Chapter 3: Monitoring of humpback whales *(Megaptera novaeangliae)* at Pender Bay, south Kimberley region

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Executive Summary

Humpback whales (*Megaptera novaeangliae*) migrate annually along the coast of Western Australia (WA) from their summer Antarctic feeding grounds to warm tropical waters in the Kimberley for breeding (Jenner et al 2001). While the population has been increasing in size since the cessation of whaling in Western Australian waters by 1963, it is important that we have a good understanding of their habitat use, in particular in critical areas, for their long term sustainable management. Key sites have been identified as important breeding grounds and high use areas for humpback whales in the Kimberley including Camden Sound, Tasmanian Shoals/Buccaneer Archipelago and Pender Bay (Jenner et al 2001, Jenner et al 2014). The Lalang-garram/Camden Sound Marine Park, including several sanctuary zones specific to humpback whales, was established in 2012 by the WA State Government largely in recognition of this (Department of Parks and Wildlife, 2013).

Given the remote nature of the Kimberley marine environment and the very large range of humpback whales across known breeding and resting areas, it can be difficult to gather sufficient data to assess their distribution and to monitor population health. A four year project underway at Two Moons Whale and Marine Research Base at Pender Bay, WA (McKay and Thiele 2008, Blake and Dapson 2011) offered an opportunity to assess the value of using a land based site manned by volunteers as a cost effective means of gathering suitable data. The purpose of this project was to evaluate the data collection methods used at this research station, extend data collection for an additional year and evaluate the 5 year dataset to understand humpback whale use of Pender Bay.

The data collection methods were evaluated and amended slightly for the whale migration season in 2013 and an appropriate field manual and training material prepared. A team field leader coordinated data collection by a group of volunteers from 1 July 2013 – 10 October 2013. Data collection included counts of all humpback whale groups (noting size and presence of calves) observed at 20 minute intervals from a cliff top viewing platform. Additional information was recorded on environmental variables (tide, sea state, weather) and the presence of vessels. These data were evaluated to assess the timing of the migration season, including peak in the number of individuals and the number of calves across the season and the distribution of whales within the Bay and adjacent waters.

Overall a total of 3,695 groups of whales (5,521 individuals) were sighted over the 88 days when observations took place throughout the season. Calves were observed in 187 of these groups. While the peak in number of groups with calves occurred in mid August to September, there was a higher proportion of groups with calves early in the season. This may indicate that calves were being born near Pender Bay, however this has not been further explored. Whales were sighted between 400m and up to 15 km from shore, however were most commonly sighted at 3-4km from shore, potentially in association with particular water depths or benthic features, though more data would be needed to evaluate this. Both observer and environmental variables were found to have an effect on the number of whales detected in each scan. For example, more whales were detected when 4 observers were present than when there were fewer observers. Similarly, more whales were detected when visibility was better (ie based on sea state and weather).

Implications for management

Land based viewing platforms can provide a cost effective means of acquiring data on whales that can be used for management and other purposes. Most important though is to have a clear question in mind and to ensure that the data that can be collected can meet this purpose. The land based site at Two Moons Whale Research Base can be used to collect data that will inform regional managers about the timing of the humpback whale migration season, as this can vary annually, including the timing and density of mother and calf groups. It can also be used as an indicator of the extent of use of Pender Bay by humpback whales, including changes in timing and whale density throughout the migration season.

The modifications to the sampling design and methodology led to additional information (animal general location and distance from shore), better temporal distribution of data across the day and reduced observer fatigue. While this information cannot be used to calculate humpback whale abundance in the Kimberley, it can give a relative understanding of the use of Pender Bay and of the timing of the annual migration season which can vary slightly each year.

Products and Tools

This project has produced a field manual describing the methodology for land observations at Two Moons Whale and Marine Research Base. It has also produced a set of presentation slides to be used in conjunction with the manual for training volunteers. These tools would be useful for interaction with community groups as well as volunteer groups that would participate in a cliff-based survey of whale distribution.

Key residual knowledge gaps

Additional research would be useful that could link the relative abundance and density of humpback whales sited at Pender Bay with the broader Kimberley so that this land based site could be used as an indicator of population health across the broader region. Other specific research projects that would add value to our understanding of whale use of Pender Bay would include assessing whale distribution in relation to water depths or bottom features in the vicinity of Pender Bay and experimentally testing the effect of some of the environmental and observer variables including sea state, number of observers and observer experience, so that these could be accounted for in a standardized methodology and analysis.

1 Introduction

The population of humpback whales (*Megaptera novaeangliae*) known as Group IV migrate annually from Antarctic feeding grounds in the summer months, along the coast of Western Australia to warm tropical waters in the Kimberley for breeding (Jenner et al 2001). The population has been increasing in size at a rate of approximately 10% per annum since the cessation of whaling in Western Australian waters by 1963, however has not yet fully recovered. It is important for the long term sustainable management of this species to ensure we have a good understanding of their use of habitat in Western Australia as the population continues to grow. This is particularly important for the north western waters identified as important breeding and resting areas. Jenner et al (2001) identified three areas of high use by humpback whales in the Kimberley breeding grounds, including Camden Sound, Tasmanian Shoals/Buccaneer Archipelago and Pender Bay. More recent surveys have confirmed that these areas continue to be of primary importance to this increasing population (Jenner et al 2014) and noted that behaviours recorded at these sites were consistent with these areas being used for resting and nursing.

The establishment of the Lalang-garram/Camden Sound Marine Park in 2012 by the WA State Government was largely in recognition of the importance of the area as a key breeding ground for the Group IV Humpback Whale population at the northern extent of their annual migration (Department of Parks and Wildlife, 2013). In particular, four Marine Park zones have been created to minimise disturbance to whale mothers and calves in the area: Camden Sound Special Purpose Zone (Whale Conservation); Montgomery Reef Sanctuary Zone; Champagny Sanctuary Zone and the adjoining western Shoals General Use Zone. It should be noted however, that the area south of the Lalang-garram/Camden Sound Marine Park remains unprotected and yet is a very important region for this species, especially the region around Pender Bay.

It is widely reported that the Group IV population of humpback whales is the largest natural breeding population in the world with current estimates of more than 20,000 (Hedley et al., 2011; Salgado Kent et al., 2012). As the population continues to increase towards its pre-whaling estimates, questions arise as to the carrying capacity of the region and the importance of known staging areas such as Pender Bay, just south of the Camden Sound region.

Whilst humpback whale surveys have been undertaken in the Kimberley region over the past two decades, there is very little publicly-available data on the population size and the use of the region for calving, mating and resting. To date research has mainly been industry led and thus site specific. There has not been a regional assessment of habitat use by humpback whales across the Kimberley nor have potential correlations between relative annual and inter-annual whale abundances and geographic spread with major climate and oceanographic drivers been explored. Given the anthropogenic pressures of increased activity from the resource sector and tourism in the Kimberley combined with a warming ocean from climate change and changes to primary productivity, it is important to have a strong understanding of the critical habitat for this species and changes in their patterns of distribution and habitat use across the Kimberley. The remote nature of the Kimberley coupled with the wide-scale distribution of whales across available habitat make establishing a cost effective program for long term monitoring a priority. Land based observations can provide a useful and cost effective tool for specific research and monitoring questions where appropriate sites exist.

A study was initiated in 2006 from a land based research station, Two Moons Whale and Marine Research Base, run by the Goojarr Goonyool Aboriginal Corporation (GGAC), to better understand humpback whale use of Pender Bay (McKay and Thiele 2008). While the research project was not able to continue beyond 2008, the GGAC contacted the Western Australian Marine Science Institution (WAMSI) to develop a joint ongoing monitoring and research program between the local aboriginal community and WAMSI. This partnership relied on WAMSI to provide scientific advice and leadership for the annual field work and Two Moons Whale and Marine Research Base to provide volunteer support. WAMSI continued the collaboration with the GGAC from 2009-2013 with the intent to use the “citizen science” research at Two Moons Whale and Marine Research Base to examine factors influencing the timing and use of Pender Bay by humpback whales (Blake et al 2011;

Blake and Dapson 2013). A land based site offers the potential for a unique and cost effective means of monitoring this population over the long term in light of important anthropogenic and natural pressures on this recovering species (Coughran et al., 2013). In particular, community monitoring programs offer a low cost means of capturing important information for management while also building conservation interests and skills in the community.

The main aim of this WAMSI project is to complete a 5 year dataset for the community program that can be evaluated to assess the effectiveness of this land based program for monitoring humpback whales. This project is a subset within the broader WAMSI project 1.2.1a which is evaluating humpback whale use of the Kimberley and exploring suitable cost effective techniques for detecting trends over time.

The specific objectives for this subproject were to use data collection and analysis in 2013 to:

- Estimate the relative abundance of humpback whales using Pender Bay;
- Investigate the distribution of humpback whales in Pender Bay in relation to other variables;
- Estimate relative proportion of adult females and calves and the timing of their use of Pender Bay; and
- Evaluate the methods and protocol for producing useful monitoring information in humpback whales in Pender Bay and the Kimberley, more broadly.

2 Materials and Methods

2.1 Study Area

The study was undertaken at Pender Bay, an open embayment at the northern end of Dampier Peninsula located north of Broome in the Kimberley region of WA (122°38'E 16°45'S). The embayment is typically 12-15 m deep with gently sloping seafloor and freshwater input mainly during the wet season (Blake and Dapson 2013). The extreme tidal range of the Kimberley is evident here, with a tidal range within the bay of up to 9m during spring tides. The Two Moons Whale and Marine Research Base serves as the base camp for the field research team and is situated 1km from the field observation site. Field observations were conducted from a cliff top 34m above MSL at the southern end of Pender Bay, (122°36.546’ E 16°45.939’ S). This site offers a 190º visibility including panoramic views of Pender Bay with observers recording whale sightings up to 8 km offshore (Figure 1). Facilities at the field site include a cement pad for observers to stand during observation periods and a caravan with windows along the ocean facing side and ends to provide shelter during field observations.

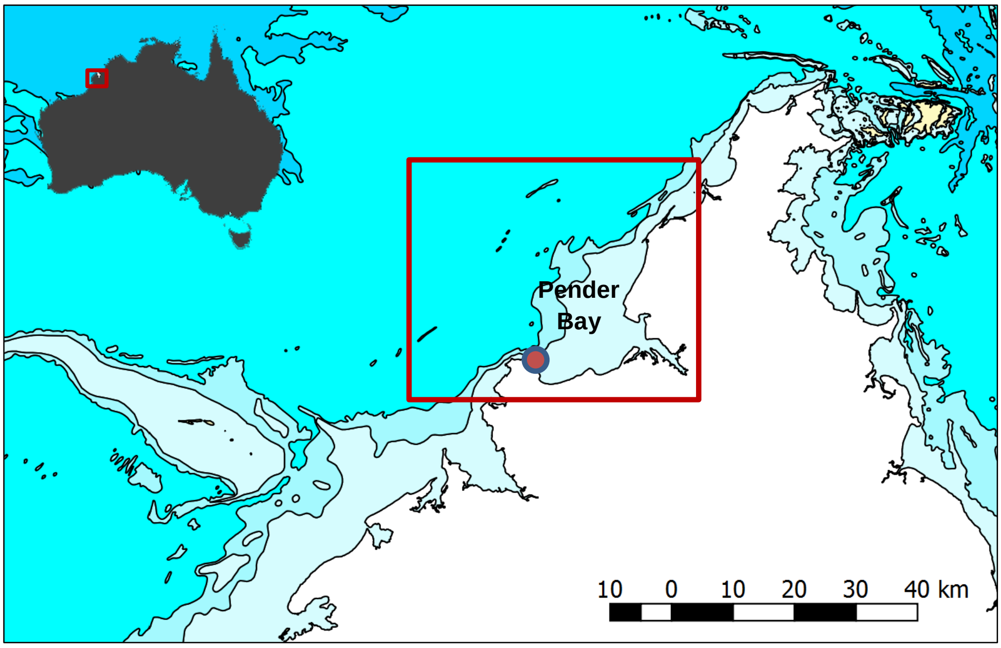

Figure 1. Location of Pender Bay (demarcated with a red square) and land-based observation location (red circle), within the Kimberley region in northwestern Australia.

2.2 Data collection

Data were collected each whale migration season for four years from 2009 to 2012 using the field methodology described by Blake et al (2011). The methodology was reviewed for the 2013 field season by the project team and, while the same basic methodology, comprising visual counts of whales within the study area was used, minor changes were made to enhance data collection and analysis. The field season for 2013 was conducted from 30 June to 10 October 2013. The research team consisted of a lead scientist and between one and four additional volunteer observers. The lead scientist was recruited from the marine science community, and was chosen based on experience with remote field work, team leadership and marine mammal research. Two Moons Whale and Marine Research Base provided the additional volunteers, the majority of whom were interested international travelers and/or local community members. Curtin University provided training of the lead scientist in the research protocol and field work expectations. It was then the role of the lead scientist to train all volunteers and establish a daily field observation schedule. The lead scientist was also responsible for overseeing the volunteers during observations and recording all data into a purpose designed data entry spreadsheet. A Field Training Manual and powerpoint presentation for volunteers was developed by the project team and provided to the lead scientist and all volunteers (Appendix 1). Blake et al (2011) and the Field Training Manual provides specific detail on the conduct of field observations, however a summary is provided below, in particular noting where changes were made in field methodology for the 2013 field season.

Sampling was stratified into morning (07:00 to 12:00) and afternoon observations (13:00 to 17:00). To manage observer fatigue only a morning or an afternoon shift was conducted in a given day and this was determined on a random allocation basis to ensure that over a 7 day period 3 morning and 3 afternoon sessions were conducted. This is a change to previous years where observations were typically undertaken each morning with afternoon sessions included only occasionally throughout the season.

During the field observation sessions the field team recorded the number of whales observed in the study site over a 5 minute period at 20 minute scan intervals. This is a slight deviation to previous years' data which was collected using 5 minute scans every 15 minutes. Reticule binoculars (rather than standard binoculars used in previous years) were used by observers to locate whales and to record information on estimated distance and compass bearing. The binoculars used had a set of vertical reticule lines that could be used to determine distance by aligning the cross-hairs with the point on the whale at the water surface. The observer then counted the number of horizontal lines from that point to the horizon (Figure 2). This information was used to calculate the position of the whale.

Scanning effort was divided depending on the number of observers present (Figure 3). These divisions are slightly different to those used in previous years and were based on dividing up the study area into shore to horizon viewing by each observer with the size of their section depending on the number of observers available. Double counting of whales was minimised by observers talking to each other to identify any overlap near the boundaries of their respective sections and by the team leader who had oversight of the full survey area and could resolve any doubts on overlap.

During the scan sample periods all observers were stationed on the cement pad in accordance with their section to view. Observers began scanning their respective sections and called out the following information when a new whale was sighted:

- ’cue observed’ (behaviour);
- number in group;
- if there was a calf in the group;
- distance (reticules down from the horizon); and
- bearing.

This information was entered by the lead scientist into a spreadsheet along with other data on presence of vessels in the area, and a range of environmental conditions: beaufort (sea state), wind speed (km, wind direction, glare (score 0-3; 3 being severe), cloud cover (8ths), visibility (km), ambient temp. (˚c), wind direction (deg), humidity (%), pressure (hpa), solar radiation, rainfall (mm), dew (deg c) and tidal height (m).

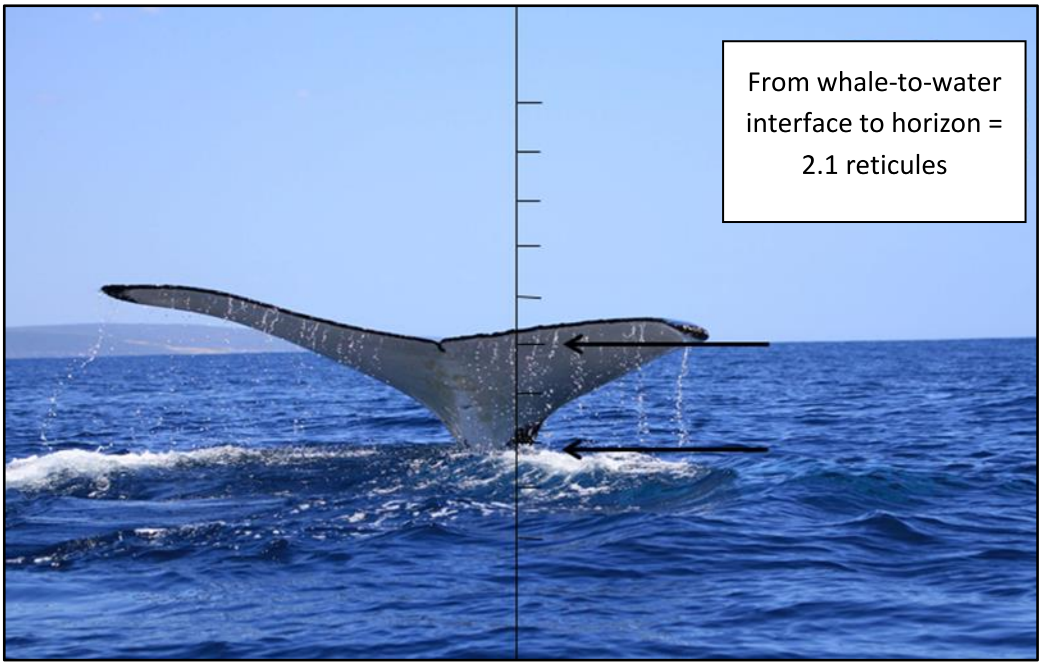

Figure 2. View of reticule cross hairs in the binocular field of view used to estimate distance the distance between the observer and the whale.

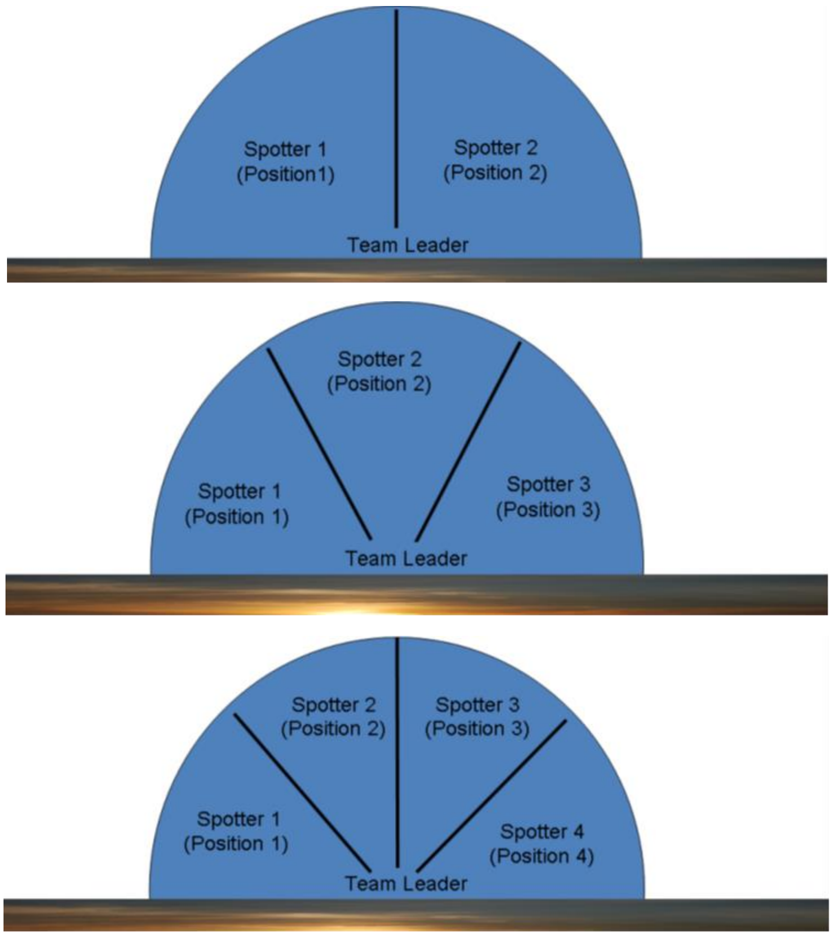

Figure 3. Example of teams with two, three, and four spotters, respectively.

2.3 Data analysis

Data were analysed to estimate the duration of the 2013 humpback whale breeding season, and the intensity of use of Pender Bay by whales, including cow-calf pairs. Observations from the first two weeks of July differed from the rest of the season as they only included estimated distance and angle measurements by eye (rather than reticule binoculars) associated with the whale sighting records. This period also consisted of a 'training' period. Thus, the broad overview of trends presented in the results include the first two weeks of the study (30^{th} June to 14 July) in the dataset, however detailed cow-calf pairs and distributional information presented in the results exclude the first two weeks of the season.

Summary statistics were determined, including the number of whale groups and individual animals sighted across the entire period, and the mean number of total groups, groups of different sizes and groups with cow-calf pairs sighted per day. Since the duration of residency of whales is unknown, and counts were made every 20 min, sightings included recounts of groups and/or individuals observed in different scan samples. Hence, 'intensity of use' of Pender Bay is reflected by relative numbers counted during a scan sample (and not the total over a day). For this reason, the number of sightings are summarised briefly at the beginning of the results, however emphasis is placed on mean relative numbers observed in 5-min scan samples.

The effect of weather conditions and survey team number (explanatory variables) on the number of whale groups (response variable) observed was assessed. The effects of time (days) over the migratory season, sea state (Beaufort condition), glare, cloud cover, and the number of observers (which varied between 1 and 4 observers) on the number of whale groups sighted were modelled as all of these variables can potentially change the visibility and therefore the detection of whales. The association between the response variable, whale group counts, with explanatory variables listed above was assessed using a log-link functions (for poisson distributed data) applied to Generalized Estimation Equations (GEE) using R (R 3.1.1, Core Team, 2013) run through RStudio (Version 0.98.501, © 2009-2013 RStudio, Inc.). A CReSS-GEE (Scott-Hayward et al., 2013a) framework was used to estimate smooth terms in the models for fitting to GEEs, since a linear fit was not expected for all explanatory variables. The packages MRSea (Scott-Hayward et al., 2013b) and geepack (Yan, 2002) were used for fitting smoothed explanatory variables to GEEs. Smoothness of covariates was selected using the function 'runSALSA1D' in the MRSea package. GEEs were used since residuals were temporally autocorrelated (Staley, 2013). The longitudinal order of the data (needed to define the autocorrelation structure in the model) was defined by a vector of the day and time in which the observations were recorded, which was expressed as 'decimal day'. Values for the vector ranged sequentially from 1 to the last date of the survey period. All models (and submodels) were run with AR-1, independent and exchangeable correlation structures, and compared using Quasi Likelihood Information Criteria (Pan, 2001). All resulting QIC were the same, therefore, AR-1 was selected since the data were time ordered (Zuur et al., 2009). The time-block used for clusters in the models (ID) was selected by identifying the period of time in which residuals autocorrelated approximated zero. The result was that single day blocks were defined as Clusters.

Explanatory variables were first explored by plotting these to ensure that there was a robust spread of samples taken over the range of values. At the extreme ends of the Beaufort and Glare scales, the number of samples were few (<20), hence the data were subset to exclude extreme values represented by few observations. This resulted in no more than four possible values for each of these scales. As a result these ordered categorical variables were treated as factors. Also, interactions were not included since many of the interaction levels had few observations (<20). Time (days) was the only covariate found to be fit best with a smooth term. Cloud cover was modelled as a linear term. Covariates were plotted against each other and Variance Inflation Factors (VIFs) were calculated to ensure that none were collinear (VIF < 3; Zuur et al., 2009). For model selection, the data were first fit to a full model, then insignificant explanatory terms were removed one by one. Each time an explanatory term was removed, the data were refitted and the submodel validated. For model validation, observed vs fitted values and fitted values vs scaled Pearson's residuals to assess the mean-variance relationship were plotted. The best submodel was selected by comparing QICu of all submodels (Hudecová & Pešta, 2013) .

Assessment was also made of the relative use of Pender Bay in conjunction with sea surface temperature (SST).

3 Results

3.1 Effort

Between 30 June and 10 October 2013, surveys were conducted on 88 days; 44 during the morning and 44 during the afternoon. The number of scan samples obtained over this period was 1148, with a maximum of 16 and minimum of one scan during a single day.

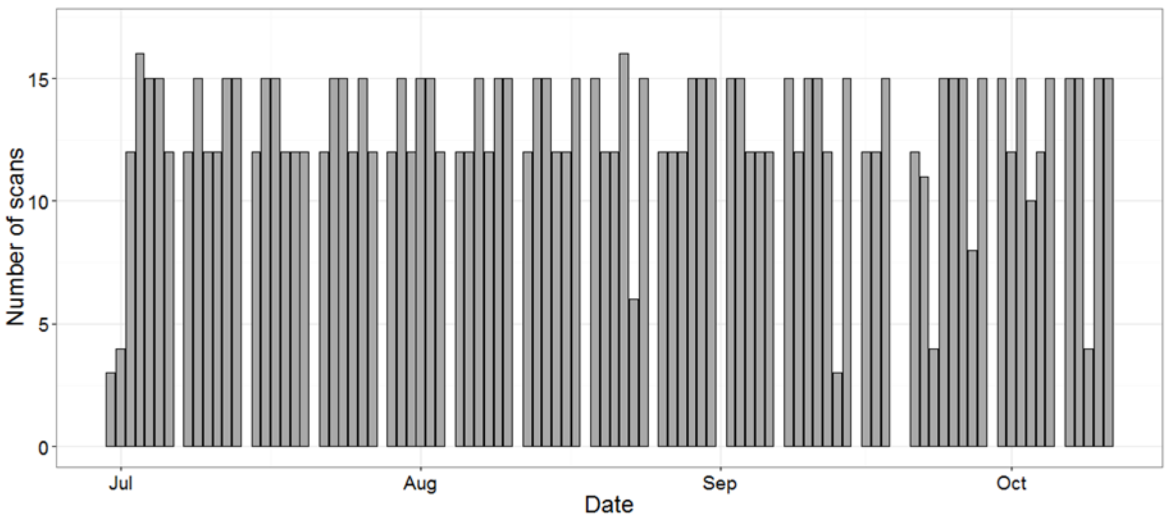

Figure 4. Total number of scans undertaken between end-June and mid-October, 2013.

Reticule binoculars were used from the 17th of July until the end of the survey season during a total of 925 scans. The maximum number of 5-minute scans in one day during this period was 16, and the minimum was one scan. Most often, the number of scans was either 12 or 15 in a day which typically related to whether the observation period was a morning (5 hour) or afternoon (4 hour) session.

3.2 Sightings

A total of 3695 group sightings, including 5521 individual whales, were made across all 5-min scans throughout the season (Table 1). Of these, 187 groups contained a cow-calf pair, and one group contained two cow-calf pairs. It should be noted that sightings include recounts of groups and/or individuals observed in different scan samples. A minimum of 0 groups and a maximum of 18 groups (32 individuals) were recorded during each scan period.

Table 1. Summary statistics for numbers of groups and individual observed, including groups with cow-calf pairs.

Cohort	Statistic		Groups	Individuals (*calves)
All groups	5-min scan samples	Min	0	0
		Max	18	32
		Mean	3.2	6.5
	Total over the season		**3695**	**5521**
Groups with Cow-calf pairs	5-min scan samples	Min	0	0*
		Max	3	3*
		Mean	0.2	0.2*
	Total over the season		**187**	**189***
	Proportion of total		0.05	0.03*

The mean number of groups detected per 5-min scan increased from approximately 2 groups in mid-July to a peak of 11 groups around mid-August, and then slowly decreased to around 1 group per scan towards mid-October (Figure 5).

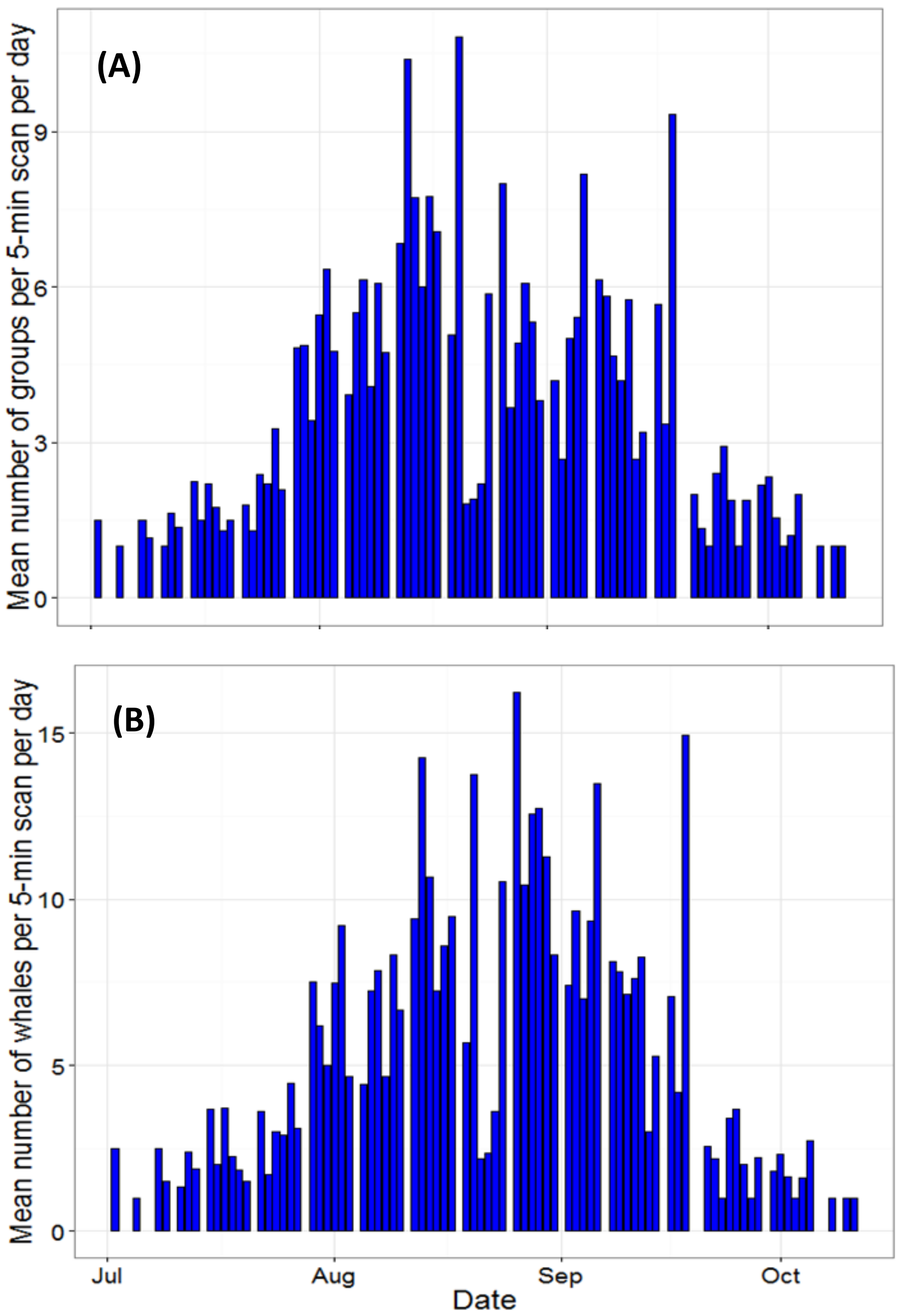

Figure 5. Mean number of groups (A) and whales (B) detected per 5-min scan (bottom panel) over the migration period between July and mid-October, 2013.

The mean number of groups with calves sighted in a 5-min scan per day ranged from approximately 0.1 to approximately 0.6, with the peak coinciding with the overall peak in whales (Figure 6). There was, however, an overall greater proportion of groups identified as having calves in them at the beginning of the migration season (in July, Figure 6). The proportion that could be identified as having calves dropped from 10-50% (depending upon the day) to between approximately 2-10% over the remainder of the migration season. The overall proportion of groups identified as having cow-calf pairs over the migration season was 5%. This was mainly due to the increasing numbers of other non-cow-calf groups as the season progressed.

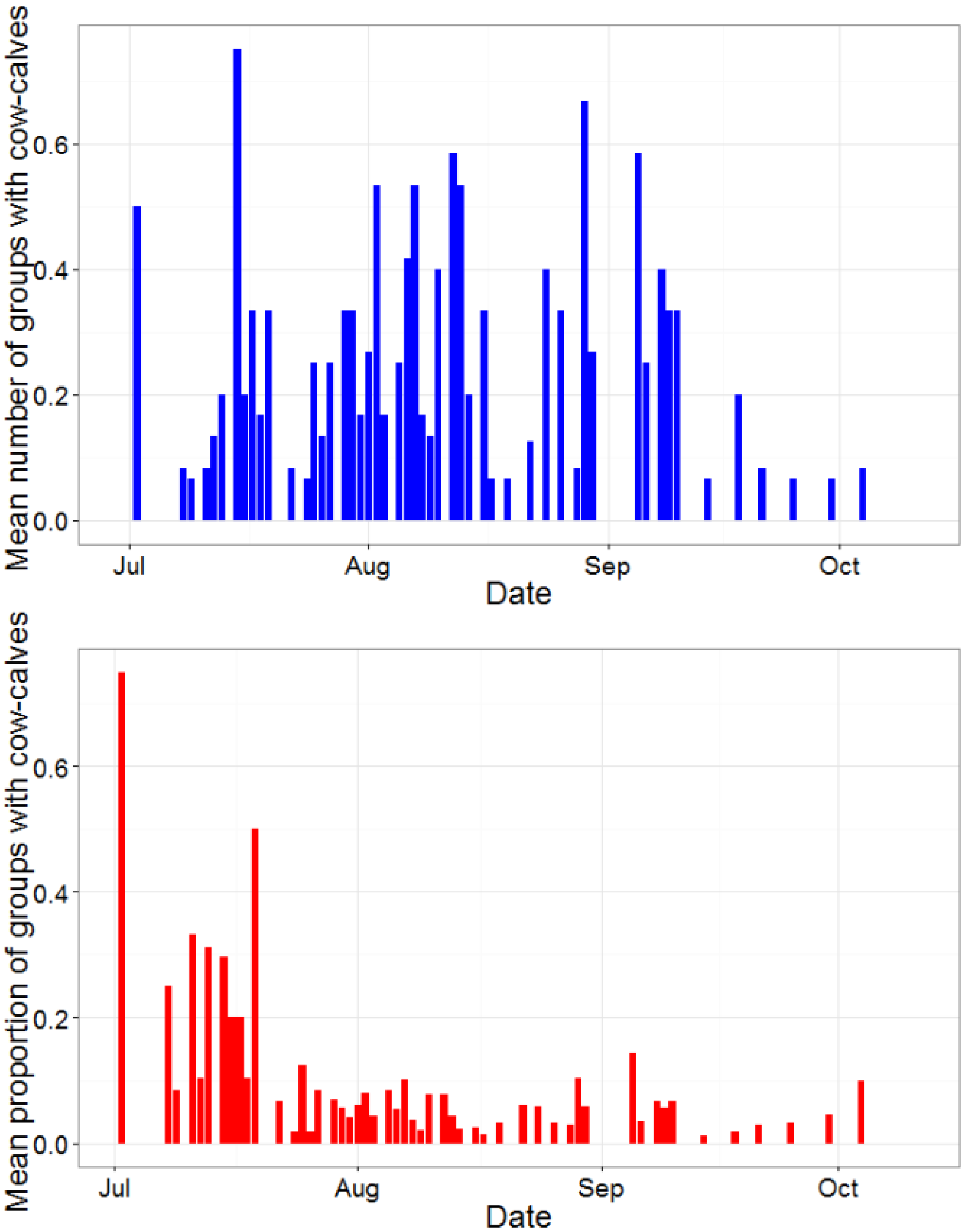

Figure 6. Mean number of groups (A) and proportion of groups (B) detected per 5-min scan with at least one confirmed cow-calf pair over the migration period between mid-July and mid-October, 2013.

The largest groups (>3 individuals) without calves were reported in late August and early September. Groups of at least two individuals (where calves were not identified) had a uni-model distribution with a peak in late August. Numbers of groups reported to have had at least one individual had a bi-modal distribution, peaking in mid-August and again in early September (Figure 7).

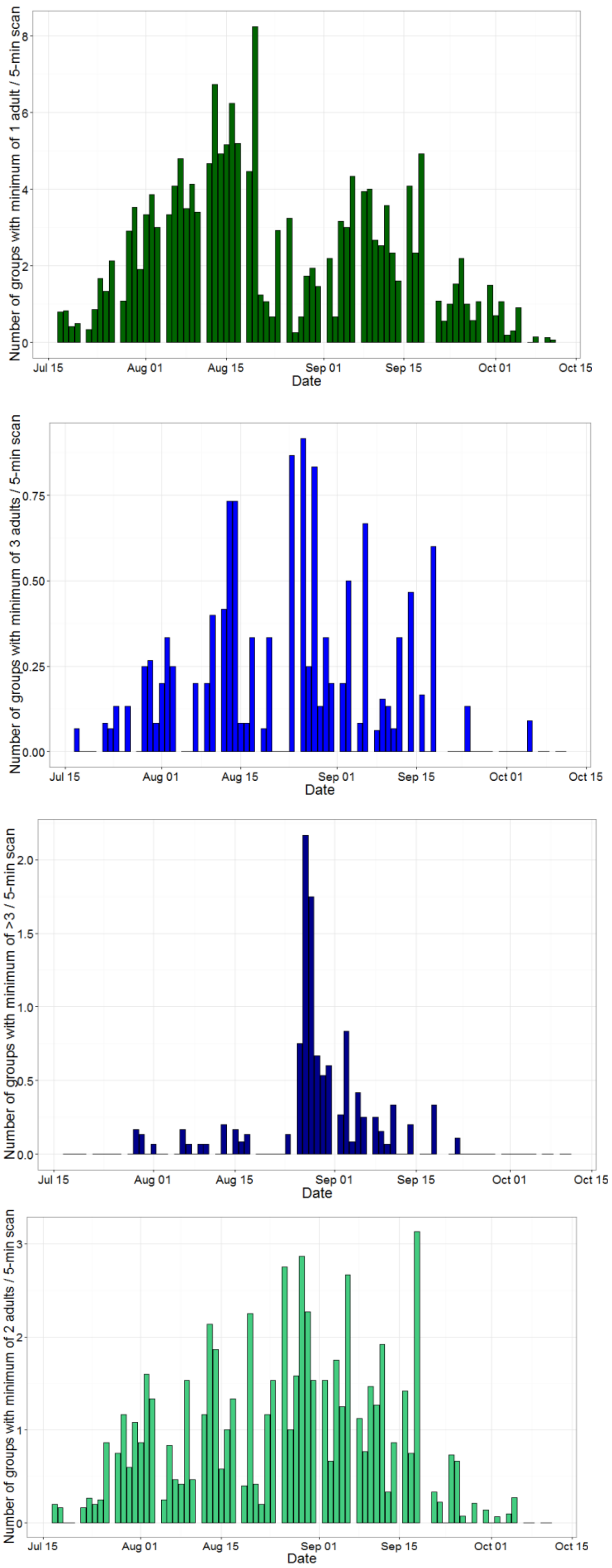

Figure 7. Mean number of groups per scan with different group sizes over the migration period between mid-July and mid-October, 2013 (groups here exclude those with confirmed cow-calves).

The maximum number of whales estimated in one group was 10 animals, and the minimum was one. The ‘minimum’ mean group size (since many group sizes could not be confirmed) estimates ranged between one and two individuals over the entire study period, with five days in late August/early September having means exceptionally greater than all other times (Figure 8).

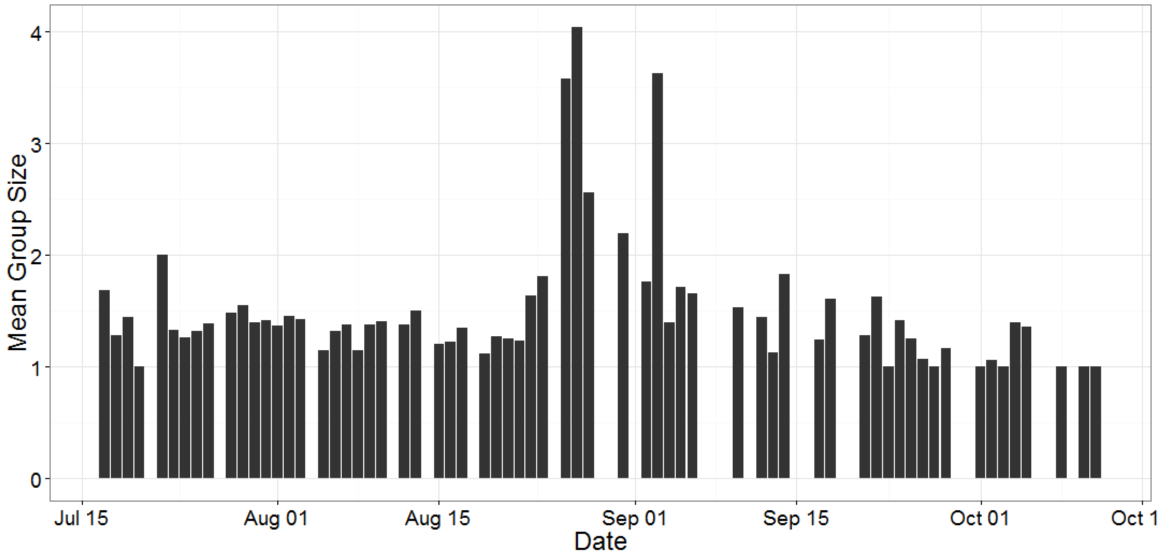

Figure 8. Mean ‘minimum’ group size estimates per day.

3.3 Effect of Environmental Conditions and Size of Observation Team on Detections

Environmental conditions recorded during scans varied over the survey season. Some surveys after mid-August had Beaufort (sea state conditions) of ≥5 (Figure 9). Surveys with these high Beaufort conditions were not conducted before mid-August. Cloud cover varied from day to day, however no large changes in the trend occurred over the survey season with an overall average of 2 sectors out of 8 having clouds. In contrast, the level of glare recorded during scans changed over the season, with more days of ‘0’ glare occurring during the latter half of the survey season.

The total number of observers in the team varied over the survey season, ranging from one to four. The most notable change in team size was a single individual operating towards the end of August, and greater numbers of scans with a team of two individuals in July (Figure 9).

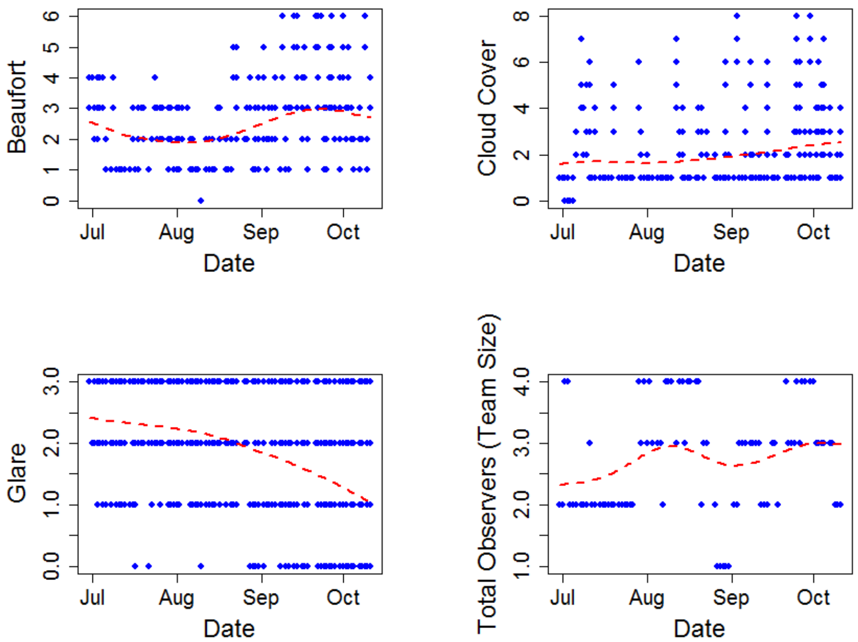

Figure 9. Change in environmental conditions and team size over the survey period (spline fit with a smoothing parameter [spar in the R smooth.spline function] = 0.9).

3.4 Association sightings with environmental variables

As a prerequisite for inclusion of variables in the Generalized Linear Model, collinearity of explanatory variables were checked. Variables (plotted against each other; Figure 10) were not collinear, with Glare and Time having the largest correlation coefficient (r = -0.4). All VIFs were less than 3.

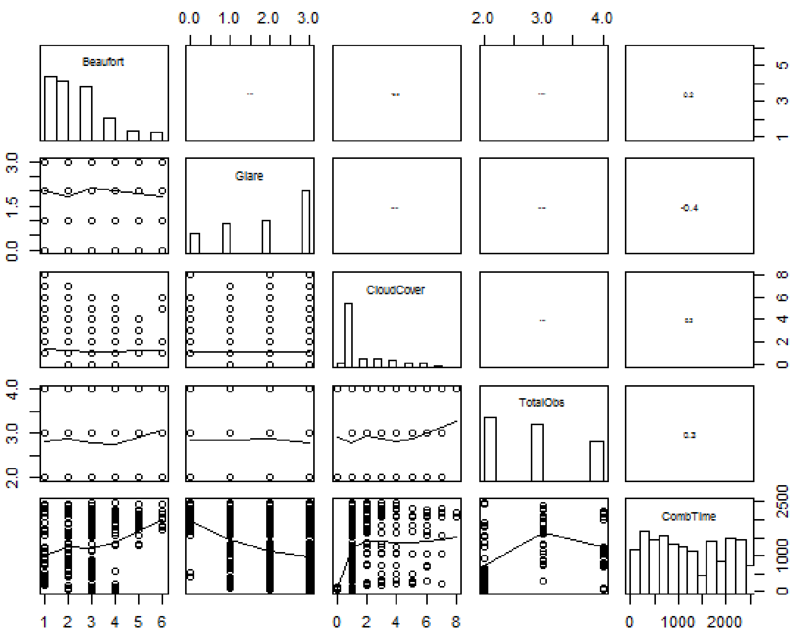

Figure 10. Pairwise collinearity plots of all environmental variables, team size (total observers), and time over the season (Time). The upper panel contains estimated pair-wise correlations. The diagonal panel contains histograms and the lower panel scatterplots with a LOESS smoother added to aid visual interpretation.

For this analysis, we needed to account for heterogeneity (more variation in peak migration period than in earlier and later periods) and temporal correlation. To visualise the heterogeneity through time, a subset of the data was taken, where the first scan for each hour was plotted over the survey day for each date of the survey season. The subset also excluded observations with a single observer (since there were few of these and they occurred at one time during the season), and those undertaken in Beaufort conditions of 0 and of 5 or greater (since these were not distributed evenly across the season). We verified that there was heterogeneity through time (within a day and over days of the season) that would need to be accounted for in the model (Figure 11).

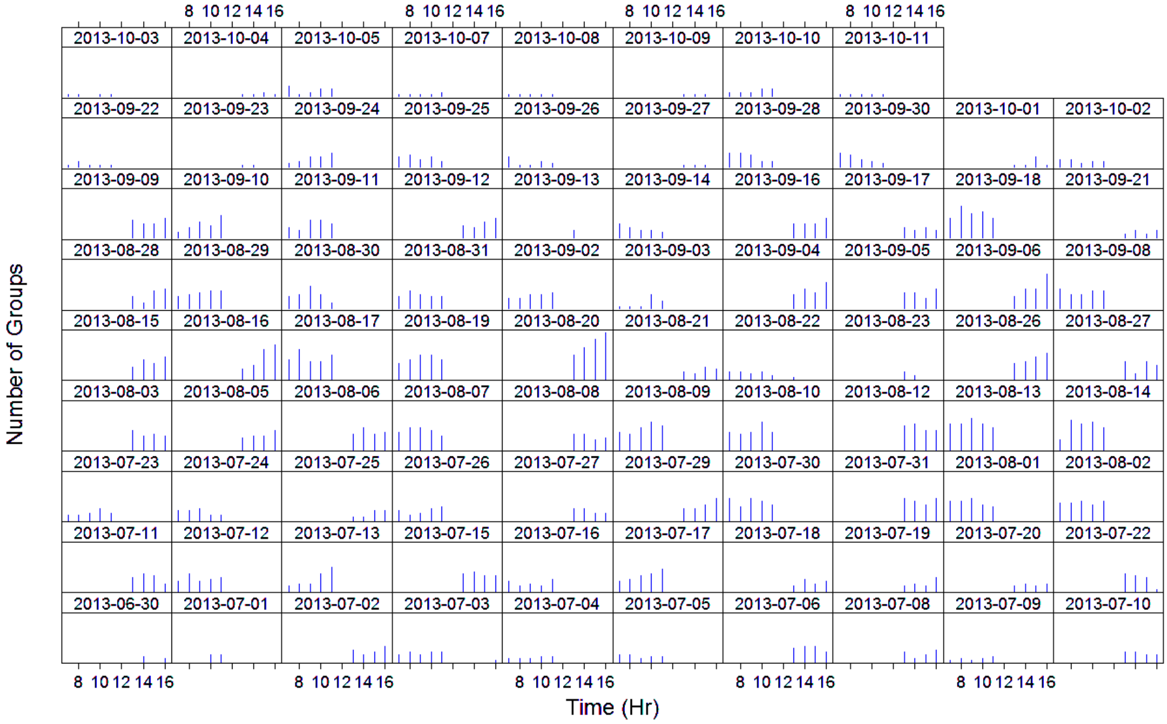

Figure 11. Number of humpback whale groups per 5-min scan during the first scan of each hour over the survey season.

Results of the best fit GEE showed that time (Days) over the season, Beaufort, glare, and total observer all were associated with numbers of groups sighted (Table 2), however cloud cover was not significant.

Table 2. Best fit Generalized Estimating Equations model (significance levels are: *** = ≤ 0.001, ** = ≤ 0.01, * = ≤ 0.05. Wald statistics are included (p-values (Pr (>|W|) were calculated from the Wald statistic). Estimated scale parameter was 1.09.

Formula				
Y = s(Days) + Total Observers + Beaufort + Glare				
Parameter Coefficients	Estimate	Std Err	z value	Pr(>|z|)
(Intercept)	1.5120	0.1759	73.88	< 2e-16 ***
(Days) spline knot 1	-0.0655	0.3272	0.04	0.84141
(Days) spline knot 2	1.2926	0.3318	15.17	9.8e-05 ***
(Days) spline knot 3	-0.4759	0.3982	1.43	0.23200
(Days) spline knot 4	-16209	0.2762	34.44	4.4e-09 ***
Total Observers 2	0.2594	0.1565	3.04	0.08128
Total Observers 3	0.2594	0.1080	5.76	0.01636*
Total Observers 4	0.4842	0.1064	20.69	5.4e-06***
Beaufort 2	0.0467	0.0766	0.37	0.54169
Beaufort 3	-0.2357	0.0743	10.07	0.00151**
Beaufort 4	-0.5589	0.1295	18.61	1.6e-05***
Glare 1	-0.2774	0.0956	8.42	0.00370**
Glare 2	-0.4146	0.1106	14.06	0.00018***
Glare 3	-0.2905	0.0925	9.86	0.00169**

The smoother for 'time' shows a significant trend with a slight increase in sightings at the beginning of the season, and then a relatively steep drop in numbers observed towards the end of the season (Figure 12). Beaufort showed a decrease in numbers of groups sighted with increasing Beaufort. All values of glare (above 0) had reduced numbers of sightings associated with them. Total observers (team size) shows greater sightings recorded when teams included more than a single individual. The numbers of sightings are similar when the team sizes were 2 and 3, but increased when the team was composed of 4 observers (Figure 12).

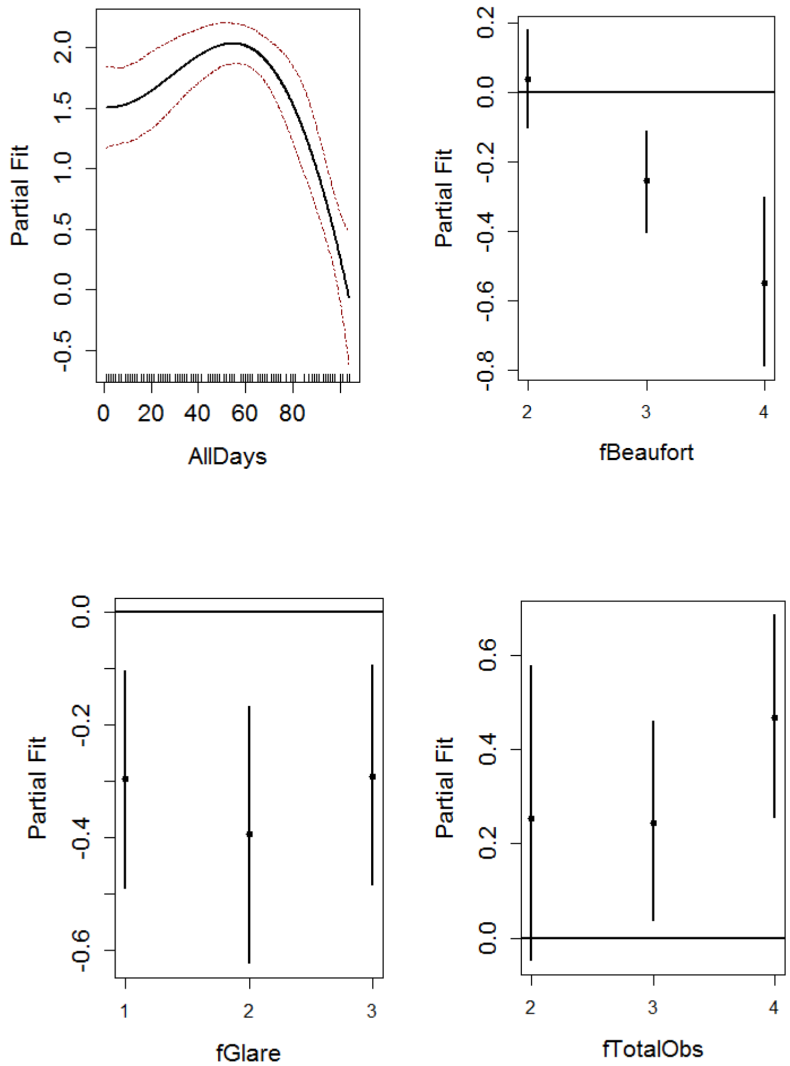

Figure 12. Partial residuals for number of groups sighted in Pender Bay as a function of Days, Beaufort condition, Glare, and Total Observers (Team size).

3.5 Distribution of Whale Groups detected

The distance from the observation site to the whale groups detected ranged from 400m to 15.57km (Figure 13). Only three observations, however, were made with calculated detection ranges beyond 10km. Detections of groups of whales were most frequent at ranges between 3 and 4km. Detections dropped off at closer distances likely due to a combination of a smaller area being sampled at close range and the decreasing water depth close to land. Detections also dropped off at ranges further than 4 km likely due to a decrease in visibility at range.

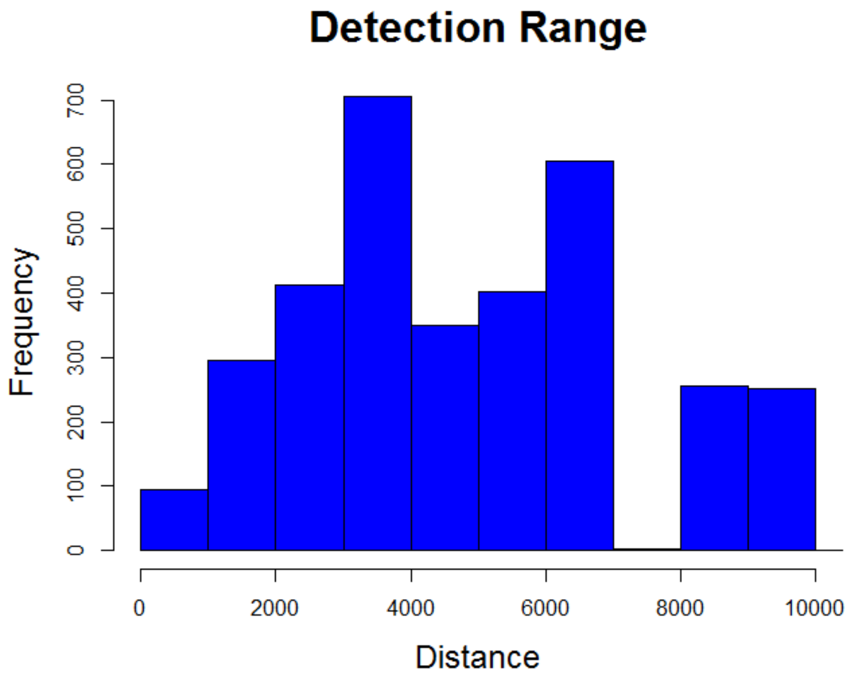

Figure 13. Detection range for first detection of all groups sighted in which the bearing and binocular reticules (down from the horizon) were reported.

The angle of detection was approximately a 180° view from the observation platform (Figure 14). Because of the limited level of precision using reticules at larger distances, 'lumping' is apparent in 'bands' of sightings (Figure 14), however, the information is useful in giving a general representation of distribution, and in particular within 4km of the land station (given the drop-off in detection with range). From the distribution of groups of whales plotted on the map, there is a clear decreasing trend in numbers towards the inside of Pender Bay (towards the east) (Figure 14).

Sightings of whale groups were almost entirely limited to water depths greater than approximately 5m at LAT (Lowest Astronomical Tide chart datum) (Figure 14). This appeared to be fairly consistent, although the subset of dates (equal number of dates selected for each 15 day block) show a higher density in close to the land station in August than in other months, and perhaps a slightly increased relative number further inside the bay towards the second half of August (Figure 15). Sightings of groups containing confirmed cow-calf pairs were observed to have a similar general distribution as other groups, ranging into the shallow waters of 5-8 m LAT (Figure 16).

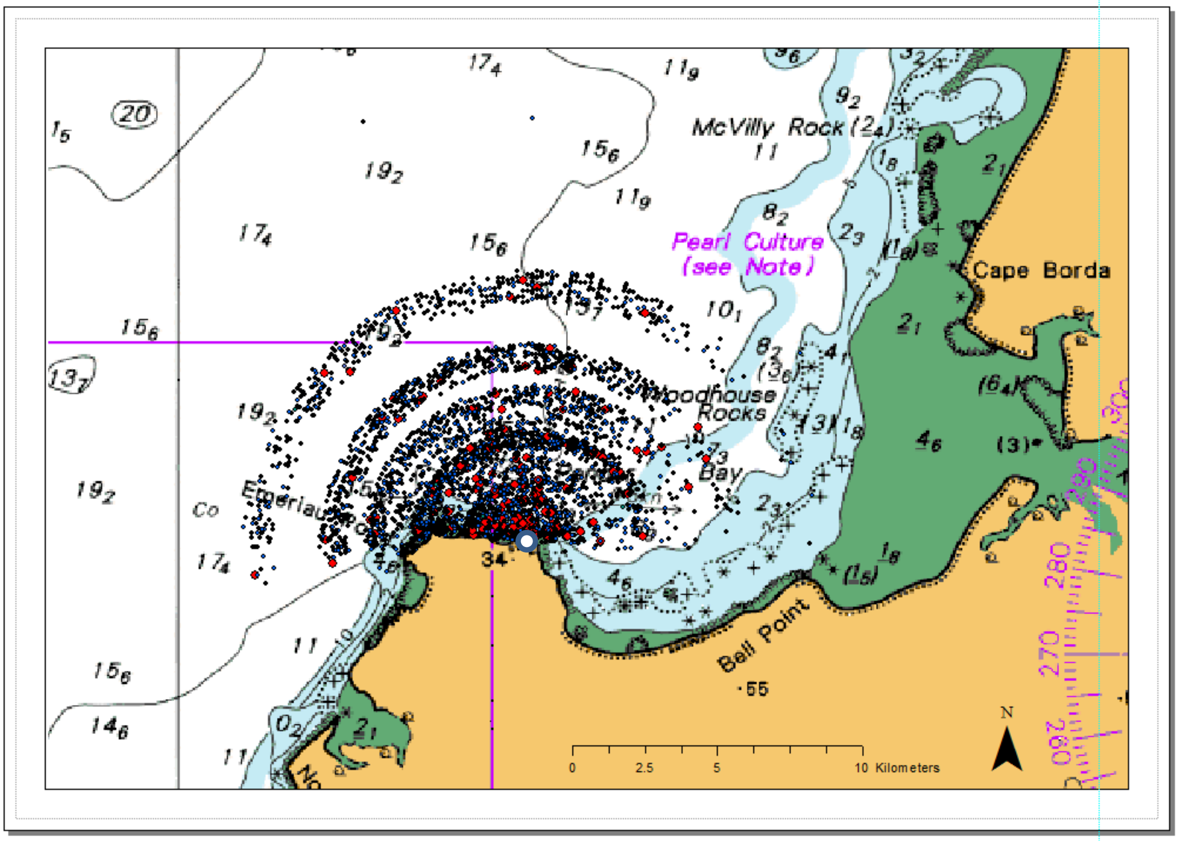

Figure 14. Detections of whale groups and estimated positions using reticule binoculars and compass from the observation platform (white circle). Black circles represent groups with at least one animal, blue circles are groups with confirmed multiple animals, and red circles are groups with cow-calf pairs. Obvious outliers (groups positions located on land) were removed.

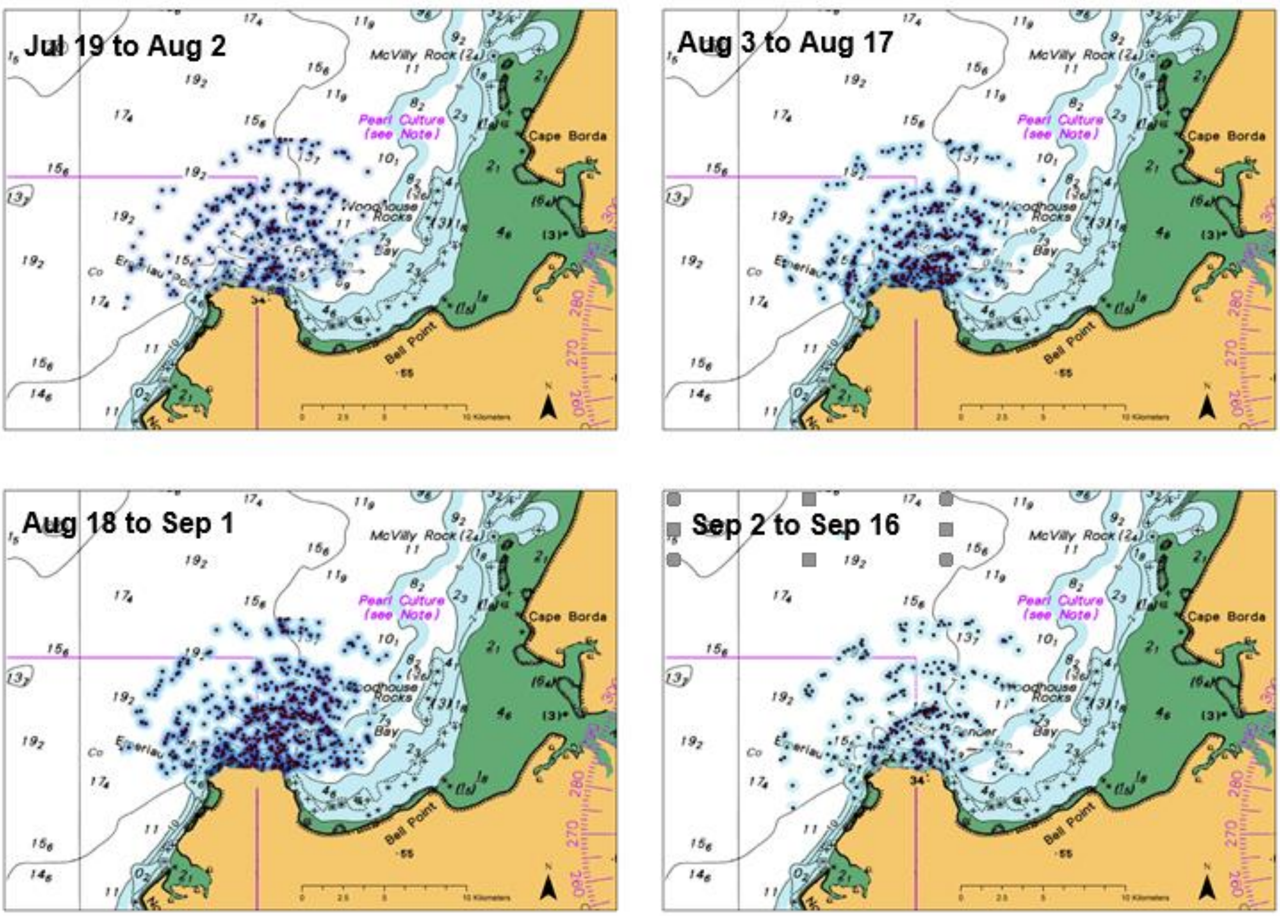

Figure 15. Detections of whale groups and estimated positions using reticule binoculars and compass from the observation platform (dark red dots) during 15-day blocks throughout the season. Kernel densities are overlayed in blue shading. Obvious outliers (groups positions located on land) were removed.

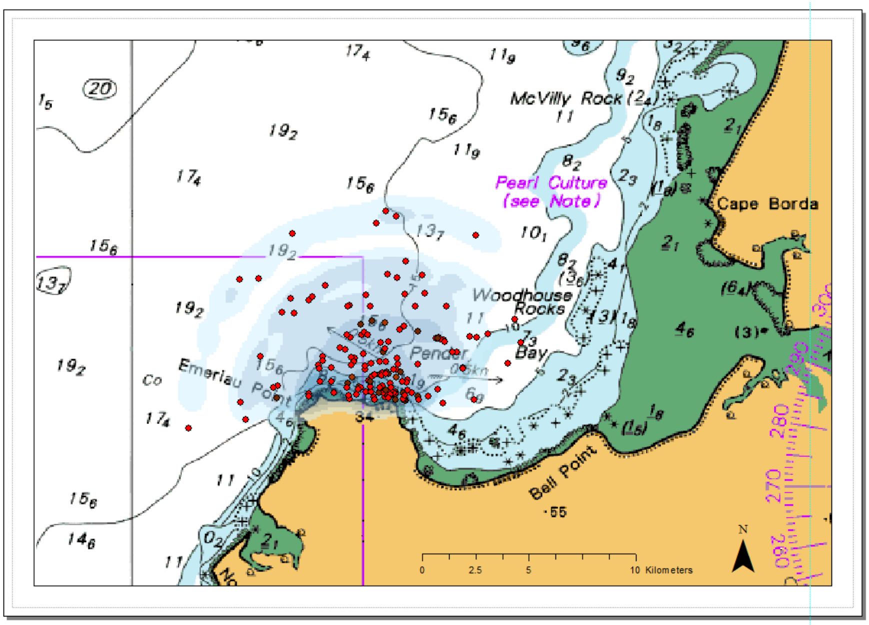

Figure 16. Detections of groups with cow-calves and estimated positions using reticule binoculars and compass from the observation platform over the entire season. Kernel densities are overlayed in blue shading. Obvious outliers (groups positions located on land) were removed.

Sea surface temperature increased steadily over the migration period from approximately 22 to 27°C. During the first half of the season, there was a steady rise in the mean number of groups of whales detected per 5-min scan. During the latter half there was a decrease in numbers of groups of whales detected (Figure 17). These data were not analysed further due to the limited number of days sea surface temperature was sampled.

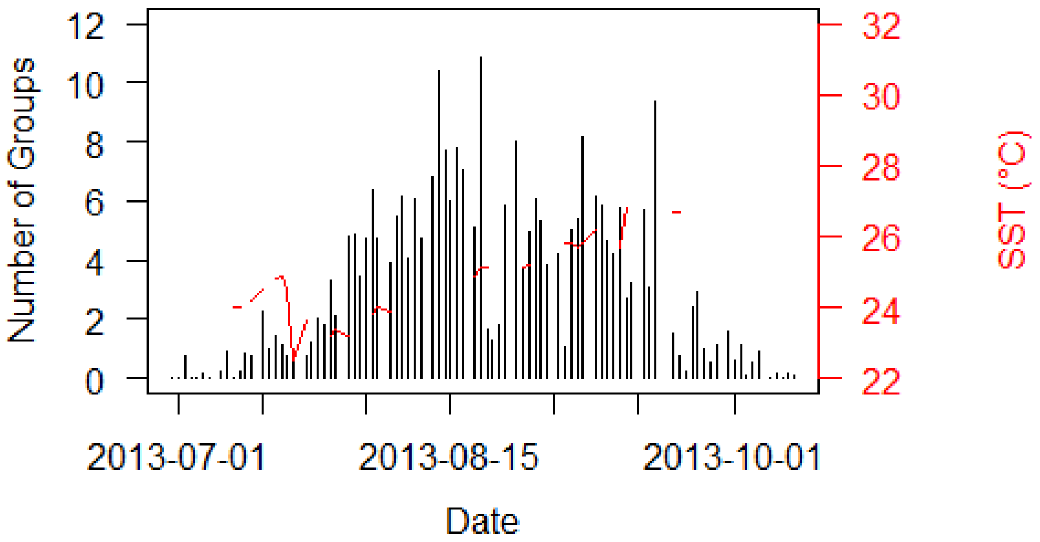

Figure 17. Mean number of groups of whales per day (over five minute scans, bars) overlayed by mean sea surface temperature in Pender Bay (SST, red line).

4 Discussion and Conclusions

4.1 General results for the season

Counts of groups of humpback whales peaked in late winter and early spring (between mid-August and September) in Pender Bay, of which the maximum number of groups of whales reported at any one time (a single scan count) was 18. This peak in the whale season is consistent with previous years' data (2009-2012) as reported by Blake and Dapson (2013) and with that reported by How et al (2013) using commercial whale tour operator data. There was a peak in reports of groups with cow-calf pairs and in the largest groups at the same time. Whereas groups containing single animals peaked just before and just after the peak in groups with cow-calf pairs. An overall greater proportion of groups contained calves at the beginning of the migration season (in July). This is early in the northern migration season and may suggest that calves are being born near Pender Bay. Some care must be taken in the interpretation of these patterns as, for example, a sighting of a single whale could have been in reality a group of 3 whales with only one whale in the group detected. Given the distance of the land based station to many of the sightings and the smaller size of calves making them more difficult to detect than adults, calves may also be under represented. The relative pattern observed could be due to the real pattern in numbers of the various group types, or a shift in distribution and/or behaviour of the different group types so that they have a greater detection probability (either they are at a closer range to the observers or the individuals are at the surface for longer periods and/or more visible). Overall, for this study, whale groups with calves are a minimum representation of calves that could have been present. The largest groups were detected in September which may be indicative of increased social activity, including mating, as well as an increase in the number of whales migrating south.

While the analyses showed that the general trend in whale presence over time was the most significant, the number of groups observed was also influenced by the variability in team size, and environmental conditions. An increase in number of observers only resulted in an increase in the number of whale groups sighted when the team size was 4, meaning that the increase in groups detected does not have a linear relationship with team size. There was likely an effect related to observers themselves (as a function of experience and skill), however this could not be tested as different observers were present at different times during the season for short periods. As expected, with decreased visibility (an increase in sea state) the number of whale groups detected also decreased. To carry the analyses to the next stage (i.e. correcting for the effects of environmental conditions and predicting numbers given constant conditions), an experiment would be required designed specifically to test for these effects. Standardising a methodology to correct for such effects in 'citizen' science observations would allow for more robust analyses with seasons and among years for trend detection.

The relationship between sea surface temperature and number of whales was briefly explored, however these data were not analysed further due to the limited number of days that sea surface temperature was sampled. Interestingly the peak in calves sighted coincides with SST of 25° SST. Over the migration there is a 5° difference in SST between the beginning (22°) and end (27°) of the migration. Water temperature may be a trigger for migration, however a long-term dataset would be required to test such hypotheses. The majority of sightings were within the 10-20 m water depth range. There were fewer sightings of whale groups where the water was shallower than 5m or less in the Eastern part of the bay. A long term data set of water temperature and fine scale bathymetry would allow for a better understanding of habitat use. Furthermore simultaneous observations conducted on a vessel will provide information on distribution further offshore.

4.2 Changes to data collection methods and how this will improve understanding

Minor changes were made to the data collection method that should improve the confidence in data collection and its utility an application to appropriate analysis techniques. For example, the interval between sampling periods was extended to reduce observer fatigue throughout the survey session. Sampling design, in particular decision making about morning vs afternoon sampling, was also standardized to ensure an even distribution of data throughout the day so that temporal patterns in distribution could be explored. Overall these changes should add value to the citizen science style project by providing a straightforward and not too onerous data collection methodology that, with a good team leader, should result in consistent and quality data collection. Given that this research is undertaken in a remote region under often taxing conditions (heat and sun exposure) means of minimizing additional stress to the observers is important to ensure confidence in the data.

4.3 Recommendations for future research or monitoring

Land based viewing platforms can provide a cost effective means of acquiring data on whales that can be used for management and other purposes. Most important though is to have a clear question in mind and to ensure that the data that can be collected can meet this purpose. The land-based site at Two Moons Whale Research Station can be used to collect data that will inform regional managers about the timing of the humpback whale migration season, as this can vary annually, including the timing and density of mother and calf groups. It can also be used as an indicator of the extent of use of Pender Bay by humpback whales, including changes in timing and whale density throughout the migration season.

Additional research would be useful that could link the relative abundance and density of humpback whales sited at Pender Bay with the broader Kimberley so that this land based site could be used as a broader indicator of population health across the broader region. Other specific research projects that would add value to our understanding of whale use of Pender Bay would include assessing whale distribution in relation to water depths or bottom features in the vicinity of Pender Bay and experimentally testing the effect of some of the environmental and observer variables noted in section 4.1 above so that these could be accounted for in a standardized methodology and analysis.

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7 Appendices

Appendix 1. Pender Bay Humpback Whale Monitoring: Field Manual 2013

Pender Bay Humpback Whale Monitoring: Field Manual 2013 WAMSI KMRP Project 1.2.1 Chapter 3 Salgado Kent et al. 2018. (www.wamsi.org.au/humpback-whale-monitoring)

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Humpback whale use of the Kimberley: understanding and monitoring spatial distribution

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