coast of Western Australia, are genetically distinct from other southern hemisphere humpback populations. The Australian continent provides a barrier from the nearest humpback population which breeds in the Great Barrier Reef off eastern Australia (Bettridge et al. 2015). These two stocks are associated with different feeding areas around Antarctica, with Stock D feeding in Area IV, a region stretching between 70-130^{o} E (Chittleborough, 1965). It is from this feeding area that they migrate to the west Australian coast.

Commercial whale watching vessels on the states south and lower west coast have recorded interactions with humpback whales from March, though infrequently. The ‘vanguard’ of the migration has been reported to reach the south coast of Western Australia from April (Chittleborough 1965), though the bulk of the population doesn’t appear until May/June, with a peak in early July. All whales tagged on their arrival on the states south coast moved north. They maintained a very constant direction which was generally aligned to the orientation of the coastline. Apart from the lower-west coast of Western Australia, they were generally coastally associated moving inside the Leeuwin Current (LC). Other than during 2013 when there was a particularly strong LC, whales were not accessed by commercial whale watching vessels in the lower-west indicating that they remained offshore through this region of the coast. This was demonstrated by tagged whales which migrated north from the Capes region offshore until north of Perth where they became more coastal.

It was postulated that whales which feed in the western portion of the Area IV (towards 70° E) may move from there on an oblique angle to reach Western Australia on the mid-west coast (Jenner et al. 2001b). Lower abundances recorded through aerial surveys between Cape Naturaliste - Mandurah (lower west) compared with a consecutive survey at Jurien Bay (mid-west) was thought to be a result of a difference in timing or through the arrival of whales from the western part of Area IV. The surveys which were conducted in 1992 were during a year of relatively weak LC flow. Therefore, it is likely that the whale arriving on the states south coast migrated outside the area of the lower west survey site before being recorded at the mid-west site where they are more coastally associated. This new information however does not preclude the possibility a northern migration of whales directly from the western parts of Area IV to the mid-west coast, with southerly migrations from Western Australia to these western feeding ground illustrated numerous times. Cues for the timing of departure from Antarctic feeding grounds to the Western Australian coast, and the pathways taken for this migration are still not know and represent a substantial gap in our understanding of humpback whale behaviour.

Satellite tagged whales exhibited greater variation in their direction of travel on the north and north-west coasts. This is likely indicative of more social behaviour than directed migrations, and is consistent with pervious satellite tagging of mothers and calves in the region (Double et al. 2010). This more social behaviour with greater interactions / contact between individuals may account for the termination of tracking for a number of whales on the states north coast. Satellite tracking of 12 whales ceased on the states north coast compared to six whose tracks terminated before reaching state's north. The remaining whales were tracked to the north coast before leaving the north coast on their return southern migration. Previous tagging of humpbacks in the region also noted the termination of tracks in this region (Double et al. 2012b), potentially due to the increased social interactions or contact with the benthos. Mud on the tails or rostrums of surfacing untagged whales was recorded on untagged whales in the region previously (Jenner and Jenner unpublished data in Double et al. (2012b). The increased contact with either the benthos or other whales is likely to damage transmitters and hence result in the termination of tracking.

On the states north coast is Camden Sound, a large body of water to the north of Broome with the sound and surrounding waters was recently (June 2012) designated as a marine park (Department of Parks and Wildlife 2013) . This marine park has specific management arrangements to protect humpback whales, including a 'special purpose zone (whale conservation)' zone with enhanced management protection measures in place due to its importance as a resting / calving and nursing area (Department of Parks and Wildlife 2013). Of the four whales that were tracked as far north as the park, only a female whale was tracked inside the park boundaries. A second female transited outside the park further north, while the two males remained offshore of the boundary. While the Camden Sound Marine Park is an important resting and calving ground, it is clearly one of many on the state's north and nor-west coast.

The north and north-west coasts are clearly the major calving grounds for humpback whales. The migration of females into the calving grounds peaks around the last week of July (Jenner et al. 2001a), which corresponds to the observations from commercial whale watching, where calf abundances on the north coast increasing from early July and peaking early September. Calves from commercial whale watching operators have also been recorded in reasonable numbers on the states north-west coast at Shark Bay and Ningaloo in early July. Satellite tracked whales migrating north were tracked to the northern part of Shark Bay where they remained for some time before transmissions ceased. These areas may represent resting grounds for some whales or additional calving ground for pregnant females.

Females may utilise these more southerly calving grounds due to excessive energetic costs of migration / thermoregulation. It is thought that all females may not undertake the migration from Antarctic feeding grounds to tropical calving and breeding grounds (Brown et al. 1995) There are considerable energetic costs associated with both reproduction and migration. Stock D whales are not thought to feed on their migration (Eisenmann et al. 2016), therefore requiring considerable energy stores to undertake the migration, with preliminary estimates that they could exceed ¼ of their annual energy budget (Brown et al. 1995). Additionally, whales may conserve heat when in cold waters easier than dissipating heat when active or in warm waters (Lavigne et al. 1990). As such, warm water on the states north coast, particularly during periods of strong LC may result in that it is preferential from a thermoregulation point of view for parturition to occur at higher latitudes and hence cooler water.

After reaching the states north and north-west coast, whales then began the return journey to their Antarctic feeding grounds. Twelve whales tagged off Augusta were seen terminating their northern migration and returning south. This occurred from late July to mid-August, with 11 whales turning on the state's north or nor-west coasts. This corresponds well to survey data from five decades earlier which recorded a change in the net migration from northerly to southerly just north of Carnarvon occurring in late August (Chittleborough, 1965).

The southern migration was still generally coastally associated, though not as directional as the northern migration. Humpbacks appeared to utilise the southward flowing LC to assist their southern migration. The longitude of migration, particularly around latitude 27^{o}S, showed southern migrating whales further offshore than during their northern migration. This corresponds to the location of the LC which is generally associated with the shelf break and hence offshore (Pearce 1991). However, in the Capes region, there was a noticeable deviation from the general coastline orientation. Eight whales were tracked to the Capes, with two tracks stopping just to the east of Augusta. The remaining six whales halted their general southern migration and moved offshore in a westerly direction.

The deviation of southern migrating whales away from the coast in the Capes region was also seen in the tracks from a number of other whales who moved offshore further north. Previous tagging off the Western Australian coast noted two of four individuals which were tracked south of Exmouth moved offshore into the eastern Indian Ocean which was a deviation from their expected migration route close to the Western Australian coast (Double et al. 2010). Whales tended to move offshore from either just south of Shark Bay, south of the Abrolhos Islands, or from the Capes region. Eleven whales were tracked moving offshore from coast, with a further five whales whose tracking ceased onshore, re-established communications with satellites from offshore locations in the eastern Indian Ocean. This previously "unexpected" movement to the eastern Indian Ocean may be a common migration pathway, rather than the more direct southerly movement from the Augusta to Antarctica. These deviations away from expected migration pathways was thought to be associated with temperate feeding areas (Stamation et al. 2007, Gales et al. 2009), though preliminary analysis seems to indicate that this isn't the case for this population, though further work is planned (Section Further development: Offshore and feeding associated movements of humpback whales in Antarctic waters).

6.4 Management considerations for mitigation of future entanglements

Analysis demonstrated a reduction in entanglements by ~60% through gear modifications which were implemented from 1 May to 31 October in waters generally deeper than 20 m. The following sections deal with the possible impacts of changes to these regulations on future entanglement rates.

6.4.1 Temporal changes

A preliminary examination of inter-annual changes in the timing of humpback whale migration indicated changes in timing evident between years (How et al. 2015). Such changes have also been shown in other better studied populations, with the changes generally not more than several weeks between years (Rugh et al. 2001), and were thought to be associated with variation in food availability in Antarctica (Chittleborough 1965).

The timing of peak migration for the stock D humpback did indeed vary over a three-four week period, though they were generally very consistent, with nine of the 18 years analysed having a peak migration with a one-week time period, though there was a clear temporal shift in the timing of migration from 2013 onwards. Notable outliers were in 2006 and 2013 when whale abundances peaked up to two weeks earlier. Prior to 2010 when the WRLF was effort controlled, the pattern of fishing between years was relatively consistent. The earlier migration which occurred in 2006 corresponded to the largest number of reported entanglements (six) during this effort controlled period of the fishery. The decline in entanglements in subsequent seasons (2007-2010) was thought to be due to reduced fishing effort and the introduction of a code of conduct to reduce whale entanglements (Groom and Coughran 2012b), upon which recent updates (Appendix 2, Appendix 3) were based. Rather now it appears that the 'unusual' number of entanglements in 2006 was due to the earlier arrival of whales on the Western Australian coast that season, resulting in more whales interacting with gear than in previous seasons.

As the peak of the migration generally occurs within a seven-day period annually, and early migrations can be a couple of weeks earlier, it is not recommended to amend the temporal component of the gear modification period. It is noteworthy though, that with an increasing whale population, while the peak migration may remain the same annually, a greater number of whales will move through prior to this peak in migration. Depending on the extent of population increase (Ross-Gillespie et al., 2014), future modifications to the duration of the gear modification period may be required to account for increased whale numbers prior to the peak of migration.

6.4.2 Spatial Changes

Depth was the major environmental predictor of habitat for migrating whales from the spatial model. There were very few detections of satellite tagged whales in the < 20 m depth region through the mid-west coast where the WCRLMF or DOF fisheries operate, which resulted in the spatial model producing the highest probabilities of habitat suitability in the 25-53 m depth range. This vindicates the reduced mitigation requirements in the shallow waters (< 20 m). Coupled with this is the modelled assessment of gear modifications indicates that the majority of whale entanglements occur in the 55–73 m (30 -39 fathom) depth category. However, it was noted previously that the assessment model was unable to assess inter-annual variation in the location of migration.

The months when whales were most susceptible to entanglement within the fishery were from May to August. This corresponds to the northern component of the humpback migration through the fishing grounds. During this period, the Leeuwin Current (LC), a dominant oceanographic feature of the region is at its peak flow. The Leeuwin current of low salinity warm water emanates from Indonesia and flows southward from the states Nor-West Cape (22ºS), along the west coast and often extending onto the south coast of Australia. The shallow and narrow current is generally located on the continental shelf, though can extend onto the shelf during periods of strong flow (Pearce 1991) and is known to impact the biology of a number of species (Hutchins and Pearce 1994, Caputi et al. 1996, Caputi 2008) and appears to influence the location of humpback migration annually.

Whales which were satellite tagged on their northern migration moved inshore of the LC in both 2015 and 2016. When the LC was slightly stronger in 2015, whales were detected further inshore and in a more discrete corridor compared to the more offshore, diffuse migration which was recorded in the weaker LC 2016 migration. During these two years, whales were observed to remain off the coast until north of Perth when they became more coastal. Despite being stronger than the 2016 LC, the 2015 LC was still weaker than have been experienced since 2000. However, in 2013 when a peak in entanglements was recorded, the LC flow was the strongest recorded in recent years. With the LC pushing more inshore on stronger flows (Pearce 1991), and the humpbacks migrating inshore of the LC on their northern migration, it is likely that the whale in 2013 moved considerably further inshore than was demonstrated by tracked whales in 2015 and 2016. This would have resulted in whales interacting with shallower gear, and also potentially gear south of Perth and the current forced the whales inshore from the top of the Capes regions. The presence of whale watching records from the Capes region in 2013 during the northern migration, which hasn't been recorded previously, adds weight to the likely movement of whales inshore from this region through the fishery.

Most of the discussions with industry during the formulation of whale entanglement mitigation package focused on the depths where no gear modifications were required. This was evident from the slight modifications to the gear modifications regulations through 2014-2016. While modelling of gear modifications effectiveness suggested that the 18 – 35 m (10 – 19 fathoms) depth range wasn't often associated with entanglements, the proportion of detections of satellite tagged whales in the 20-39 m depth range for the mid-west was 20-30%. Therefore, a relaxation of the spatial extent by increasing the depth before gear modifications were required would expose a larger proportion of whales to unmodified gear. There are two additional factors that need to also be considered before a relaxation of the spatial extent of the gear modifications is permitted. This project did not tag mother and calf pairs. These whales are known to move slower and in shallower waters than the remainder of the population, possibly to reduce predation risks on the calves (Double et al. 2010). Therefore, with this proportion of the population not included in the assessment, a great number of whales would be expected in shallower waters with the inclusion of this component of the population.

Finally, the two years where whales were satellite tagged was in relatively weak LC years. As whales move inside of the LC, these detections likely underestimate the number of whales what would move through shallower water. A stronger LC, such as that which occurred in 2013 likely moved whales further inshore and into greater exposure to fishing gear. While climate modelling suggests that the LC is predicted to weaken in the future (Sun et al. 2012), recently there have been unseasonal and unexpected changes to the LC (Feng et al. 2013). Given the impact of the LC on spatial whale distribution, and the tracking of whales during weak LC years, precaution should be used before a spatial relaxation of gear modification regulations.

7. Conclusion

Whale entanglements were reduced through the introduction of gear modifications to two pot and line based fisheries off the West Australian coast. Modifications which focused on reducing the amount of rope, floats and floating rope in waters generally greater than 20 m accounted for a reduction in entanglements of about 60%. This empirical assessment of gear modification effectiveness accounted for an increasing whale population, changes in fishing effort, reporting rate and availability.

Modelling of gear modifications was unable to account for inter-annual spatial variation in the location of the whale migration. Satellite tracking revealed, that during the peak entanglement period (May- July), northbound whales migrate inside the Leeuwin Current (LC), the dominant oceanographic feature off the Western Australian coast during the austral winter. With inter-annual variance in the strength of the LC demonstrated previously, it is likely that whales moved further inshore in 2013 which was a stronger LC flow year. Therefore, it is likely that there was greater overlap of fishing gear and migrating whales in 2013 resulting in the greater number of entanglements. However, climate change predictions estimate that the LC flow will reduce, and hence possibly reduce the likelihood of strong LC years which may force northbound humpback whales inshore.

The WRLF catches have been influenced by different recruitment levels resulting from, in part, variations in Leeuwin Current strength. To manage these variations in settlement levels, the fishery has undergone a number of management changes which have influenced the number of pots which are fished (de Lestang et al., 2012). These management changes, when under an input control system, generally resulted in a reduction effort (the number of pots fished) and hence rope days. Had effort reductions for sustainability reasons (e.g. 2005/06 and 2007/08 onwards; de Lestang et al. 2012) not been implemented it is likely that entanglements would have increased solely due to the increasing whale population. When the model replayed the effort distribution of 2004 (closed season 1 July-14 November, no gear modifications) from 2004 until 2017, the resultant modelled entanglements was very similar to model simulations incorporating actual annual effort distributions up until 2009. There was a divergence in 2009 when another series of effort reductions was enforced in the WCRLF to sustainably manage the fishery (de Lestang et al. 2012), resulting in a decline in the amount of ropes/float in the water. Further and more dramatic effort reductions occurred during the 2010 migration, with some parts of the fishery closed by mid-May (de Lestang et al. 2012). While reported entanglements increased in 2011, they were very similar to what was reported in other years under effort-based management. Our modelling suggests that has the pattern of effort in 2004 continued through until 2017, the estimated number of entanglements would have been over ten in 2017. Importantly this suggests that a simple management response of reverting to previous effort-based management including no effort between 1 July and 14 November is unlikely to have resulted in a reduction in whale entanglements to levels lower than those recorded pre-2010.

While entanglements can have serious impacts on populations size and recovery (Johnson et al., 2005; Knowlton & Kraus, 2001) the issue of humpback whale entanglements off Western Australia is not considered to impact the populations recovery (Bettridge et al., 2015). The concern over whale entanglements in this instance is social / ethical to reduce prolonged periods of suffering (Moore et al., 2006). It appears the decline in reported whale entanglements from 2013 to 2017 is due in a large part to the implementation of gear modifications. Model estimates have shown gear modifications to result in reducing entanglement by about 60%. However, with an increasing whale population size off Western Australia (Ross-Gillespie et al., 2014) as with other humpback populations world-wide (Bettridge et al., 2015), future entanglements are likely to increase. Also the total number of whales entangled each year is not known and difficult to estimate. To continue to mitigate whale entanglements, a better understanding the mechanisms of entanglements and the migratory behaviour of whales is necessary. This will greatly assist in the further development of appropriate gear modification or management arrangements to permit fishing during the whale migration.

This project represents a continuation of FRDC 2013-037 "Effectiveness of mitigation measures to reduce interactions between commercial fishing gear and whales" (How et al. 2015), which was initiated after the increase in whale entanglements in 2012. The primary objective of FRDC 2013-037 was to examine the effectiveness (practicality) of potential gear modifications to reduce whale entanglements. To identify these modifications an industry workshop was run, producing a list of potential gear modifications but a range of other ways to mitigate the issue (Lunow et al. 2013). In total 21 "mitigation" measures were identified and were categorised into six groups, based on their perceived outcome (How et al. 2015). Through this project (2014-004) and the proceeding FRDC 2013-037 (How et al. 2015), 19 of the 21 measures were assessed, with only those classed as having "No effect on whale entanglement rates of subsequent disentanglement" were not addressed by these projects (Appendix 9). Five options were assessed and deemed unsuitable in reducing entanglements of humpback whales in pot fisheries off Western Australia. The remaining 14 measures have either been directly implemented into fisheries management arrangements (n = 3), incorporated into the whale entanglement mitigation specific management arrangements (n = 7) or implemented despite falling outside the remit of fisheries management (n = 3). Only one option has been partially assessed and requires additional research (biodegradable rope) should it wish to be considered further as a mitigation option. Therefore, these two FRDC projects represent a thorough examination, and implementation of appropriate gear modifications identified by industry to reduce whale entanglements. The collaborative approach between research and industry is undoubtedly an integral aspect in the success of these project in reducing whale entanglements off the West Australian coast.

8. Implications

While the primary beneficiaries of this research project are the commercial WCRLMF and octopus fishers, other fisheries and sectors will also benefit. Through identifying the times when and locations where the humpback whale migration occurs, targeted spatial and temporal management arrangements could be implemented to reduced impost on fishers. Without such measures, there was the potential to revert back to previous closed season for the WRLF, which was estimated to reduce the GVP of the fishery by about $50-100 million.

As well as reducing the potential financial impacts on fishers, the empirically demonstrated effectiveness of gear modifications, and the tangible reduction in entanglements has bolstered the fisheries' "social license to fish". Fisheries are under increasing public scrutiny to perform in a socially responsible manner. The negative public perception around a fatal whale entanglement could have serious ramifications on the fishery. However, this research has mitigated this outcome through reducing entanglements, but also through demonstrating industries willingness to implement proven effective gear modifications.

9. Recommendations

From the findings of this research, the recommendations are to maintain the current package of management arrangements to reduce whale entanglements. Gear modifications have been shown to be effective in reducing entanglements by ~60%. The spatial and temporal components of the management have also been shown to be appropriate with a reduced risk of entanglement in shallow water where there are reduced management arrangements.

There are areas of further development required to completely research which was outside the scope of this FRDC project.

9.1 Further development

9.1.1 Factors affecting transmission success and deployment longevity of implantable satellite tags

The 62 tags deployed during this project varied in terms of their implant location, angle and depth, as well as the deployment pressure, tag construction and whale size and sex. These variables will be assessed against a number of transmission variables (e.g. number of transmission, number of detections and longevity). It is envisaged that this will assist in determining the most effective tagging regime for transmission and longevity. This will assist in future cetacean tagging programs.

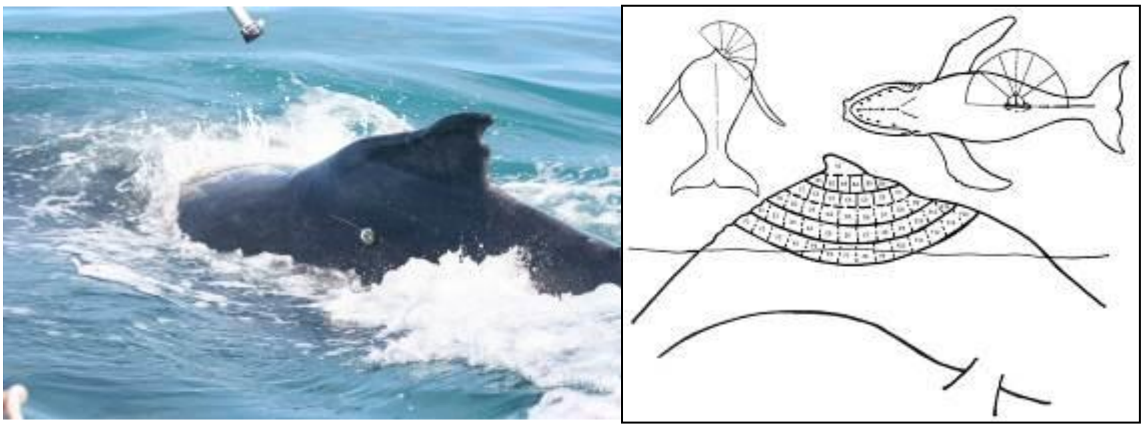


Plate 2 Image of a deployed satellite tag on a humpback whale (left) and how this and other deployments will be recorded for the three dimension of deployment (right)

9.1.2 Offshore and feeding associated movements of humpback whales in Antarctic waters

Twelve humpback whales tagged off the Western Australian coast were tracked back to feeding grounds off Antarctica. These movements were outside the scope of this project, though provide a previously unavailable insight into the offshore and feeding associated movement of Stock D humpback whales. The association of humpback whales with Leeuwin Current will also be explored further for southern migrating whales to see if eddies from the LC serve as cues for whales moving offshore. Feeding associated movements will be determined through switching state-space model. Identified specific feeding areas and this will be assessed against a range of environmental parameters and known prey distributions to determine what factors may influence Antarctic feeding patterns.

9.1.3 Movement patterns of Mother-calf pairs

The focus of whale tagging in this project was sub-adult and adult humpback whales, with mother-calf pairs not targeted. Additional permitting would have been required to target these animals. Eight calves and four adults with calves in attendance have been reported entangled off the Western Australian coast. Previous tagging of this demographic has only occurred on the state's north coast and indicated that they frequent shallow water more than the rest of the population (Double et al. 2010). This places them at a greater risk of entanglement, especially under the current management arrangements. There is a far greater social risk as well if these whales are entangled as they engender a large degree of public sympathy. Therefore, consideration should be given to better understand the migration and resting areas of mother-calf pairs.

10. Extension and Adoption

The progress and outcomes of this project has been disseminated to industry and the broader community project through a range of presentations (below), or flyers (Appendix 7and Appendix 8). The adoption of aspects of this research has been discussed above (Conclusion) and it practical implementation in Figure 45.

10.1 Industry meetings

Ministerial Whale Entanglement Taskforce and Operational Whale Entanglement Reference Group

- Hillarys & Perth – November 2015
- Hillarys & Perth – February 2015

Western Rock Lobster Annual Management Meetings

- Fremantle and Geraldton – July 2016
- Fremantle and Geraldton – June 2015
- Fremantle and Geraldton – June 2014

Western Rock Lobster Council Research and Development Advisory Group

- Hillarys – January 2017
- Hillarys – November 2016
- Hillarys – May 2016
- Hillarys – February 2016

10.2 Scientific Forums

Global Assessment of Large Whale Entanglement and Bycatch Reduction in Fishing and Aquaculture Gear – Portland USA, May 2016

Government Cetacean Management Workshop – Melbourne February 2016

Trans-Tasman Rock Lobster Congress – Fremantle, May 2015

Marine Stewardship Council Annual Audit – Hillarys, April 2015

10.3 Public or Other Forums

South Padbury Primary School (all of school presentation) – December 2016

Marine Rangers Presentation (Depart. Parks and Wildlife) – October 2014

11. Project materials developed

Several materials were developed as part of, in or collaboration with this project and are listed below:

App: While funded as part of FRDC 2013-037, an update to the WhaleSightingsWA app was developed to cover sightings of all marine 'mega' fauna, Marine Fauna Sightings. This enables sightings of whales, dolphins, turtles, sea snakes, seals/ sea lions and dugongs to be reported utilising a single app, and can receive sightings from all around Australia. The development was a lengthy process and release is expected prior to the whale migration season in 2019.

Code of Practice

Western Rock Lobster Fishery (2015) (Appendix 2)

Western Rock Lobster Fishery (2016) (Appendix 3)

Octopus Fisheries (Appendix 4)

Scientific Paper:

Gear modifications reduced whale entanglements in a commercial rock lobster fishery (in prep)

Fact Sheet:

Satellite Tracking Handout for Whale Watching Vessels (Ningaloo) (Appendix 7)

Satellite Tracking Handout for Whale Watching Vessels (Augusta) (Appendix 8)

12. Appendices

Appendix 1

Researchers and project staff

Department of Fisheries, Western Australia

- Jason How
- Kelvin Rushworth
- Benjamin Hebiton
- Simon de Lestang
- Owen Young
- Amber Bennett
- Joel Durrell
- David Murphy

Department of Parks and Wildlife, Western Australia

- Douglas Coughran

Australian Antarctic Division

- Michael Double
- Virginia Andrews-Goff

Blue Planet Marine

- David Paton

Murdoch University

- Joshua Smith

JASCO Applied Sciences

- Craig McPherson

Marine Acoustic Biodiversity Solutions

- Geoff McPherson

Curtin University

- Angela Recalde Salas
- Chandra Salgado-Kent

Western Rock Lobster Council

- John McMath

Western Australian Fishing Industry Council

- John Harrison

Appendix 2

Code of Practice Western Rock Lobster Fishery (2015)

Western Rock Lobster Council Inc.

West Coast Rock Lobster Managed Fishery
Code of Practice
for
Reducing Whale Entanglements

Introduction

The Western Rock Lobster Council developed a Whale Entanglement Code of Practice (CoP) in 2007 in association with Government and non-government agencies to reduce interactions with whales in Western Australian waters. Through a consultation process involving a range of stakeholders it was recognised that a CoP was necessary. This CoP is specifically aimed at minimising entanglement of whales in rock lobster pot lines, although the strategies proposed will also minimise entanglements with other marine wildlife.

The CoP helps the industry to make progress against the following Government and management considerations:

- Fishing activities in which fishing gear is set, using trailing ropes or tethered buoys, is identified as a potentially threatening process, particularly for migrating Southern Right and Humpback whales which are protected under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Western Australian Wildlife Conservation Act 1950;*
- Whale entanglements are recognised as a management issue for the West Coast Rock Lobster Managed fishery by both the WA and Commonwealth Governments;

Benefits of the Code of Practice

1. As a conservation measure to assist in protecting whales from entanglement.
2. The profile of the rock lobster industry can be improved by:
   - their direct involvement in the reduction of whale entanglements by acknowledging best fishing practices at industry level; and their involvement in the disentanglement program.
3. Avoiding loss of gear and catch from lobster pots.
4. Safe working practice for boat crews to avoid injuries.
5. Safe working disentanglement network. The need exists for fast reporting of incidents so the disentanglement process can begin.

Please see overleaf for mandatory gear configurations
Contact Jason How on 9203 0247 for any queries on Whale Sightings
Contact WRL Management on 9482 7333 for any queries on gear modification requirements

To notify of an entanglement call:
08 9219 9840
or
***Wildcare Helpline* on 08 9474 9055**

What to do if encountering a whale entanglement

- Report entanglements as soon as possible

Rapid reporting ensures entanglement response teams have the best possible chance of successfully disentangling whales. Fishers should monitor entanglement situations, with due regard for the safety of the vessel and the whale, until assistance teams arrive.

- Stand-by the entangled whale

When possible this enables the disentanglement team to find the whale quicker and gain all the necessary information from the fisher prior to attempting disentanglement.

- DO NOT attempt to cut the whale free

The attached line allows a safe working line for the disentanglement team.

- Be co-operative when responding to entanglements

Fishers can voluntarily participate in Department of Parks and Wildlife training programs for involvement in disentanglement operations. This training will ensure that fishers are aware of procedures and are familiar with disentanglement team personnel.

Fishers should not attempt disentanglement of whales without the assistance of the WA Government's Whale Disentanglement Team

Practices that reduce the risk of whale entanglements

Rock Lobster fishermen should:

- Be aware of whales between May and November
- Adhere to the mandatory gear modifications

(see overleaf) during the period 1 May to 14 November inclusive.

- Participate in the Whale Sightings WA app

to support researchers in better understanding the paths of migrating whales.

- Dog boning of rope

Dog boning of rope can occur if fishers wish to reduce rope on or near the surface when fishing in the whale zone with less than 32.9 m of rope.

- Avoid setting pots in clusters
- Regularly check pots

The Disentanglement teams have a greater chance of success if the entanglement is discovered quickly.

- DO NOT leave pots in the water for prolonged periods

(mandatory to pull pots with weighted ropes once every 7 days).
Pots should be retained on board or returned to shore when they are not fishing for prolonged periods.

- Collect abandoned/lost or cut pot lines, rope or fishing gear
- Investigate all new technologies that may reduce entanglements

Gear modifications

On 1 May 2015 new modified whale entanglement mitigation measures were implemented in order to reduce the risk of whale entanglements in the fishery during the whale migration season.
These measures will be place from 1 May to 14 November inclusive each year. As part of these changes a 'whale zone' (described in Schedule 14 of the Management Plan; *image below*) was introduced which allows fishers who fish with ropes less than or equal to 32.9m (18 fathoms) in water within the 'whale zone' to have minimal gear restrictions.

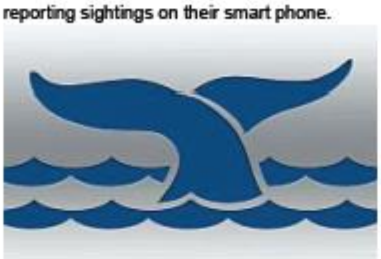
Further information on the exact co-ordinates of the 'whale zone' can be found at the Department of Fisheries website and downloaded in the form of gpx and c-plot files.

Fishers who use more than 32.9m (18 fathoms) of rope, or in waters outside the 'whale zone' are required to abide by the gear modifications which include restrictions on rope length and requirements of negatively buoyant rope and minimum pot retrieval requirements (*image below; not to scale, guide only*).

Specific details on the gear modifications can also be found at the Department of Fisheries website as well as the Western Rock Lobster Council website.

Whale App to help get the big picture on WA migration

A whale app is now available to encourage all fishers to assist with whale migration research by reporting sightings on their smart phone.

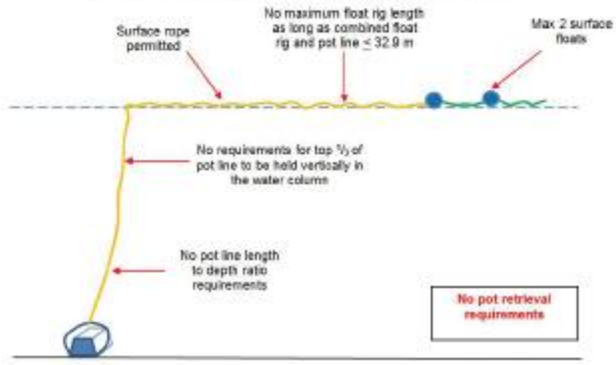


Whale Sightings WA can be downloaded for free from iTunes and it enables all water users to submit their sightings of whales along the coast. The WRLC requests that all rock lobster fishers download and use this app to report all whale sightings.

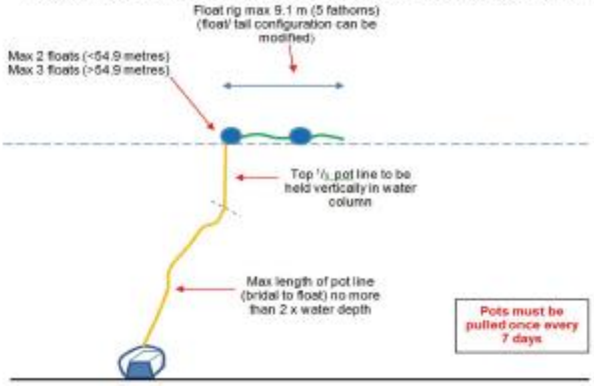
To map the migration corridor of humpback whales, dedicated app users are required to log all sightings when returning to port in June and September.

If you are interested please contact Jason How (details overleaf).

When fishing with ropes ≤ 32.9 m (18 fathoms) in the waters described in Schedule 14 of the Management Plan



When fishing with > 32.9 m (18 fathoms) of rope, or in waters outside those described in Schedule 14 of the Management Plan



Revised May 2015

Appendix 3

Code of Practice for Western Rock Lobster Fishery (2016)

Western Rock Lobster Council Inc.

West Coast Rock Lobster Managed Fishery
Code of Practice
for
Reducing Whale Entanglements

Introduction

The Western Rock Lobster Council (WRLC) developed a Whale Entanglement Code of Practice (CoP) in 2007 in association with Government and non-government agencies to reduce interactions with whales in Western Australian waters. Through a consultation process involving a range of stakeholders it was recognised that a CoP was necessary. This CoP is specifically aimed at minimising entanglement of whales in rock lobster pot lines, although the strategies proposed will also minimise entanglements with other marine wildlife.

The CoP helps the industry to make progress against the following Government and management considerations:

- Fishing activities in which fishing gear is set, using trailing ropes or tethered buoys, is identified as a potentially threatening process, particularly for migrating Southern Right and Humpback whales which are protected under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the *Western Australian Wildlife Conservation Act 1950;*
- Whale entanglements are recognised as a management issue for the West Coast Rock Lobster Managed Fishery by both the WA and Commonwealth Governments;

Benefits of the Code of Practice

1. As a conservation measure to assist in protecting whales from entanglement.
2. The profile of the rock lobster industry can be improved by:
   - their direct involvement in the reduction of whale entanglements by acknowledging best fishing practices at industry level; and their involvement in the disentanglement program.
3. Avoiding loss of gear and catch from lobster pots.
4. Safe working practice for boat crews to avoid injuries.
5. Safe working disentanglement network. The need exists for fast reporting of incidents so the disentanglement process can begin.

Please see overleaf for mandatory gear configurations
Contact Jason How on 9203 0247 for any queries on Whale Sightings
Contact WRL Management on 9482 7333 for any queries on gear modification requirements

To notify of an entanglement call:
08 9219 9840
or
***Wildcare Helpline* on 08 9474 9055**

What to do if encountering a whale entanglement

- **Report entanglements as soon as possible**

Rapid reporting ensures entanglement response teams have the best possible chance of successfully disentangling whales. Fishers should monitor entanglement situations, with due regard for the safety of the vessel and the whale, until assistance teams arrive.

- **Stand-by the entangled whale**

When possible this enables the disentanglement team to find the whale quicker and gain all the necessary information from the fisher prior to attempting disentanglement.

- **DO NOT attempt to cut the whale free**

The attached line allows a safe working line for the disentanglement team.

- **Be co-operative when responding to entanglements**

Fishers can voluntarily participate in Department of Parks and Wildlife training programs for involvement in disentanglement operations. This training will ensure that fishers are aware of procedures and are familiar with disentanglement team personnel.

Fishers should not attempt disentanglement of whales without the assistance of the WA Government's Whale Disentanglement Team

Practices that reduce the risk of whale entanglements

Rock Lobster fishermen should:

- **Be aware of whales between May and November**
- **Adhere to the mandatory gear modifications**

(see overleaf) during the period 1 May to 31 October inclusive.

- **Participate in the Marine Fauna Sightings app**

To support researchers in better understanding the paths of migrating whales.

- **Dog boning of rope**

Dog boning of rope can occur if fishers wish to reduce rope on or near the surface when fishing with less than 32.9 m of rope.

- **Avoid setting pots in clusters**
- **Regularly check pots**

The Disentanglement teams have a greater chance of success if the entanglement is discovered quickly.

- **DO NOT leave pots in the water for prolonged periods**

(mandatory to pull pots with weighted ropes once every 7 days).
Pots should be retained on board or returned to shore when they are not fishing for prolonged periods.

- **Collect abandoned/lost or cut pot lines, rope or fishing gear**
- **Investigate all new technologies that may reduce entanglements**

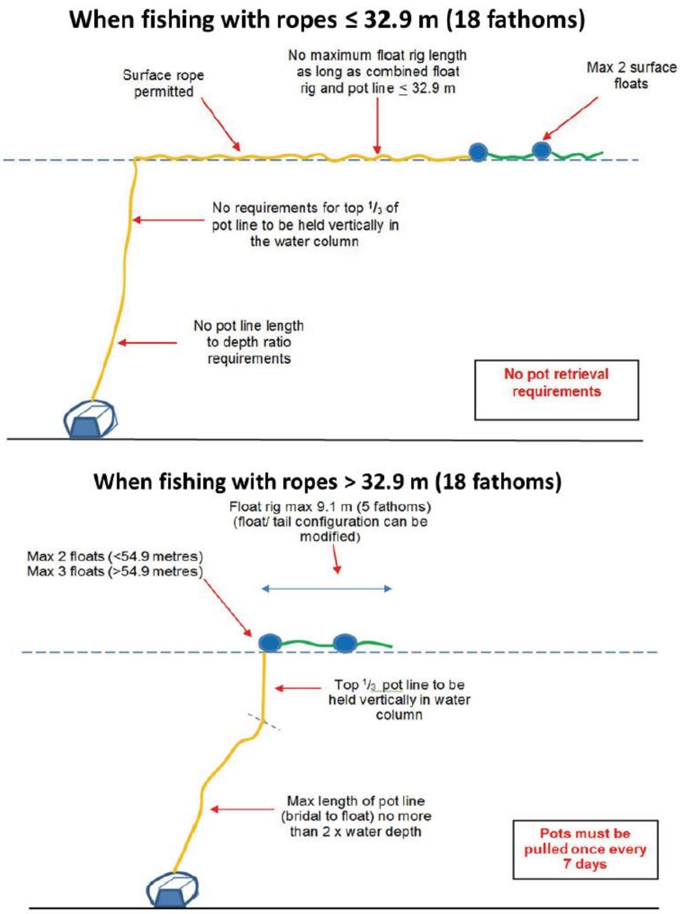
Gear modifications

On 1 May 2016 new modified whale entanglement mitigation measures were implemented in order to reduce the risk of whale entanglements in the fishery during the whale migration season.

These measures will be place from 1 May to 31 October inclusive each year. As part of these changes the 'whale zone', which was introduced in 2015, has been removed

To simplify the requirements, fishers who use more than 32.9m (18 fathoms) of rope, are required to abide by the gear modifications which include restrictions on rope length and requirements of negatively buoyant rope and minimum pot retrieval requirements (*image below; not to scale, guide only*).

Specific details on the gear modifications can also be found at the Department of Fisheries website as well as the WRLC website.



Whale App to help get the big picture on WA migration

A whale app is now available to encourage all fishers to assist with whale migration research by reporting sightings on their smart phone.

Marine Fauna Sightings can be downloaded for free and it enables all water users to submit their sightings of whales along the coast. The WRLC requests that all rock lobster fishers download and use this app to report all whale sightings.

To map the migration corridor of humpback whales, dedicated app users are required to log all sightings when returning to port in June and September.

If you are interested please contact Jason How (details overleaf).

Revised April 2016

Appendix 4

Code of Practice for Octopus Fisheries

Code of Practice for Reducing Whale Entanglements

In the Cockburn Sound Line & Pot Fishery and Octopus Fishery

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The Cockburn Sound Line & Pot Fishery and the Octopus Fishery have developed this Code of Practice in conjunction with the Department of Environment and Conservation (DEC) and SeaNet Environmental Extension Service, to reduce interactions with whales in Western Australian waters. Through a consultative process involving a range of stakeholders it was recognised that a Code of Practice was necessary. The Code of Practice has been developed with specific strategies aimed at minimising entanglements of whales and other marine life in octopus pot lines

The Code of Practice will also help the industry to make progress against the following government and management considerations:

- Fishing activities in which fishing gear is set, particularly methods that use trailing ropes or tethered buoys, is identified as a potentially threatening process, particularly for migrating Southern Right and Humpback Whales which are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* and the *Western Australian Wildlife Conservation Act 1950*
- Whale entanglements are recognised as a management issue by Western Australian Octopus Fishery Management.
- Whale entanglements and the need for disentanglement training are recognized as a priority issue by Department of Environment and Conservation (DEC) and the Department of Sustainability, Environment, Water, Population and Communities.

Fishery Description – octopus fishery

The octopus fishery in Western Australia targets *Octopus cf. Tetricus*. In the northern parts of the fishery *O. Ornatus* and *O.cyanea* are occasional captured, while *O.maorum* is captured in the southern and deeper sectors. Fishing activities targeting octopus in Western Australia can be divided in four main categories. The West Coast Rock Lobster Managed Fishery (WCRLF) harvests octopus as a by-product, and currently accounts for the majority of total octopus landings. Unbaited or passive (shelter) octopus pots are used to harvest octopus in the Cockburn Sound (Line and Pot) Managed Fishery (CSLPF). The Developmental Octopus Fishery (DOF) uses both passive shelter pots and active (trigger pots) traps to selectively harvest octopus.

Octopus caught in the WCRLF are restricted to the boundaries of that fishery (between latitude 21° 44' S and 34° 24' S). Octopus catch in the CSLPF is limited to Cockburn Sound. Octopus caught in the DOF are limited to the boundaries of the developmental fishery, which is an area bounded by Coral Bay in the north and Esperance in the south with each Exemption Holder restricted to a section of the coastline that excludes the others[3].

Fishery Description – Cockburn Sound Line & Pot Fishery

The Cockburn Sound Line & Pot Fishery is restricted to the inner waters of Cockburn Sound, from South Mole at Fremantle to Stragglers Rocks, through Mewstone to Carnac Island and Garden Island, along the eastern shore of Garden Island, and back to John Point on the Mainland.

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Commercial fishing effort is managed under input controls, via limitations on vessels, the number and specification of traps able to be used. Seasonal and daily temporal restrictions also apply. Professional fishermen harvest crabs once they have reached 130mm carapace width for male and 135mm for female, this is well above the size at sexual maturity (<100mm carapace width), allowing female crabs to spawn at least once before entering the fishery and ensuring an adequate breeding stock is left untouched. The fishery was closed in 2006 due to a low stock abundance resulting from a combination of biological, environmental and fishery dependent factors. The fishery has since reopened for the 2009/10 season[2].

Environmental Management

The recommendations that have come from the Commonwealth Department of the Environment and Water Resources (DEW), *Assessment report of the Western Rock Lobster Fishery*, have been used to highlight areas requiring attention in the Octopus Fishery.

Information requirements - DEW Strongly recommends the continual monitoring and collection of information on all cetacean interactions in the fishery.

Assessment - The submission indicates that cetaceans may be at risk of entanglement in pot lines. It states that the increased level of interaction in the fishery may be related to two factors: the movement of fishers into shallower waters without shortening float lines; and the southward and northward migration of the humpback whales.

Management response - The report states that when fishers move to shallow waters the lines should be shortened to account for the change in depth and avoid excess line suspended in the water column or floating on the surface.

Conclusions - DEW recognizes that the Western Australian Department of Fisheries (WADF) are working with industry and DEC to address the issue of whale entanglement in the fishery and encourage WADF, in conjunction with industry and the relevant officers in DEC, to review the management strategies in place to minimize these interactions. Particular attention should be given to the overlap between the fishing season and whale migration and the activities of fishermen when operating in shallow waters.

[1] Sourced from Hart, A. and Murphy, D. 2010. Octopus Fishery Status Report. In: State of the Fisheries and Aquatic Resources Report 2009/10 eds. W.J. Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp 90-94.

[2] Sourced from Johnston, D. and Harris, D. 2010. West Coast Blue Swimmer Crab Fishery Status Report. In: State of the Fisheries and Aquatic Resources Report 2009/10 eds. W.J. Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp 54-61.

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Whale Ecology and Management

In Western Australia there are some whale species more vulnerable due to their migratory patterns. The most vulnerable is probably the Southern Right Whale (*Eubalaena australis*) listed under the *EPBC Act* as an endangered species. Other species likely to be affected in WA waters are migrating Humpback Whales (*Megaptera novaeangliae*) and the critically endangered Blue Whale (*Balaennoptera musculus*). The characteristics of some species that may lead to vulnerability are:

Southern Right Whale:

- Slow swimming, migrates through coastal waters, breeds inshore in coastal waters during winter between May to October
- Has rough callosities on head and very long baleen, which could increase the risk of entanglements
- Difficult to disentangle due to uncooperative nature

Humpback Whale:

- Migrates Northward through Western Australian waters during late May to August, returning Southward, September to December
- Slow swimming, has very long flippers with knobby leading edges

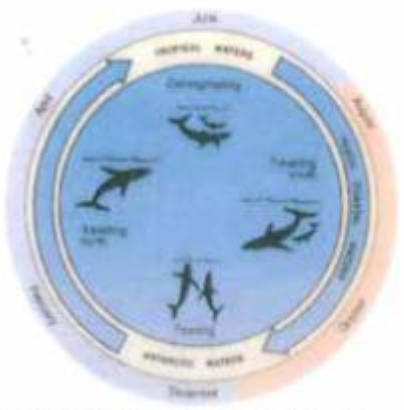

Figure 2. Annual whale migratory routes. Artwork courtesy of DEC

Blue Whale:

- Fast streamlined whale; feeds in West Australian waters from December to May
- Danger of entanglement in baleen or flippers while feeding
- Size and power could make it very difficult to rescue.

Entanglement of cetaceans with fishing gear poses a serious threat to some species, particularly those that are endangered. The causes of entanglement in Australia are varied but records of the types of materials involved include lobster pot lines and octopus lines. Wildlife managers believe that the likelihood of further entanglements occurring in WA will increase as whale numbers increase.

The scale of whale entanglement in fishing gear varies from state to state. In Western Australia a total of 33 whale entanglements between 1990 and 2004 have been recorded. Twenty three of these entanglements (relating to Humpback Whales) have involved Western Rock lobster pot lines. On the South Coast, one Southern Right Whale was entangled in King George Sound, including one dead Humpback found washed up on the Beach. The remaining entanglements involve other fishing gears.

Entangled Humpback whale. Photo courtesy of DEC

There is a particular concern about whale entanglements because of their size. Whale entanglements present complex and often dangerous situations that require specialist skills and training if the whale is to be released unharmed. In addition, there is increasing public interest and concern about such events when they do occur.

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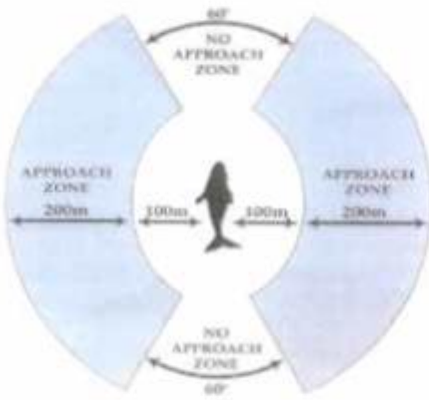
Fishing industry practices that reduce the risk of whale entanglements

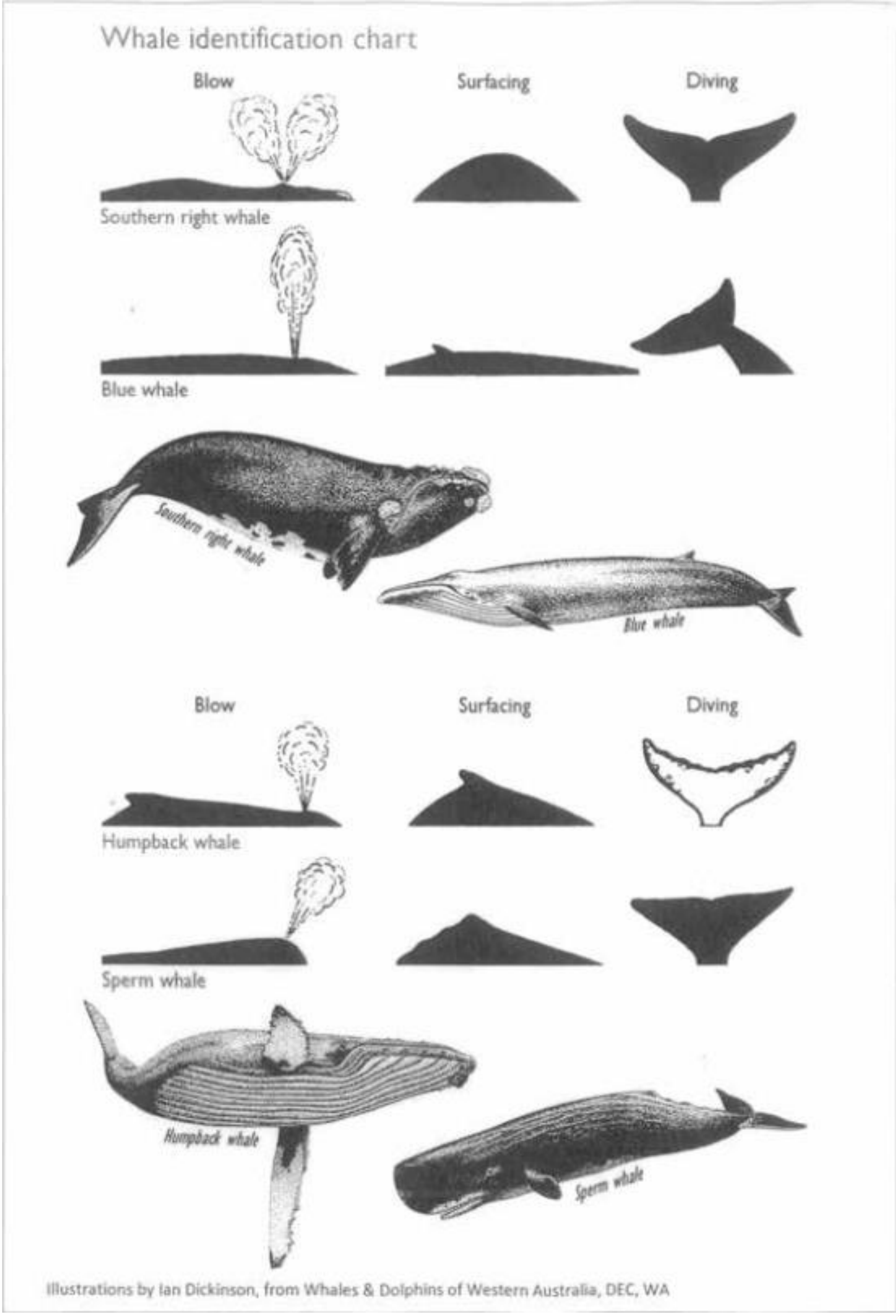
Fishermen should:

- Remain vigilant during the month of June
- Avoid excessive slack in pot ropes, particularly during the start and finish of the fishing season. Ropes should be adjusted to a length appropriate to the depth and strength of tide being worked, especially inshore. Excess slack in pot ropes can be coiled and tied close to floats. Slack should be limited to enough rope to allow for recovery and to commence hauling safely (Dog bone / shanking);
- Where possible avoid setting pots in clusters;
- Regularly check pots, as per standard fishing practice. The Disentanglement teams have a greater chance of success if the entanglement is discovered quickly;
- **Do Not** leave pots in the water if not fishing for prolonged periods. Pots should be retained on board or returned to shore when they are not fishing for prolonged periods;
- Report entanglements as soon as possible. Rapid reporting ensures entanglement response teams have the best possible chance of successfully disentangling whales. Fishers should monitor entanglement situations, with due regard for the safety of the vessel and the whale, until assistance teams arrive;
- Keep up to date contact details aboard; adopt a cooperative approach to avoiding entanglements and responding to entanglements when they occur. Fishers can voluntarily participate in Department training programs for involvement in disentanglement operations. This training will ensure that fishers are aware of procedures and are familiar with disentanglement team personnel. **The readiness, local knowledge and vessel handling skills of fishers are beneficial to disentanglement operations. Fishers should not attempt disentanglement of whales without the assistance of DEC;**
- Collect any abandoned / lost or cut pot lines, rope or fishing gear
- Investigate new technologies that may reduce entanglement



Recommended approach distance.
Artwork courtesy of DEC

A pot line shortened for a shallow water set


Whale identification chart
Blow
Surfacing
Diving
Southern right whale
Blue whale
Southern right whale
Blue whale
Blow
Surfacing
Diving
Humpback whale
Sperm whale
Humpback whale
Sperm whale
Illustrations by Ian Dickinson, from Whales & Dolphins of Western Australia, DEC, WA

Disentanglement program

The Department of Environment and Conservation is dealing with the entanglement through the 'kegging' technique in use by Conservation officers in Western Australia for several years. This technique was developed by the Centre for Coastal Studies in eastern USA. The disentanglement training program provides a standard operating procedure for attaching long lines and heavy buoys to the whale to slow it down, tire it out and keep it on the surface, allowing trained personnel to approach more safely and attempt to remove the entanglement completely.

Disentanglement procedure. Photo courtesy of Kevin Crane

The entanglement is cut away using specialised knives attached to long poles. It is important to remove the rope not just free the animal. This procedure is being adopted by all Australian state government agencies.

The rescue operations are conducted according to a recognised response system used for emergency situations in Australia. Fishers are also encouraged to participate in future training programs.

While disentanglement provides a means for dealing with some individual incidences as they arise, the best 'solution' to the problem also involves treating it at the source. This can be done by finding ways to minimise risk of entanglement through a range of means as outlined in this protocol.

Benefits of the Code of Practice

1. As a conservation measure to assist in protecting whales from entanglement
2. The profile of the octopus fishery can be improved by:
   - their direct involvement in the reduction of whale entanglements by acknowledging best fishing practices at industry level; and
   - their involvement in the disentanglement program.
3. Avoiding loss of gear and catch from lost octopus pots.
4. An established disentanglement network. The need exists for fast reporting of incidents so the disentanglement process can begin.

Important contact information

To notify DEC of an entanglement call
0419 947 708

Wildcare – 08 9474 9055 or

General enquiries – 08 9334 0292

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Appendix 5

Industry survey of gear modifications and whale migration

Whale Interactions

Introduction

Have your Say about the 2014 Whale Gear Modifications

Gear modifications were introduced this season and we have had a reduction in whale entanglements recorded for the industry. As part of assessing how the gear modifications have performed we are asking you to complete this quick nine question survey. The questions are about how industry found the 2014 gear modifications and also how possible interactions with whales may have changed as a result of the gear modifications.

You are not asked for your personal detail and you can not be identified by your submission. This will hopefully ease any concerns you have regarding providing information on previous interactions with whales.

So please complete this survey, and encourage other members to do the same. Information from this will guide future decisions regarding whale mitigation measures for the fishery, so it is in your best interests to complete it and be as honest as possible. This survey will form the basis of what you have to do next year and into the future.
We thank you for your time and assistance in helping your industry address the issue of whale entanglements

Regards
John McMath
CEO
Western Rock Lobster Council

Whale Interactions

Where do you fish

1. Which port is closest to where you fish during the whale migration period

2. What depths did you fish this year during the whale migration period

- ☐ Shallows (less than10 fathoms)
- ☐ Teens (10-19 fathoms)
- ☐ Twenties (20-29 fathoms)
- ☐ Thirties (30-39 fathoms)
- ☐ Deep (more than 40 fathoms)

Whale Interactions

Impact of gear modifications

3. Did the gear modifications make you adjust where you would normally fish?

- ◯ No, I fished in the same places I normally do
- ◯ Move your fishing shallower
- ◯ Move your fishing deeper
- ◯ Move your gear out of the water (modifications made it too hard to fish)

Whale Interactions

Gear Modifications 2014

How did you find using the gear modificaitons that were implimented in June 2014

4. Please rank the following statements

	Disagree	Neither Disagree Nor Agree	Agree
The mitigation devices were initially easy to use	◯	◯	◯
The mitigation devices became easier to use	◯	◯	◯
Do the gear modifications need changing for 2015 season	◯	◯	◯

Please provide comments if you think changes to gear modificaitons should occur for the 2015 season

Whale Interactions

Interactions with Whales: 1

This page helps to understand the possible number of pots that were involved in whale interactions

5. Approximately, how many pots were lost from possible interactions with whales in:

2013 [ ]

2014 [ ]

6. Approximately, how many pots were moved from possible interactions with whales in:

2013 [ ]

2014 [ ]

Whale Interactions

Interactions with Whales: 2

This page helps to understand more about where and when possible whale interactions occured

7. Please rank the months that you think generally are the worst for whale interactions where you fish

- May
- June
- July
- August
- September
- October
- November

Whale Interactions

Copy of page: Interactions with Whales: 2

This page helps to understand more about where and when possible whale interactions occured

8. Please rank the depths that you think generally are the worst for whale interactions where you fish

- Shallows (less than 10 fathoms)
- Teens (10-19 fathoms)
- Twenties (20-29 fathoms)
- Thirties (30-39 fathoms)
- Deep (more than 40 fathoms)

Whale Interactions

Contact details

9. If you are interested in Department of Fisheries interviewing you to see where whales move through the area you fish, or you have further comments to make on gear modifications, please complete the information below so you can be contacted

Name

Email Address

Phone Number

Appendix 6

Questionnaire to assess WRLC's Whale CoP awareness and uptake

Please ask the skippers the following questions regarding whale entanglements and their knowledge of the code of practice to reduce entanglements with whales

*Vessel LFB*_________________ *Port*_______________________ *Date*____________________

1. Are you aware of the fisheries implications with whale entanglements Y - N

2. Are you aware of the fisheries code of practice for whale entanglements Y - N

3. Do you know if the code has been updated since it was released in 2006 Y - N

4. Would you know where to get hold of the code Y - N

   If Yes where ____

5. Do you know the major points the code highlights?

Ask the fisherman and circle Y for any that they mention (do not prompt them)

a. Remain vigilant Y - N
b. Avoid excessive slack in pot ropes, Y - N
c. Avoid setting pots in clusters; Y - N
d. Regularly check pots, Y - N
e. Do not leave pots in the water if not fishing for prolonged Y - N
   a. periods (>7 days)
f. Report entanglements as soon as possible. Y - N
g. Keep entanglements contact details aboard Y - N
h. Collect any abandoned / lost or cut pot lines, rope or fishing gear; and Y - N
i. Investigate new technologies that may reduce entanglements. Y - N

6. Do you know what to do if you see an entangled whale Y - N

If answered YES which actions do they know about (tick)

a) ☐ Report entanglement ☐ b) Stand-by whale ☐ c) DON'T cut line

7. Do you do anything when fishing to reduce you chance of whale entanglements? Y - N

   If Yes what ____

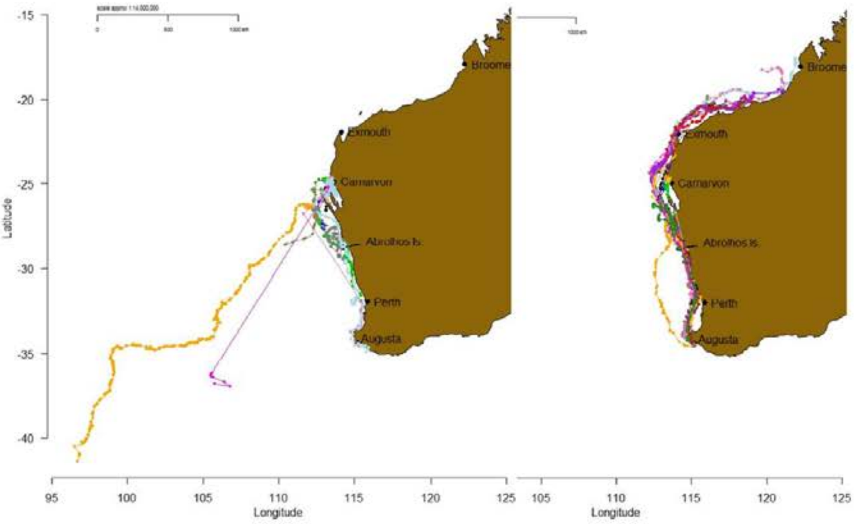
Appendix 7

Satellite Tracking Handout for Whale Watching Vessels (Ningaloo)

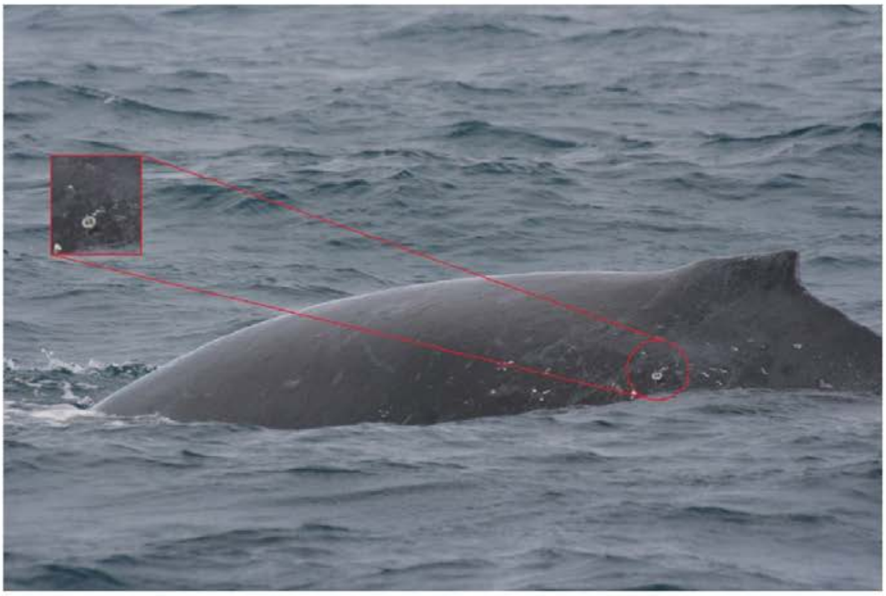
Satellite Tracking of Humpback Whales (*Megaptera novaeangliae*) in Western Australia

Humpback Whales (*Megaptera novaeangliae*) off the West Australian coast are recovering strongly, and are now considered to be close to their pre-whaling numbers. With this increase have come a greater number of interactions between the whale and fishing gear. This rise prompted governments to respond to this situation by assessing and implementing measures to reduce interactions between fishing gear and whales.

As part of the response to this the Western Australia Department of Fisheries in conjunction with the Australian Antarctic Division have been tracking Humpback Whales with satellite tags to follow their migration along the West Australian coast. South-moving whales have been tagged off Carnarvon in 2014 (below left), while those moving north have been tagged off Augusta in 2015(below right). Their subsequent tracks show a high affinity to the coastline, particularly on their northern migration. Tagging occurred at both of these locations again in 2016.



Tagged Humpback Whale Re-sightings Wanted!



Resighting photos of tagged humpbacks are wanted to help inform ongoing research of the duration and condition of satellite tags.

Tags (as shown in image above) are located below the dorsal fin on either the left or right side of the animal. They have a small black aerial with a small stainless steel collar visible.

What is needed: **-High resolution images of the tag**

-Time, date and location (latitude, longitude) of sighting

Please send any images or reports to jason.how@fish.wa.gov.au.

Government of Western Australia Department of Fisheries

FRDC Fisheries Research & Development Corporation

WAFIC

Australian Government Department of the Environment Australian Antarctic Division

PARKS AND WILDLIFE

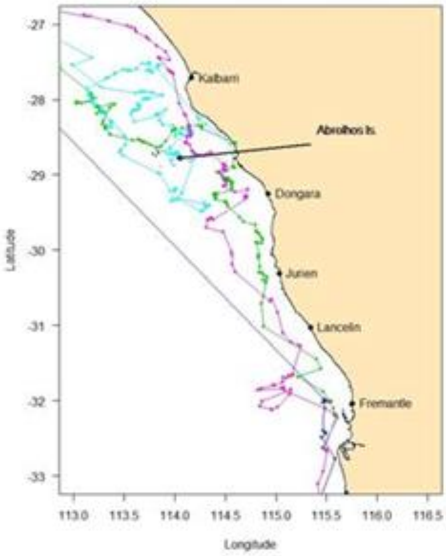
Western Rock Lobster Council Inc.

Appendix 8

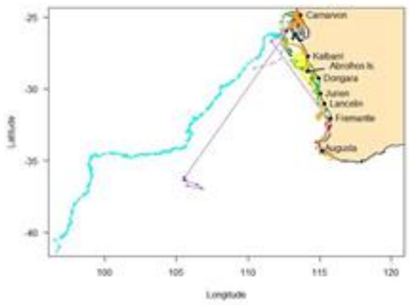
Satellite Tracking Handout for Whale Watching Vessels (Augusta)

Satellite tracking of humpback whales (*Megaptera novaeangliae*) in Western Australia

Since 2010, there has been an increase in whale entanglement reported off the Western Australian coast. The majority of entanglements have involved humpback whales (Megaptera novaeangliae). The rise in entanglements prompted governments to respond by assessing and implementing measures to reduce the entanglement rate. These entanglements have primarily occurred with western rock lobster fishing gear though other fisheries have also been involved. The increase has been driven by an increasing humpback whale population overlapping fishing grounds and seasons.



Currently little is known of the migration of humpback whales off the WA coast. To better understand the migration, the Department of Fisheries WA in conjunction with the Australian Antarctic Division are satellite tagging humpback whales to track them on their migration off the WA coast. Whale tagged if Carnarvon in September 2014 provided spatial data on the southern migratory pathways and tagging to investigate the northern migration is occurring off Augusta in June 2015.



Government of Western Australia Department of Fisheries
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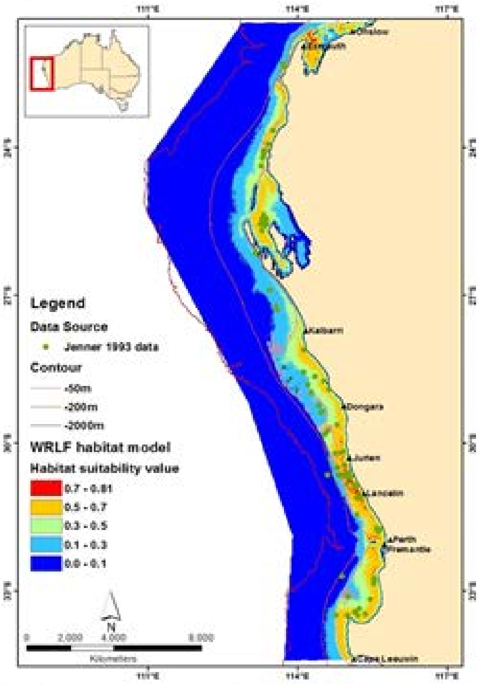
FRDC
Australian Government Department of the Environment Australian Antarctic Division
Western Rock Lobster Council Inc.
WAFIC

Whale Surveyors Needed

In order to determine the location of the humpback whale migration, the Department of Fisheries in collaboration with its research partners are undertaking a range of research initiatives. A spatial model has been developed to allow the combination of data to establish where the main areas of use are for migrating humpbacks (see example below). The spatial model will be the major research tool used to inform how fishing gear modifications may be structured by depth etc. This model is currently based on a historical survey from 1993, and incorporates both the northern and southern migrations in the one model. More recent data is being included into the model, however, to better understand how the migration changes between the northern and southern migration and also between years, we require the assistance of all water users.



Spatial model of whale habitat suitability

With both commercial fishers and the general public being on the water during the migration time, we are asking you to log all whale sightings while you are out on the water. By following the instructions overleaf, and the use of the whale sightings app, this should provide an easy and accurate way to record your sightings. This is an opportunity to generate a large, current and robust data set which can be incorporated into the model. This can then provide greater certainty when determining any management changes involving either the timing or the location of the whale migrations.

By participating in this program, you will doing your part for whale conservation and be helping with the management of this large charismatic species. If you are interested, please download the app and follow the instructions overleaf and start logging your whale sightings

Search "Whale Sightings WA" from the iTunes store
https://itunes.apple.com/au/app/whale-sightings-wa/id897799081?mt=8

1. Create a report which launches the report page (❸)
2. Select species from the species list (❹). You can tap on the ⓘ icon for more information about the species
3. Choose the behaviour from the drop down list that best reflects what the whales are doing (❺).
4. Enter the number of adults and calves (calves are less than half the size of an adult) (❻)
5. Select 'Use current location' (❼)
6. Press submit (❾)
7. Repeat for each pod

Appendix 9

Progress against gear modification options identified by Lunow et al 2013 pertinent to Western Rock Lobster Fishers

Mitigation options identified during an industry workshop (Lunow et al 2013), and subsequently (*Use of acoustic pingers*) with the progress against each option; incorporated into current management (green), in progress / partially addressed (blue), assessed and deemed an unsuitable option (red) or not addressed (black)

Mitigation Option	
No effect on whale entanglement rates of subsequent disentanglement	
Take humpback whales off endangered species list	Recent publications has highlighted the status of the humpback whale population in Australia (Ross-Gillespie et al., 2014) and worldwide (Bettridge et al., 2015).
WAFIC undertake a public whale education program	Not Addressed
Options to increase the number of disentanglements	
Government funded increase in the number of disentanglement teams along the coast	DPaW has undertaken additional training of regional staff to respond to whale entanglements throughout the state.
Tracking identified entangled whales using GPS or other tagging equipment to help locate whales after being reported	A project funded by the Dept of the Environment has developed an entanglement tracking buoy which will be provided to entanglement teams along the coast to increase the capacity to locate entangled whales after reporting
Closures to reduce whale entanglement rates	
Spatial controls (i.e. limit fishing to inside 20 fathoms during migration period, or other depth closures)	**[Part of the current mitigation management measures]** Spatial controls have been incorporated with no gear modifications required in waters generally less than 20 m
Seasonal closure during peak migration (i.e. June - July for northern and October for southern migration)	This option would reduce the number of whale entanglements, though would also be at a significant cost to the industry (~$100 million) and as such it is not a suitable option while other mitigation options are proving effective
Reduction in number of vertical lines in the water column	
Removal or adjustment of maximum size limit and or setose rule	The maximum size limit for females was removed in 2015, with several trials of setose retention occurring from 2014-2016
Pot reduction during peak whale migration times	**[Part of the current mitigation management measures]** Fishers are only able to fish 50% of their entitlement

Remove gear from the ocean if not being used for a while (i.e. >7 days)	**[Part of the current mitigation management measures]** Fishers fishing in waters generally greater than 20 m are required to attend their gear at least every seven days or remove it from the water
Multiple pots on each line to reduce the number of float lines in the water	This has always been permitted as part of the regulations and management plan of the West Coast Rock Lobster Managed Fishery
Deregulate pot size and number (promotes catching efficiency and therefore reducing time pots and lines are in the water)	The regulations around pot construction have recently been simplified resulting in pot dimensions which result in an overall volume increase of approximately 14%.
Gear modifications to reduce whale entanglement rates or subsequent disentanglement	
Using sectional ropes (to remove slack in float lines)	**[Part of the current mitigation management measures]** The amount of rope that can be used is restricted according to water depth. The fishers current use of sectional ropes permits easy adherence to this regulation
Reduced the number of floats on a float line in Winter (fewer but larger floats)	**[Part of the current mitigation management measures]** Fishers are only able to fish with a maximum of three floats, and a maximum of two floats in waters less than 54.4 m (30 fathoms)
Using sinking rope/line between pots/traps and for float/lead-line	**[Part of the current mitigation management measures]** Rope is to be held vertical in the water column with no surface rope for fishing in waters greater than 20 m. This has been widely achieved by fishers through the use of sinking rope in their line between the pot and floats
Using bio-degradable ropes	These were examined as part of How et al. 2015 but were not examined further as sufficient work has not been undertaken on the degrading times and how this would be affected by 'working' the rope. This is an option which could be used in the future but additional trials would be required.
Use of remote float releases such as acoustic releases or anode timed releases	These were assessed as part of How et al. 2015 and deemed an expensive and impractical option for the WRLF
"Dog and bone" slack in float lines	
Weak link in lead-line to allow it to break if an entanglement is about to occur	These were assessed as part of How et al. 2015 and deemed an expensive and impractical option for the WRLF
Use of acoustic pingers	These were assessed as part of How et al. 2015 and in this current study and unsuitable for the WRLF
Miscellaneous	
Code of Practice renewal and upgrading if required, following workshop and industry extension	Multiple codes of practices have been produce as part of this project in conjunction with the WRLC to ensure they remain up to date
Gear modifications only during migration period	**[Part of the current mitigation management measures]** Gear modifications are only required during the whale migration (1 May – 31 October)

Appendix 10

Agostinelli C, Lund U. 2013. R package “circular”: Circular Statistics (version 0.4-7). .

Bannister JL, Kemper C., Warneke RM. 1996. The Action Plan for Australian Cetaceans. .

Bejder M, Johnston DW, Smith J, Friedlaender A, Bejder L. 2015. Embracing conservation success of recovering humpback whale populations: Evaluating the case for downlisting their conservation status in Australia. Marine Policy 1999: 1–5.

Bellchambers LM, How J, Evans S, Pember M, Lestang S De, Caputi N. 2017. Resource Assessment Report Western Rock Lobster Environmental Resources of Western Australia.

Bettridge S, Baker CS, Barlow J, Clapham P, Ford M, Gouveia D, Mattila DK, Pace RM, Rosel PE, Silber GK, Wade PR. 2015. Status review of the the Humpback whale (Megaptera novaeangliae) under the endangered specied act. 263.

Brown MR, Corkeron PJ, Hale PT, Schultz KW, Bryden MM. 1995. Evidence for a sex-segregated migration in the humpback whale (Megaptera novaeangliae). Proceedings. Biological sciences / The Royal Society 259: 229–34.

Caputi N. 2008. Impact of the Leeuwin Current on the spatial distribution of the puerulus settlement of the western rock lobster (Panulirus cygnus) and implications for the fishery of Western Australia. Fisheries Oceanography 17: 147–152.

Caputi N, Fletcher WJ, Pearce A, Chubb CF. 1996. Effect of the Leeuwin Current on the Recruitment of Fish and Invertebrates along the Western Australian Coast. Marine and Freshwater Research 47: 147.

Chittleborough R. 1965. Dynamics of two populations of the humpback whale. megaptera no vaeangliae (borowski). Australian Journal of Marine and Freshwater Research 1964: 33–128.

Department of Parks and Wildlife. 2013. Lalang-garram / Camden Sound Marine Park Management Plan 73 2013–2023. .

Double MC, Ball I, Childerhouse S, Laverick S, Gales N, Marine A, Centre M, Division AA. 2012a. Satellite tracking of northbound humpback whales (Megaptera novaeangliae) off Western Australia. .

Double MC, Ball I, Childerhouse S, Laverick S, Gales N, Marine A, Centre M, Division AA. 2012b. Satellite tracking of northbound humpback whales (Megaptera novaeangliae) off Western Australia. 23.

Double MC, Gales N, Jenner KCS, Jenner MM. 2010. Satellite tracking of south-bound female humpback whales in the Kimberley region of Western Australia Final Report. .

Eisenmann P, Fry B, Holyoake C, Coughran D, Nicol S, Bengtson Nash S. 2016. Isotopic evidence of a wide spectrum of feeding strategies in Southern hemisphere humpback whale baleen records. PLoS ONE 11: 1–20.

Elith J, Kearney M, Phillips SJ. 2010. The art of modelling range-shifting species. Methods in Ecology and Evolution 1: 330–342.

Elith J, Phillips SJ, Hastie T, Dudı´k M, Chee YE, Yates CJ. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17: 43–57.

Erbe C, McPherson C, Craven A. 2011a. Acoustic characteriszation of pingers on Queensland shark control nets. Journal of the Acoustical Society of America 129: 2369–2369.

Erbe C, McPherson C, Craven A. 2011b. Acoustic investigation of bycatch mitigation pingers. Technical Report for the Australian Marine Mammal Centre .

Erbe C, McPherson C, Craven A. 2011c. Acoustic characterization of pingers on Queensland Shark Control nets.

Erbe C, Reichmuth C, Cunningham K, Lucke K, Dooling R. 2016. Communication masking in marine mammals: A review and research strategy. Marine Pollution Bulletin 103: 15–38.

Ersts PJ, Rosenbaum HC. 2003. Habitat preference reflects social organization of humpback whales (Megaptera novaeangliae) on a wintering ground. Journal of Zoology 260: 337–345.

Feng M, McPhaden MJ, Xie S-P, Hafner J. 2013. La Nina forced unprecedented Leeuwin Current warming in 2011. Scientific Reports 1277: 1–9.

Freitas C, Lydersen C, Fedak MA, Kovacs KM. 2008. A simple new algorithm to filter marine mammal Argos locations. Marine Mammal Science 24: 315–325.

Gales N, Double MC, Robinson S, Jenner C, King E, Gedamke J, Paton D, Raymond B. 2009. Satellite tracking of southbound East Australian humpback whales (*Megaptera novaeangliae*): challenging the feast or famine model for migrating whales. Paper SC61/SH/17 presented at the IWC scientific committee. Portugal, Madeira 1–11.

Groom CJ, Coughran DK. 2012a. Entanglements of baleen whales off the coast of Western Australia between 1982 and 2010 : patterns of occurrence , outcomes and management responses. Pacific Conservation Biology 18: 203–214.

Groom CJ, Coughran DK. 2012b. Entanglements of baleen whales off the coast of Western Australia between 1982 and 2010: Patterns of occurrence, outcomes and management responses. Pacific Conservation Biology 18: 203–214.

Harcourt R, Pirotta V, Heller G, Peddemors V, Slip D. 2014. A whale alarm fails to deter migrating humpback whales: an empirical test. Endangered Species Research 25: 35–42.

Hedley SL, Bannister JL, Bravington M, Double MC, Du Fresne S, Hodgson AJ, Salgado Kent C, Smith JN. 2012. Survey plans to estimate absolute abundance of Breeding Stock D humpback whales off Western Australia . Paper to the International Whaling Commision 1–10.

How J, Coughran DK, Smith JN, Harrison J, Mc Math J, Hebiton B, Denham A. 2015. Effectiveness of mitigation measures to reduce interactions between commercial fishing gear and whales. FRDC Project No 2013/03.

Hutchins JB, Pearce A. 1994. Influence of the Leeuwin Current on Recruitment of Tropical Reef Fishes at Rottnest Island, Western Australia. Bulletin of Marine Science 54: 245–255.

Jenner KCS, Jenner M-NM, Mccabe KA. 2001a. Geographical and temporal movements of humpback whales in western australian waters. Appea Journal 749–765.

Jenner KCS, Jenner MM, McCabe KA. 2001b. Geographical and temporal movements of humpback whales in Western Australian waters. Appea Journal 2001: 749–765.

Johnston DW, Chapla ME, Williams LE, Mattila DK. 2007. Identification of humpback whale Megaptera novaeangliae wintering habitat in the Northwestern Hawaiian Islands using spatial habitat modelling. Endangered Species Research 3: 249–257.

Lavigne DM, Innes S, Worthy GAJ, Edwards EF. 1990. Lower critical temperatures of blue whales, Balaenoptera musculus. Journal of Theoretical Biology 144: 249–257.

Lien J, Barney W, Todd S, Seton R, Guzzwell J. 1992. Effects of Adding Sounds to Cod Traps on the Probability of Collisions by Humpback Whales. In: J Thomas, R Kastelein, and A Supin, editor. Marine Mammal Sensory Systems Springer US. p. 701–708.

Lunow CP, Tucek M, Harrison J. 2013. Western Australian Fishing Industry Council Inc. and Western Rock Lobster Council Inc., Western Rock Lobster Fishery and Developmental Octopus Fishery Whale Interaction Mitigation Workshop, 12 February 2013, Hillary's Research Centre. .

McConnell BJ, Chambers C, Fedak MA. 1992. Foraging Ecology of Southern Elephant Seals in Relation to the Bathymetry and Productivity of the Southern-Ocean. Antarctic Science 4: 393–398.

Merow C, Smith M, Silander J. 2013. A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 1058–1069.

Noad MJ, Cato DH. 2007. Swimming speeds of singing and non-singing humpback whales during migration. Marine Mammal Science 23: 481–495.

Patterson T, McConnell BJ, Fedak MA, Barvington M, Hindell M. 2010. Using GPS data to evaluate the accuracy of state-space methods for correction of Argos satellite telemetry error. Ecology Letters 91: 273–285.

Paxton C, Hedley SL, Bannister JL. 2011. Group IV humpback whales: their status from aerial and landbased surveys off Western Australia, 2005. Journal of Cetacean Research Management Special Issue 3: 223–234.

Pearce A. 1991. Eastern boundary currents of the Southern Hemisphere. Journal of the Royal Society of Western Australia 74: 35–45.

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259.

Pirotta V, Slip D, Jonsen ID, Peddemors VM, Cato DH, Ross G, Harcourt R. 2016. Migrating humpback whales show no detectable response to whale alarms off Sydney, Australia. Endangered Species Research 29: 201–209.

Plomp R, Bouman M. 1959. Relation between hearing threshold and duration for tone pulses. Journal of the Acoustical Society of America1 31: 749–758.

R Core Team. 2016. R: A language and environment for statistical computing. .

Rugh DJ, Shelden KEW, Schulman-Janiger A. 2001. Timing of the gray whale southbound migration. (Eschrichtius robustus). Journal of Cetacean Research and Management 3: 31–39.

Salgado C, Burton C, Marley S, Kniest E. 2014. /////////. .

Salgado Kent C, Jenner C, Jenner M, Bouchet P, Rexstad E. 2012. Southern Hemisphere Breeding Stock D humpback whale population estimates from North West Cape , Western Australia. Journal of Cetacean Research Management 12: 29–38.

Smith JN, Grantham HS, Gales N, Double MC, Noad MJ, Paton D. 2012. Identification of humpback whale breeding and calving habitat in the Great Barrier Reef. Marine Ecology Progress Series 447: 259–272.

Stamation K a., Croft DB, Shaughnessy PD, Waples K a. 2007. Observations of Humpback Whales (<I>Megaptera novaeangliae</I>) Feeding During Their Southward Migration Along the Coast of Southeastern New South Wales, Australia: Identification of a Possible Supplemental Feeding Ground. Aquatic Mammals 33: 165–174.

Sun C, Feng M, Matear RJ, Chamberlain MA, Craig P, Ridgway KR, Schiller A. 2012. Marine Downscaling of a Future Climate Scenario for Australian Boundary Currents. Journal of Climate 2947–2962.

Todd S, Lien J, Verhulst A. 1992. Orientation of humpback whales (Megaptera novaeangliea) and minke whales (Balaenoptera acusorostrata) to acoustic alarm devices deigned to reduce entrapment in fishing gear. Marine Mammal Sensory Systems 727–739.

Todd SK. 1991. Acoustical properties of fishing gear: possible relationships to baleen whale entrapment. Memorial University of Newfoundland, St. John’s.

Tougaard J, Wright AJ, Madsen P. 2015. Cetacean noise criteria revisited in the light of proposed exposure limits for harbour porpoises. Marine Pollution Bulletin2 90: 196–208.

Whiteway TG. 2009. Australian Bathymetry and Topography Grid. .

Wright DJ, Pendleton M, Boulware J, Walbridge S, Gerlt B, Eslinger D, Sampson D, Huntley E. 2012. ArcGIS Benthic Terrain Modeler. .