Spatial and temporal distribution of sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon in relation to oceanographic variables

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Abstract

The Kaikoura area is a valuable feeding spot for sperm whales with the presence of a submarine canyon close to shore. Male sperm whales can be found there year around, close to the shore and exhibiting almost constant foraging activities. This thesis investigates the distribution and habitat use, both spatially and temporally, of sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon, New Zealand. The primary aim was to determine which oceanographic variables and bathymetric features influence the sperm whale distribution patterns off Kaikoura.

A theodolite was used to track surfacing and movement of sperm whales from a shore-based station. The accuracy of positions recorded by the theodolite was investigated by comparing theodolite measurements of an object of known position. A calibration technique was then developed as the vertical angle was not accurately determined by the theodolite.

In addition to investigating the distribution of sperm whales, the daily abundance of sperm whales within the Kaikoura submarine canyon was estimated. Distance sampling and mark-resight models showed an average of 4 (SEM = 0.13) individuals present in the study area at any given time. The mark-resight technique using photo-identification was not possible from a shore-based station so a spatio-temporal model was built in order to track the identity of individuals. The model was tested using photo-identification of sperm whales collected from a boat-based station. Results showed that 88% of the modeled identifications corresponded to the photo-identification database.

Sperm whales off Kaikoura were strongly associated with depth, slope and distance from the nearest coast. They were found in waters between 500 m to 1250 m deep and preferred shallower waters in winter. In spring, sperm whales occurred further from the coast, mainly in the Hikurangi Trough, north-east of the shore-based station. Generalized Additive Models (GAM) were used to identify significant oceanographic variables predicting the presence of sperm whales off Kaikoura. Models indicated that sea surface temperature (SST), chlorophyll*a* (Chl*a*) and distance from sea surface temperature fronts were all important parameters in predicting sperm whales presence. Results showed that sperm whales aggregated in the section of the study area with the lowest SST and near SST fronts. This study provides a detailed insight into the use of the Kaikoura submarine canyon by male sperm whales.

1. General Introduction

1.1. Behavioural ecology

The habitat of an organism is the place where it lives. It provides the conditions and resources required for the survival and reproduction of this organism. Organisms spend the majority of their time in advantageous habitats (Odum 1971, Krebs *et al.* 1974). In analyzing the relationships between organisms and their environments, a central goal is to understand why organisms select particular habitats (Huey 1991, Krebs 2001). Patterns of habitat use indicate the importance of these habitats for the biological requirements of a species and are critical in understanding the distribution and behaviour of individuals (Lack 1971, Schoener 1974, MacArthur and Pianka 1966, Rosenzweig 1981). These relationships are scale-dependent, reflecting the different scales at which different organisms operate. Before starting a study involving species-habitat relationships, determining the appropriate spatial and temporal scales of the study is the most important decision to make (Wiens 1989, Redfern *et al.* 2006).

Knowledge of the species distribution and habitat relationship is a useful tool for conservation (Ferrier 2002). The most important factor causing species extinctions is widely considered to be habitat destruction caused by human activities. Concerns over habitat destruction often lead to the development of conservation and management plans, and efforts on multiple scales to protect threatened species and their environments (Sih *et al.* 2000, Minteer 2009). Species distribution modelling is a useful tool for conservation management (Redfern *et al.* 2006). All habitat suitability models attempt to quantify species-environment relationships by relating species presence to the environmental factors which directly or indirectly affect a species' distribution; this information can then be used to predict the probability of a species' occurrence in other areas and to develop conservation plans (Guisan and Zimmermann 2000, Austin 2002, Boyce *et al.* 2002, Mandleberg 2004, Kaschner *et al.* 2006).

1.2. Kaikoura submarine canyon

The Kaikoura region is an ideal place to study sperm whales (*Physeter macrocephalus*) and their habitat use. The proximity of the Kaikoura submarine Canyon makes it one of the few places in the world where male sperm whales are found close to shore year round (Gordon *et al.* 1992, Jaquet *et al.* 2000). A great number of studies have examined correlations between cetacean distribution and bathymetry (e.g. Whitehead *et al.* 1992, Mullin *et al.* 1994, Viale and Frontier 1994, Waring *et al.* 1997, Cañadas *et al.* 2002, Gannier *et al.* 2002, Hamazaki 2002, Drouot *et al.* 2004, Cañadas *et al.* 2005, Panigada *et al.* 2005, Laran and Gannier 2008, Praca *et al.* 2009). Studies focusing on sperm whales have shown that water depth is the most characteristic attribute of sperm whale habitats (Caldwell *et al.* 1966) and they occur in greatest numbers near the lower continental slope and deep water (Baumgartner *et al.* 2001, Gregr and Trites 2001).

Sperm whales found off the coast of Kaikoura are mostly young adult males or mature males (Gaskin 1968, Todd 1991). Male and female sperm whales have different distributions. Male sperm whales are either solitary or in bachelor groups and are found in colder waters than females and young. Females have a more restricted habitat, usually in areas with sea surface temperature greater than 15°C, whereas male sperm whale habitats are only limited by ice (Gulland 1974, Rice 1989), which explains the predominance of males off Kaikoura (Berzin 1971, Whitehead *et al.* 1991, Whitehead *et al.* 1992, Gaskin 1973). While the individuals present may vary, sperm whales can be found off Kaikoura on most days throughout the year (Gordon *et al.* 1992, Childerhouse *et al.* 1995, Jaquet *et al.* 2000). In the Kaikoura Canyon, two groups of sperm whales can be distinguished. Residents spend several weeks or months in the area and return to the area over years. Transients stay days or hours in the canyon area (Childerhouse *et al.* 1995, Jaquet *et al.* 2000). The foraging behaviour of sperm whales is made up of two distinct phases. They allocate 75% of their time foraging during deep dives and between these dives, they spend approximately 10 min at the surface, resting, before diving again (Best 1979, Clarke *et al.* 1980, Christal and Whitehead 2001).

Kaikoura canyon is a feeding ground for sperm whales. The particular topography of the submarine canyon directly influences the hydrological system of the coastal waters off Kaikoura. The Kaikoura area is an upwelling area, resulting from the mixing of the warm northern water from the East Cape current and the cooler water from the Southland current (Garner 1953, Hart *et al.* 2008). This upwelling can bring deep nutrient rich waters to the surface producing an area of very high productivity and a valuable feeding spot for sperm whales (Gaskin and Cawthorn 1967, Heath 1972, Farrell *et al.* 1991, Chiswell and Schiel 2001, Hart *et al.*2008, De Leo *et al.* 2010).

Physical characteristics of water play an important role in marine ecosystems (Le Fevre 1986, Longhurst 2006). Mixing of different water masses, a strongly stratified zone with high surface temperature and a colder homogenous zone has a tendency to increase biomass (Hamazaki 2002, Whitehead 2003, Rivas 2006). Also, upwelling (Berzin 1971, Gulland 1974, Smith and Whitehead 1993, Jaquet *et al.* 1996, Rendel *et al.* 2004), convergence zones (Gaskin 1968, 1973, Berzin 1971, Chiswell and Schield 2001), and frontal zones (Viale 1991, Jaquet and Whitehead 1996) are correlated with peak primary productivity. In the Mediterranean Sea, sperm whales favour areas with thermal fronts (Viale 1991, Gannier and Praca 2007).

The canyon area is more productive than other places around New Zealand, with an average concentration of Chl*a* above 1 mg/m^3. For comparison, the average Chl*a* concentration around New Zealand varied between 0.26 and 0.43 mg/m3 (Hart *et al.* 2008).

Primary productivity is correlated with Chl*a* distribution and concentration (Behrenfeld and Falkowski 1997). Fiedler *et al.* (1998) suggested that hotspots of marine mammal richness are associated with peaks of primary productivity so a correlation between marine mammals and high Chl*a* is expected. It is easy to understand the correlation between the concentration of Chl*a* and presence of baleen whales, because their main prey is euphausiid shrimp. Euphausiids are found at a low trophic levels and their abundance is directly linked to primary productivity and Chl*a* concentration (Littaye *et al.* 2004). Such relationships between baleen whales and Chl*a* have been widely documented (Woodley and Gaskin 1996, Laran and Gannier 2008). For sperm whales, which feed on squid and fishes, and thus at a higher trophic level, some doubt remains about the correlation between the presence of sperm whales and Chl*a*. Jaquet *et al.* (1996), studying sperm whale distribution in the tropical Pacific, suggested that Chl*a* concentration is a good indicator of sperm whale distribution, while Whitehead *et al.* (2010) maintain that Chl*a* alone is not the best indicator for sperm whale distribution from studies in the northwest Atlantic and eastern Pacific Oceans. Additionally, the presence of a temporal and spatial lag between the peak of Chl*a*, zooplankton and then the presence of cetaceans needs to be taken into consideration (Littaye *et al.* 2004, Laran and Gannier 2008, Notarbartloo-Di-Sciara *et al.* 2008). For sperm whales, the correlation with Chl*a* still needs to be investigated to test if this parameter is useful to understand sperm whale distribution.

Sea surface temperature (SST) is a great determinant and predictor of biodiversity. Phytoplankton abundance is inversely related to SST (Jutla *et al.* 2011). In previous studies SST was the best predictor in determining the abundance of zooplankton (Rutherford *et al.* 1999), as well as the distributions of tuna, billfish (Worm *et al.* 2005), seabirds (Stahl *et al.* 1985, Guinet *et al.* 1997) and cetaceans (Whitehead *et al.* 2010). And studies have shown a relationship between cold water and sperm whales foraging success (Whitehead *et al.* 1989, Smith and Whitehead 1993).

Understanding the habitat use by cetaceans is of central importance for population conservation (Lack 1971, Schoener 1974, Redfern *et al.* 2006, Laran and Gannier 2008), as habitat degradation or loss of habitat are threats to species sustainability (Macleod *et al.* 2004). In addition, knowing why species are more abundant in some habitats than in others is fundamental in ecology (Huey 1991).

1.3. Whale watching off Kaikoura

In 1993, the International Whaling Commission (IWC) declared that whale watching is a sustainable use of cetacean resources (International Fund for Animal Welfare, 1995). Consequently, in many countries this activity appears to have become an economic alternative to whaling (Hoyt 1995). Sperm whales have been studied in Kaikoura during the past few decades and their behaviour and ecology have been investigated, as they are the focus of a whale watching industry (Gordon *et al.* 1992, Childerhouse *et al.* 1995, Dawson *et al.* 1995, Jaquet *et al.* 2000, Richter *et al.* 2003). In other parts of the world, as in Kaikoura, research has been conducted to investigate the effects of whale watching on cetaceans (Magalhães *et al.* 2002, Williams *et al.* 2002, Scheida *et al.* 2004, Lundquist *et al.* 2006, Würsig *et al.* 2007, Schaffar and Garrigue 2008, Schaffar *et al.* 2009). These studies have been carried out because it is crucial to identify the whale watching impact on the cetacean population (Lusseau and Slooten 2002). This effect can result in a shift of habitat by cetaceans as a result of these human activities (Norris and Dohl 1980, Scheidat *et al.* 2004).

Other research on marine mammals has explained the necessity to conduct research at a fine scale, considering that environmental factors influencing distribution vary between region and species (Baumgartner 1997, Hastie *et al.* 2005). This is establishing the importance of this study which is focused on a fine temporal and spatial scale whereas most studies on sperm whales have opted for larger scales (Jaquet and Whitehead 1996, Jaquet *et al.* 1996).

1.4. Research overview

The aim of this thesis was to investigate the distribution and habitat use of sperm whales within the Kaikoura submarine canyon, both spatially and temporally, and to determine if the habitat selection by sperm whales off Kaikoura was related to oceanographic variables. This study is the first attempt to model sperm whale distribution on fine temporal and spatial scales off Kaikoura and to correlate those patterns with local oceanographic parameters.

The data collection was carried out from a shore-based station located on the Kaikoura peninsula, offering the opportunity to cover the whole Kaikoura canyon area and to track animals without disturbing their behaviour. Data were collected continuously during two years (2010-2012) in order to be able to extract fine scale patterns in the sperm whale distribution. This study used GIS to integrate the sperm whale sightings with the different environmental datasets (e.g. SST, Chl*a*). Spatial analysis and predictive models were conducted using ArcGIS tools. General additive models were used to determine the factors influencing the sperm whales distribution within the canyon in order to determine if the presence of sperm whale within the Kaikoura submarine canyon was related to oceanographic variables.

1.5. Thesis structure

This thesis was completed by preparing a series of academic papers, with the general objective of adding to the knowledge on the sperm whales off Kaikoura. In accordance with University of Canterbury standards I am the first author and primary contributor in all papers. The contents of the chapters are as follows:

Chapter 2: Correcting positional errors in shore-based theodolite measurements of animals at sea.

A technique was developed to improve the accuracy of the data collected using a theodolite. By using data simultaneously recorded from the shore-based station and two onboard GPS devices, the positional error of the theodolite measurements was corrected. This method increased the accuracy of estimating positions of sperm whales found at larger distances from the shore-based station. This positional correction was used on the full database and for all the following chapters.

Ophélie Sagnol, Femke Reitsma, Christoph Richter, and Laurence H. Field, "Correcting Positional Errors in Shore-Based Theodolite Measurements of Animals at Sea," Journal of Marine Biology, vol. 2014, Article ID 267917, 8 pages, 2014. doi:10.1155/2014/267917 Journal of Marine Biology.

Chapter 3: Estimating sperm whale (*Physeter macrocephalus*) daily abundance from a shore-based survey within the Kaikoura submarine canyon, New Zealand.

Daily abundance of sperm whales within the Kaikoura canyon was analyzed here using mark-resight and distance sampling methods. The study illustrated the application of distance sampling and mark-resight methods from a shore-based station. In this study techniques usually selected from boat based platforms were used. This chapter offered alternative methods to determine abundance from a shore-based station.

Sagnol, 0., Richter, C., Reitsma and Field, L. H. Estimating sperm whale (*Physeter macrocephalus*) daily abundance from a shore-based survey within the Kaikoura submarine canyon, New Zealand. **Revisions submitted**. New Zealand Journal of Marine and Freshwater Research.

Chapter 4: Tracking individual sperm whales from a shore-based station dataset using a spatio-temporal model.

A technique to extract the sighting of the same individual from a shore-based station where photo-identification is not possible was the main focus of this chapter. In this study, I introduced for the first time an alternative method to extract sperm whale individuals from a shore-based station dataset by using a spatio-temporal model.

Sagnol, O. and Reitsma, F. A spatio-temporal model to track individuals from a shore-based station: A case study for sperm whales (*Physeter macrocephalus*) off Kaikoura, New Zealand. **Revisions submitted**. Aquatic mammals.

Chapter 5: Spatial and temporal distribution of sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon, New Zealand in relation to bathymetric features.

Seasonal and monthly distribution of sperm whales was detailed in relation to the bathymetry features and distance from shore. General additive models were used to determine which physiographic factors significantly influence the sperm whale distribution off Kaikoura.

Sagnol, O., Richter, C., Field, L. H. and Reitsma, F. Spatio-temporal distribution of sperm whales (*Physeter macrocephalus*) off Kaikoura, New Zealand in relation to bathymetry. **Revised and resubmit.** New Zealand Journal of Zoology.

Chapter 6: Small scale distribution of sperm whales (*Physeter macrocephalus*) in relation to oceanographic features within the Kaikoura submarine canyon.

For the first time, the distribution of sperm whales off Kaikoura was modeled in relation to oceanographic variables. General additive models were used to determine sperm whales' key areas within the canyon in relation to SST, chl*a* and distance from SST fronts. These models will be very useful for conservation management of a sperm whale population which supports local tourism and has frequent interactions with tour vessels, and also understanding the distribution of sperm whales off Kaikoura.

Sagnol, O., Richter, C., Field, L. H. and Reitsma, F. Seasonal distribution of sperm whales in relation to oceanographic features within the Kaikoura submarine canyon. **In review**. New Zealand Journal of Marine and Freshwater Research.

From April 2010 to June 2011 I was part of a Department of Conservation (DOC) project, to assess the effect of whale watching vessels on sperm whales off Kaikoura from three platforms: a small quiet boat, a shore-based station and the tour vessels themselves. I was in charge of two platforms: the shore-based station and data collected onboard tour vessels. The results are presented in two publications which I prepared and these are included in Appendices. The first describes the behaviour and movement patterns of sperm whales across season in the presence and absence of tour vessels and aircraft. The second examines the whale watching tourism activity off Kaikoura, areas in which whale watching vessels operate, and interaction of vessels with sperm whales using the tour vessels and aircraft themselves as research platforms.

- Sagnol O., Markowitz T.M. and Markowitz W.J. 2011. Shore-based monitoring of sperm whales in Kaikoura canyon: Behaviour, distribution and interactions with tour vessels. Chapter 2: report for the Department of Conservation, New Zealand.

- Sagnol O. and Markowitz T.M. 2011. Remote tracking and onboard monitoring of whale watching activity at Kaikoura, New Zealand. Chapter 3: report for the Department of Conservation, New Zealand.

Sagnol O., Reitsma F., Richter, C. and Field, L. H. Correcting positional errors in shore-based theodolite measurements of animals at sea. Poster presented at: 27th European Cetacean Society conference; 2013 April 8-10; Setubal, Portugal.

Sagnol O., Richter C., Field L. H. and Reitsma F. Seasonal distribution of sperm whales (*Physeter macrocephalus*) in a submarine canyon in relation to oceanographic variables. Oral presentation. 20th Biennial Conference on the Biology of Marine Mammals, Otago University, Dunedin, New Zealand, 9-13 December.

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2. Correcting positional errors in shore-based theodolite measurements of animals at sea

2.1. Summary

Determining the position of animals at sea can be particularly difficult and yet, accurate range and position of animals at sea are essential to answer a wide range of biological questions. Shore-based theodolite techniques have been used in a number of studies to examine marine mammal movement patterns and habitat use, offering reliable position measurements. In this study we explored the accuracy of theodolite measurements by comparing positional information of the same objects using two independent techniques: a shore-based theodolite station and an onboard GPS over a range of 25 km from the shore-based station. The technique was developed to study the habitat use of sperm whales (*Physeter macrocephalus*) off Kaikoura, New Zealand. We observed that the position accuracy fell rapidly with an increase in range from the shore-based station. Results showed that the horizontal angle was accurately determined, but this was not the case for the vertical angle. We calibrated the position of objects at sea with a regression based correction to fit the difference in distance between simultaneously recorded theodolite fixes and GPS positions. This approach revealed the necessity to calibrate theodolite measurements with objects at sea of known position.

2.2. Introduction

Knowing the accurate geographical position is essential for studying the spatial behaviour of animals at sea. Accurate positional data can answer a wide range of biological questions related to their movement patterns, habitat use, and the effects of human activities (Denardo *et al.* 2001, Bailey and Thompson 2006).

A number of tracking methods can be used in order to obtain the position of animals at sea including recoverable data loggers, satellite tags (Kooyman 1989, Hindell *et al.* 1991, Delong *et al.* 1992, Watkins *et al.* 1999, Heide-Jørgensen *et al.* 2001, Amano and Yoshioka 2003), acoustic monitoring (Watkins and Schevill 1977, Stafford *et al.* 1998, Heupel *et al.* 2006, Wiggins and Hildebrand 2007), and boat surveys (Ballance 1992, Cañadas *et al.* 2002, Hastie *et al.* 2005, Ferguson *et al.* 2006). All of these methods require expensive equipment and time to collect data and the observer can be a source of potential disturbance (Barr and Slooten 1999). As a result, the geographical coordinates of animals at sea are ideally determined from shore using a surveyor's theodolite, first introduced by Roger Paine in 1972 (Describe in Würsig *et al.* 1991) (Würsig *et al.* 1991). Shore-based theodolite tracking is a technique offering an inexpensive and non-disturbing alternative to other tracking techniques.

By tracking animals at sea from land, a small amount of equipment is required and a larger area can be monitored in a shorter amount of time compared to boat-based station. The theodolite readings (horizontal and vertical angle) can be converted to longitude and latitude when the exact theodolite position and height above sea level are known (Würsig *et al.* 1991, Gailey and Ortega-Ortiz 2002). However, shore-based tracking can only occur with animals passing close enough to the coastline to be sighted from the shore-based station. Previous studies using theodolite tracking have focused on coastal species such as dolphins within 5 km from shore (Barr and Slooten 1999, Bailey and Thompson 2006, Photopoulou et al 2011). Shore-based tracking has also been used to monitor whales during their migration when their course passes close to shore (Best *et al.* 1995, Patenaude 2000, Morete *et al.* 2003, Morete *et al.* 2008, Schaffar *et al.* 2009, Barendse *et al.* 2010, Boye *et al.* 2010, Findlay *et al.* 2011) or to examine the effects of human activities on whales (Ollervides 1997, Funk *et al.* 2005, Lundquist *et al.* 2006, Gailey *et al.* 2007, Markowitz and McGuire 2007).

A number of parameters can influence the accuracy of the calculated position from theodolite fixes, such as the accuracy inherent to the theodolite, weather parameters (heat haze or swell) and the experience of the observer. One of the main problems with shore-based theodolite data is the increasing error in positional fixes with increasing distance. In order to improve the accuracy of theodolite readings Würsig *et al.* (1991) summarized several of the necessary elements to organize a shore-based study. Errors in the calculation of the station elevation will bias the calculations of the animal's position. Therefore, the theodolite station height should be greater than 45m and errors in the elevation calculation should be within ± 10 cm (Würsig *et al.* 1991). Thus far, a better understanding of the calculation of the elevation has been the focus of improvements in theodolite accuracy (Würsig *et al.* 1991, Bailey and Lusseau 2004).

Previous boat-based platform studies have assessed the accuracy of distance measurements of animals at sea at close range (0-2 km) using video cameras and binoculars. Gordon (2001) compared the photogrammetric technique with laser rangefinding binoculars and non-differential GPS, and determined that there was a good agreement for ranges measured between these three techniques. Kinzey and Gerrodette (2003) identified the accuracy with which distances can be measured from ships using the reticles in binoculars at a range of 0-8 km. They determined that the accuracy of distance measurements decreased with the distance of the object at sea (Kinzey and Gerrodette 2003). Concerning shore-based tracking, DeNardo *et al.* (2001) established and calibrated a shore-based technique to measure inter-animal spacing using a theodolite and a video camera over a 2 km range from the station.

In this paper, we compare positional information of the same objects from two independent techniques: a shore-based theodolite station and an onboard vessel GPS. By analysing how the difference in the positions from both techniques relates to the distance of the measured object from the shore-based station, we build a model to correct positions estimated from theodolite measurements. The objective of this study is mainly to describe a protocol that should be used when tracking animals at sea from a shore-based station. This protocol will offer the possibility to easily correct the positional error arising in such shore-based data.

2.3. Method

The theodolite accuracy correction was developed for a sperm whale (*Physeter macrocephalus*) habitat study within the Kaikoura submarine canyon in New Zealand. The proximity of the Kaikoura submarine canyon to the coast of the South Island makes it one of the few places in the world where male sperm whales are found close to the shoreline (Gordon *et al.* 1992, Jaquet *et al.* 2000), offering the opportunity to track sperm whales from shore. A shore-based station was set up on a hill situated at the east end of the Kaikoura peninsula (42°25’47. 1’’ S, 173°41’54. 6’’ E) (Fig. 1) at a height of 99.88 m (± 0.04 m) above sea level (method described by Würsig *et al.* (1991). This location provided a good vantage point overlooking the study area encompassing the Kaikoura canyon and surrounding near shore habitat.

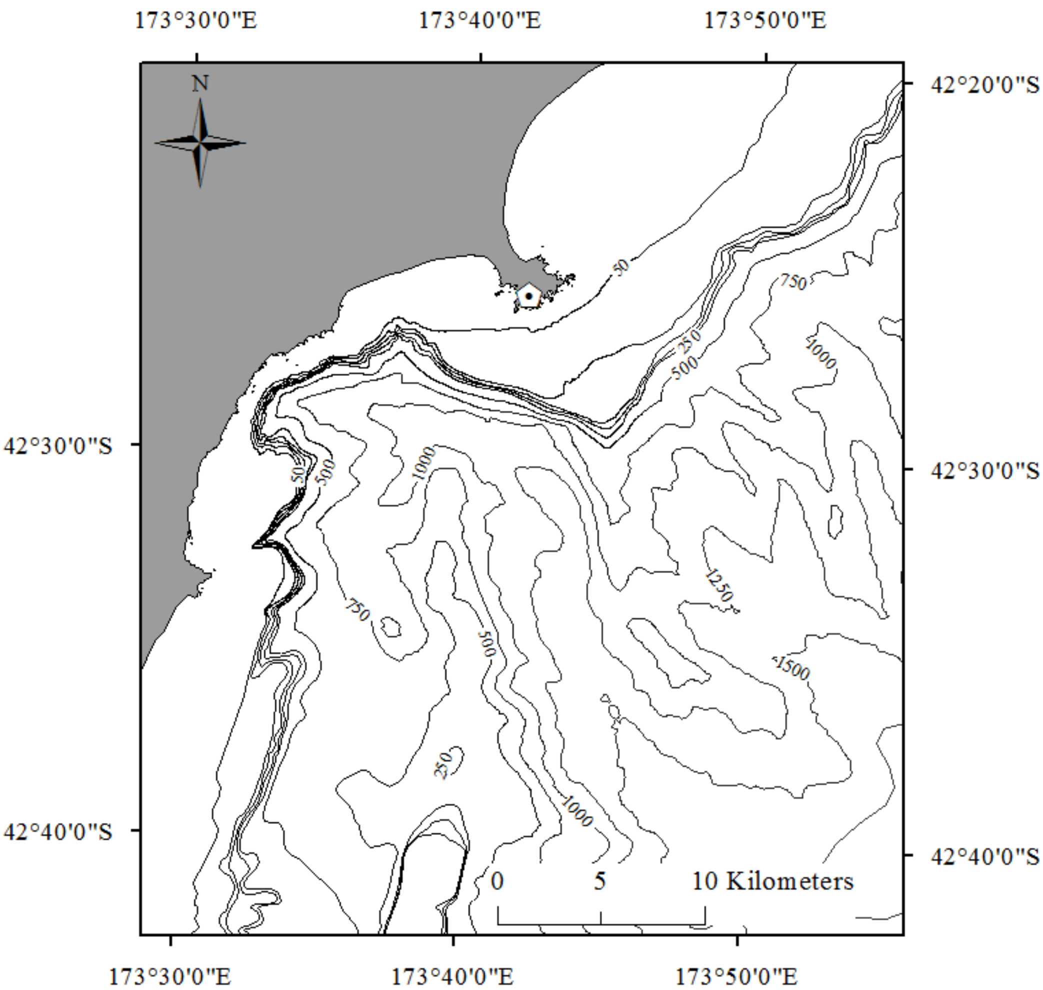

Figure 1. Bathymetry of the study area and location of the shore-based station (pentagon).

2.3.1. Data collection

To determine the theodolite's accuracy, we needed independently derived, and accurate, geographical positions of the same objects taken at the same time as recorded by the shore-based theodolite station. During our study, two research boats were operating inside our study area. One of the research vessels was a 6 m aluminium monohull used for behavioural and acoustic observation on sperm whales. The second vessel was a 5.5 m rigid-hull inflatable vessel used for a study on dusky dolphins (*Lagenorhynchus obscurus*). Both vessels were equipped with a GPS (accuracy within 3m), and recorded the vessel's position every 15 seconds. From shore, we collected the positions of these research vessels using a Sokkia Set4000 theodolite (Accuracy of angle measurement ± 5" and measuring time less than 0.5

sec). For consistency, we fixed the boat positions by placing the theodolite crosshair at the waterline at the centre of the vessel. We connected the theodolite to a laptop running the tracking program Pythagoras (Gailey and Ortega-Ortiz 2002). The software transformed real-time thedolite readings into GPS coordinates corrected for curvature of the Earth and tide level and stored them for analysis (Gailey and Ortega-Ortiz 2002).

2.4. Results

During the study period we recorded a total of 347 theodolite fixes of research vessels (Table 1). The positions recorded were between 2 km and up to 26 km from the theodolite station (Table 1) and were distributed along the whole study area (Fig. 2). For each research vessel position recorded with the theodolite, we extracted the time related position recorded with the vessels' onboard GPS.

Table 1. Distance summary of the two research vessels from the theodolite station (± SE).

	Sperm whale research vessel positions		**Dolphin research vessel positions**
	2010 (N=66)	**2011 (N=137)**	**2012 (N=144)**
Mean distance (m)	12.99 (± 0.74)	11.93 (± 0.39)	7.93 (± 0.28)
Maximum distance (m)	25.85	25.22	18.52
Minimum distance (m)	2.96	4.76	2.45

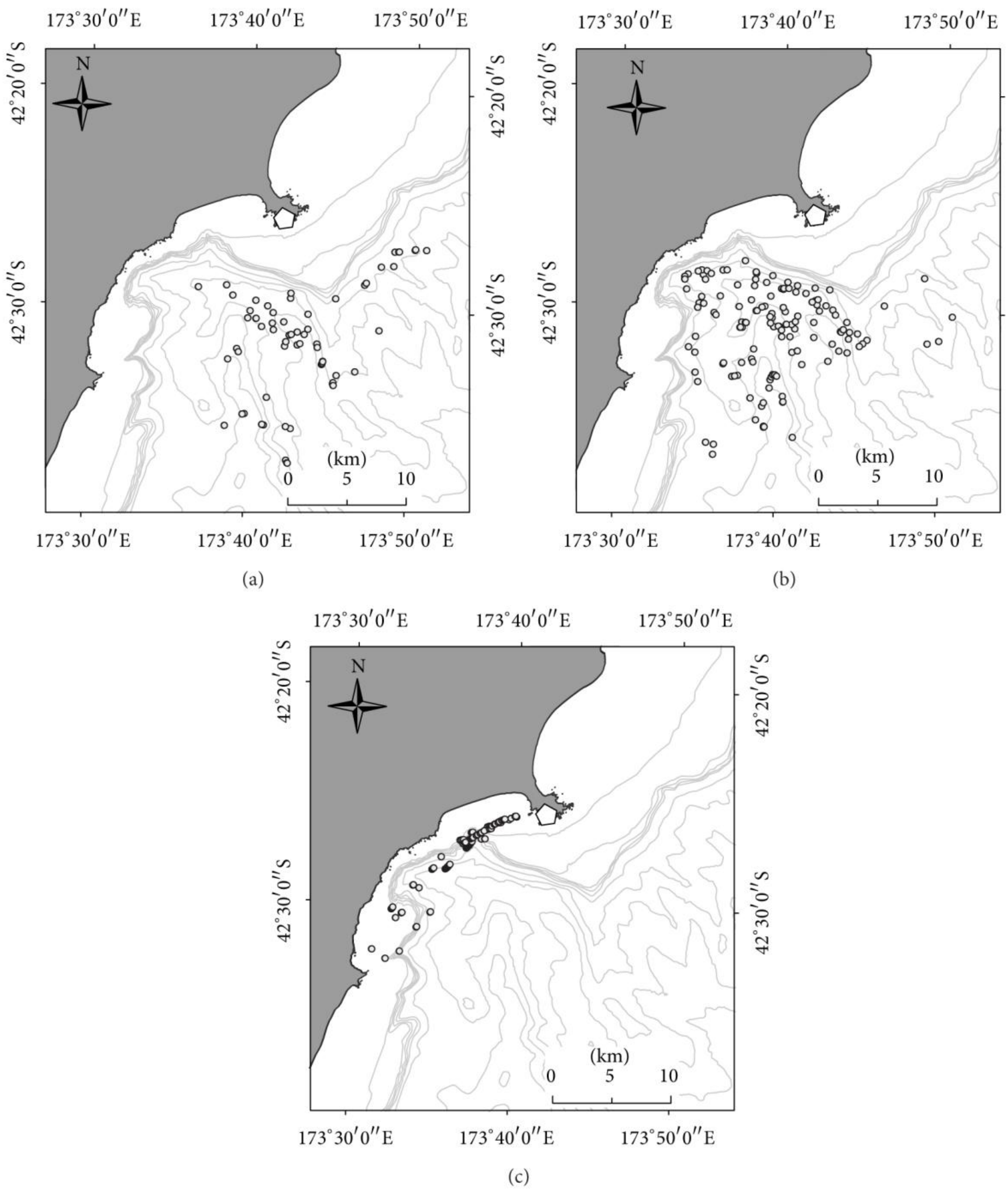

Figure 2. Research vessels locations recorded by onboard GPS by year. (a) and (b) are fixes from the sperm whale research vessel (2010 and 2011) and (c) is fixes from the dolphin research vessel(2012) (pentagon= shore-based station, grey dot= research vessels positions.

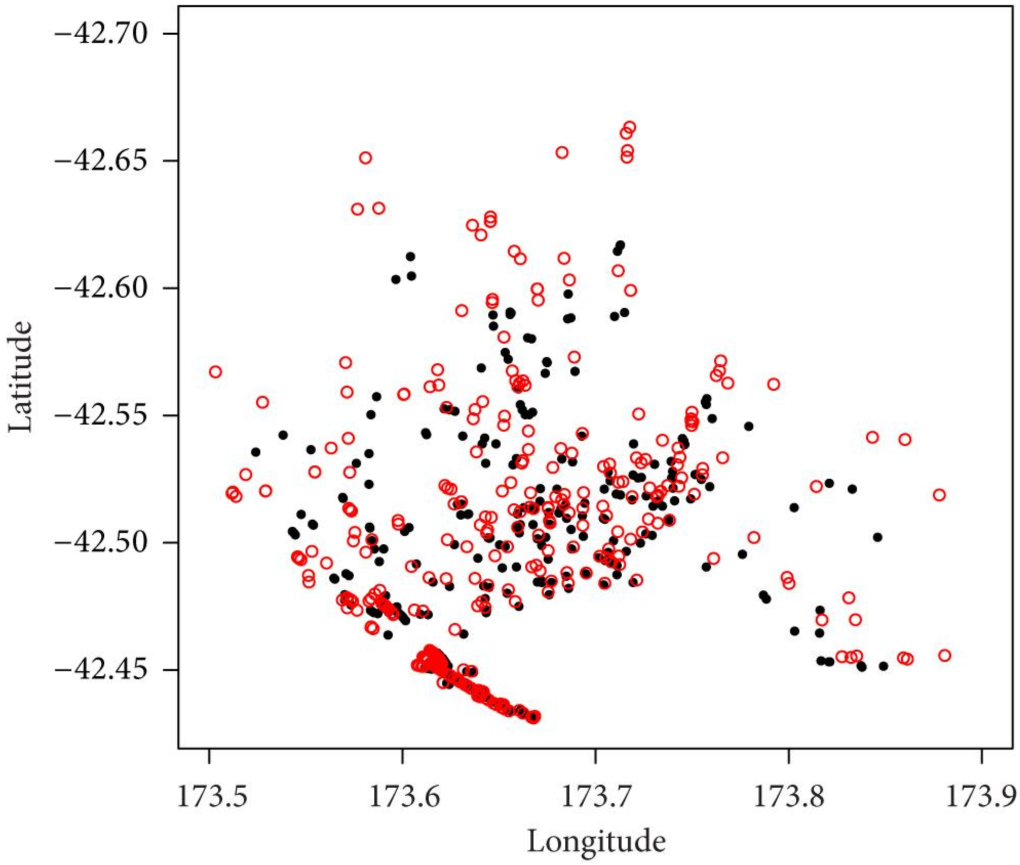

Figure 3. Comparison of all research vessel positions over all years recorded by theodolite (red dots) and by onboard GPS (black dots).

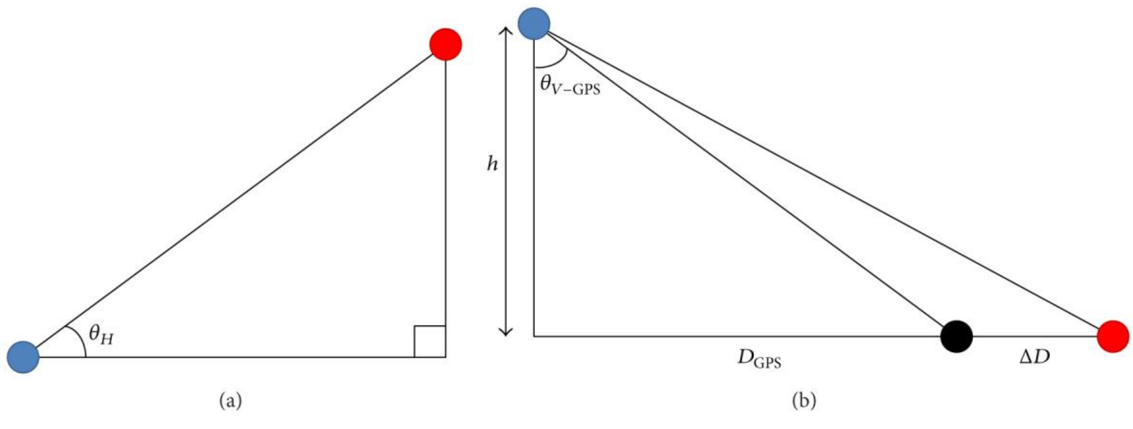

Figure 4. (a) Plan view and (b) side view schematic for the GPS position of a particular position recorded by the theodolite (red dot) compared to the position collected with the onboard GPS (black dot) extracted from Fig. 3. The blue dot is the shore-based station.

We compared vessel positions based on theodolite readings with the time-related positions extracted from the vessels' onboard GPS (Fig. 3). Theodolite and GPS positions appeared to be on the same line as seen from the theodolite station when viewing from plan view (Fig. 4a). However, when seen from the side, theodolite and GPS positions differed (Fig. 4b). We hypothesized that while horizontal angles recorded with the theodolite were accurate, vertical angles were inaccurately determined. We investigated this hypothesis by separately examining the relationships between horizontal and vertical angles measured by GPS and theodolite.

To compare the accuracy, all theodolite fixes and onboard GPS positions were converted to a Cartesian system using the tool "calculate geometry" in ArcGIS 10.1. We also converted the geographic coordinates of the theodolite station in order to centre all the positions with the theodolite station. In order to calculate an angle towards a given position, we made use of the fact that we know the length of the vertical distance (y is latitude converted to the Cartesian system) and the horizontal distance (x is longitude converted to the Cartesian system) to this position.

The horizontal angle (θH) to the research boat position (GPS) or theodolite position (TH) can be calculated using the relationship

tan(θH-GPS) =yGPS/xGPS,

tan(θH-TH) =yTH/xTH.

The vertical angle (θV) to the research boat position (GPS) or theodolite position (TH) can be calculated using the relationship using the distance from the position (D) and the theodolite station height (h):

tan(θV-GPS) = D_{GPS}/ h = (yGPS/cos(θH-TH))/h,

tan (θV-TH) = D_{TH}/ h = (yTH/cos(θH-TH))/h.

The error in distance (ΔD) is given by subtracting the distances recorded from the GPS positions (D_{GPS}) and the distances recorded from the theodolite (D_{TH}):

$\Delta D = D_{\text{TH}} - D_{\text{GPS}}$.

We then determined the distance of the object at sea. As expected, D differed significantly between theodolite and onboard GPS positions (Mann Whitney U test, P = 0.013). While the θH is resolved very accurately with the theodolite (MannWhitney U test, ns), θV is not (MannWhitney U test, P = 0.013).

Since distance from the platform can influence accuracy of theodolite readings, we examined the relationship between distance from shore and the distance error between simultaneously recorded theodolite fixes and GPS positions (Fig. 5). We tested a couple of models to determine the best fitted model and we used the Akaike Information Criterion (AIC) to select the best model. A quadratic model of the form y=a*x^b fitted the data best (Table 2) and we plotted the best curve fitting for visualization (Fig. 5).

Table 2. Results of models analyses (AIC = Akaike Information Criterion; Δ_i (AIC) = AIC_i – min AIC).

Model	AIC	ΔAIC
y ~ a*x^b	**5138.896**	**0**
y ~ x*b	5502.441	363.545
y ~ x+b	6722.799	1583.903
y ~ x	5267.642	128.746
y ~ -1 + x	5502.441	363.545

The best model (y ~ a*x^b) was used to correct theodolite fixes based on their distance from the theodolite station. After applying this correction to our data, the vertical angles of the theodolite fixes did not differ from the GPS positions (Mann Whitney U test, ns). After calibration, theodolite positions did not differ from GPS positions anymore (Fig. 6, Mann whitney U test, ns).

The corrected positions showed normal distributions of errors in distance suggesting no evidence of overall bias in distance after the correction (Fig. 7).

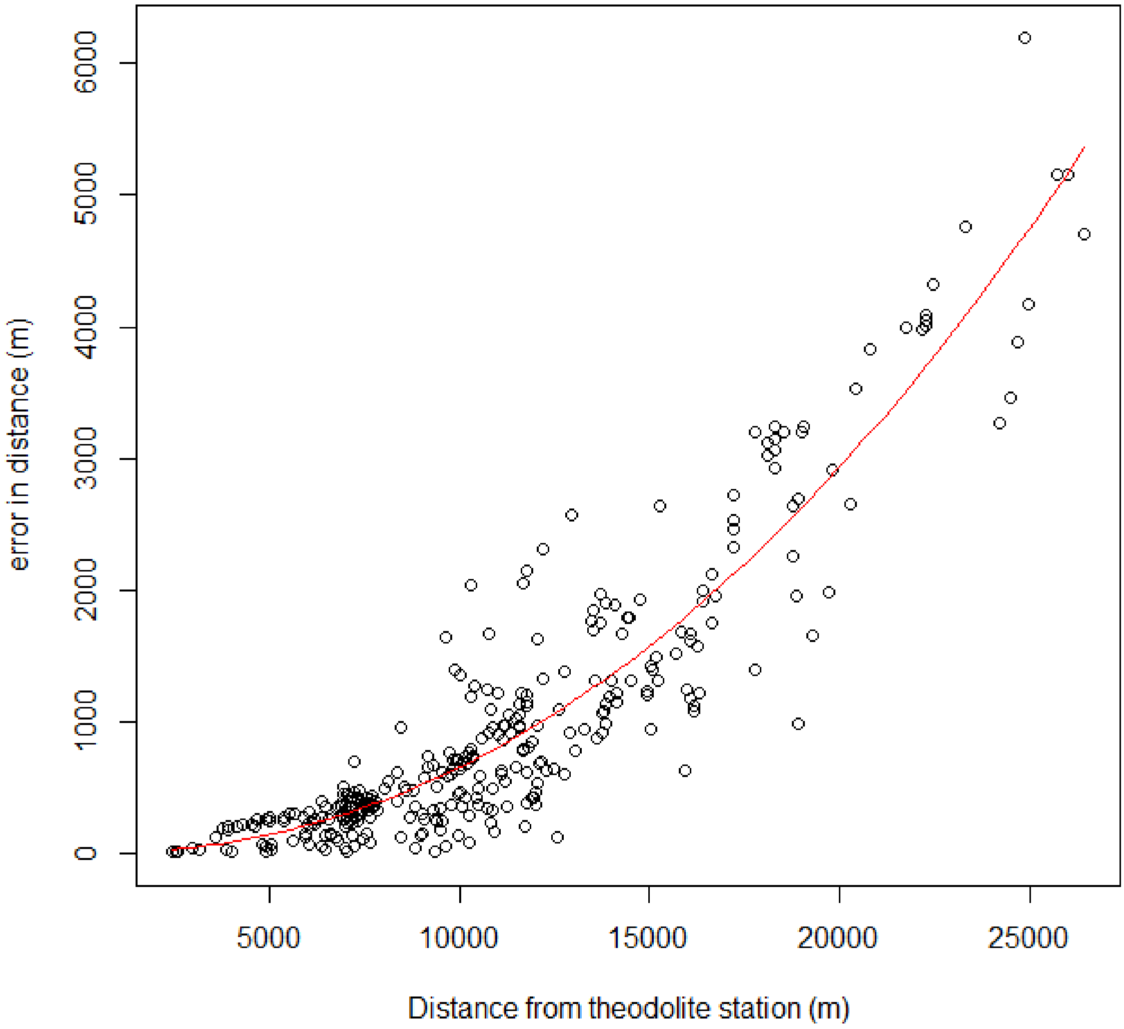

*Figure 5. Error in measurements of distance between theodolite fixes and GPS positions. Red line= best fitting curve (y ~ a*x^b).*

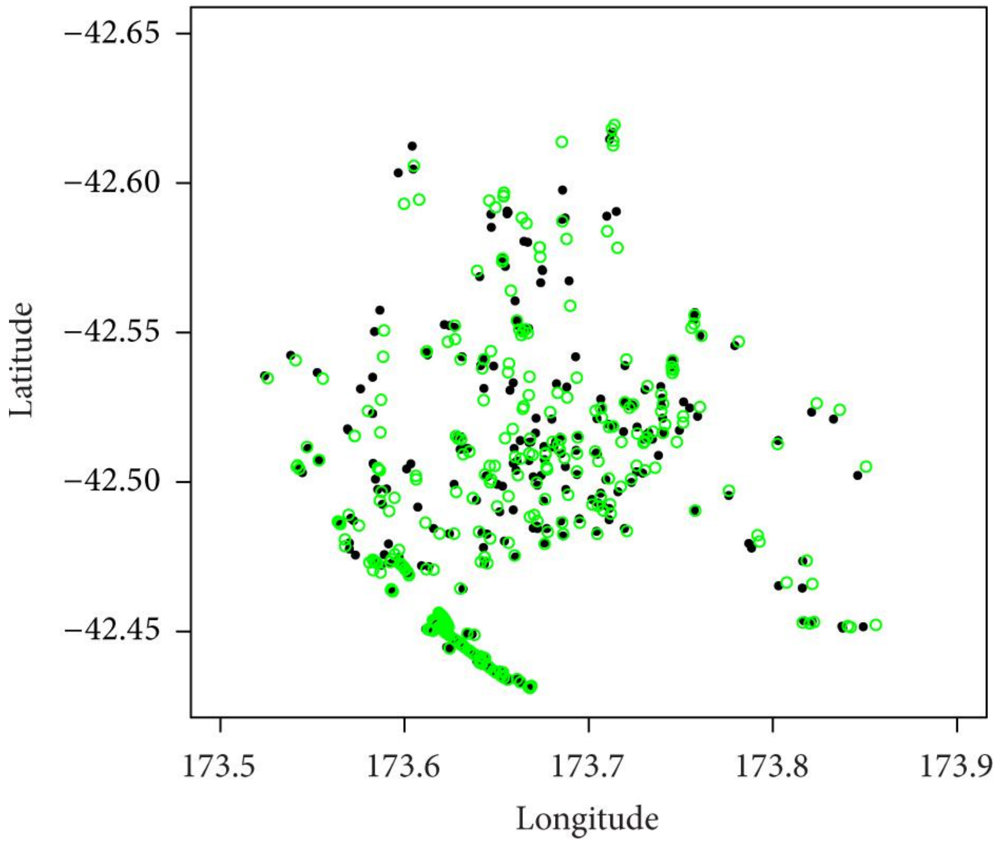

Figure 6. Comparison of the corrected positions of the research vessel over all years recorded by theodolite (green dots) and by onboard GPS (black dots).

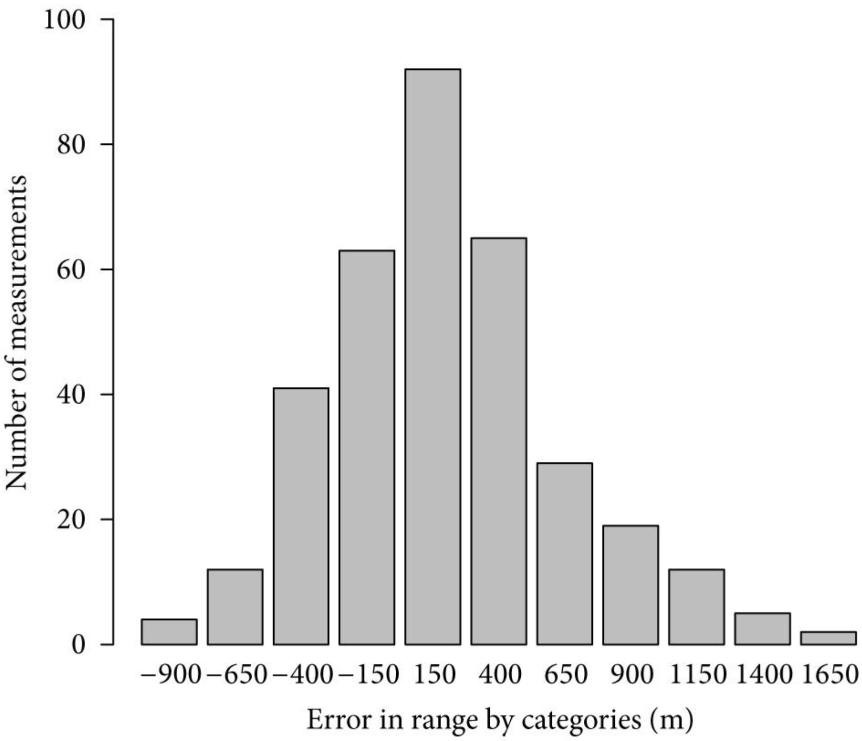

Figure 7. Distribution of ΔD after correction.

2.4.1. What is influencing this error?

A number of parameters can influence the accuracy of theodolite positions, such as the observer experience, the size of the boat, incorrect calibration, imprecision in measuring the theodolite height above sea level (waves, swell, and tidal estimation) and the refraction (Gordon 2001, Kinzey and Gerrodette 2003).

We illuminated the possibility of an error coming from an imprecision in measuring the height of the shore-based station. In order to avoid such an error we determined the height of the theodolite station twice during our study. We also checked the height of the theodolite eyepieces during the day to make sure that it did not vary. To determine the possible effect of the observers on the theodolite fixes, we modelled separately the error with distance depending on the year. During 2010, different people collected the data through the year and data collected from mid-2011 and 2012 were entirely collected by the same observer. By comparing the distance error on the annual dataset with the general distance error on the whole dataset we could assess whether experienced versus inexperienced observer influenced the accuracy in theodolite fixes. We hypothesized that a presence of observer bias will be described by a better accuracy of theodolite fixes towards the end of the fieldwork. However, there was no significant difference in the theodolite fixes corrected by years or corrected using the complete database (Mann Whitney *U* test, ns). We also compared the error in distance from data collected from the same observer with the distance error in the whole dataset and there was no significant difference (MannWhitney *U* test, ns). After these analyses we determined that, in our study, the observer did not significantly influence the accuracy of theodolite fixes.

We then looked at the possible impact of the size of the object being tracked. Analysis showed that there was no significant influence of the boat size on the fixes accuracy (Mann

Whitney *U* test, ns). Therefore, neither observer experience nor object size influenced accuracy of theodolite positions.

Because data were collected from a shore-based station, it was not possible to obtain accurate values for the swell height and the Beaufort sea state. Data were collected only during favourable weather conditions, limiting the effect of swell and Beaufort sea state on research vessels/sperm whales detection. Consequently, it was unlikely that these conditions influenced our results.

The possibility of an error in positioning the theodolite crosshair on the waterline can be one of the factors causing an overestimation of the distance from the shore-based station. Since size of the object will decrease with the distance, it became increasingly difficult for the observer to establish the position of the object waterline. In addition, the size of the theodolite crosshair remained constant, covering up distant and thus small objects, making it difficult to accurately locate the waterline. Therefore the error can come from the difficulty by the observer to accurately position the theodolite crosshair on the waterline which leads to an error that increases with distance.

2.5. Discussion

This study presented the accuracy in determining the position of object at sea using a surveyor theodolite over a distance range of 25 km from the shore-based station. Our results indicated that the model we provided can successfully correct the positional error in shore-based theodolite measurements of animals at sea.

The particularity of this study was to focus on objects found at large distance from the shore-based station. The accuracy and precision of determining the distance of objects at sea has been previously studied for a range up to 8 km from the shore (Denardo *et al.* 2001, Gordon 2001, Kinzey and Gerrodette 2003). Studies using a surveyor theodolite for marine mammals tracking avoided collecting data at large distances because of the likelihood of inaccuracy in the distance estimation. These studies limited their data collection to a critical distance from the theodolite station in order to ensure consistent data (Denardo *et al.* 2001, Findlay *et al.* 2001, Williams *et al.* 2002, Boye *et al.* 2010). By having known GPS positions over the whole study area we significantly improved our theodolite measurements and this allowed us to collect data to the limit of the visual capacity. The method presented here could easily be used in other locations in order to accurately survey a larger study area from a shore-based station.

Theodolite estimation has been shown to be biased by the observer experiences. Our results showed that this factor was not significantly influencing the error. Our observers were trained before the fieldwork and one main observer was in charge of most of the theodolite data collection.

Previous studies found that the swell and Beaufort sea state were important factors influencing the accuracy of distance estimates for sightings of marine mammals (Barlow *et al.* 2001, Kinzey and Gerrodette 2003). In our case, it was not possible to access a database providing information on swell and Beaufort sea state. We looked at the year effect and it was not statistically significant in our model, which suggests that the weather factors did not explain the bias in overestimation of the theodolite measurements.

The effect of refraction was not directly tested during our study. Light does not travel in straight lines; when light travels through the Earth's atmosphere, it is subject to refraction. Mirages and other refraction events are the result of the bending of rays in the Earth's atmosphere. For range measurement studies the effect of refraction will result in an angular error and the distance estimates of distant objects will be seriously affected. Several studies integrated a correction for the refraction for surveys using binoculars and video camera (Gordon 2001, Leaper and Gordon 2001, Kinzey and Gerrodette 2003) based on the air temperature and pressure measured daily during their data collection. If the range measurements are not corrected with the refraction correction, distances will be negatively biased. In our results, the error increase with the distance, rejecting the possibility of an impact caused by the refraction. In addition, by regularly collecting the position of an object at known range during fieldwork all the parameters influencing the error can be corrected.

Optical errors can be an important factor in theodolite accuracy and can be affected by the fact that theodolite scopes are composed of a monocular scope with a single eyepiece. Therefore, it is harder to see the object due to the decreasing field of view, increasing the possibility of an optical error. Parallax error was also considered when positioning the theodolite crosshair. This error is caused by a change in the position of the eye which will change the point of aim of the scope. If the parallax error was important it should influence both vertical and horizontal angles and should differ between observers and days. However, in our study we determined that the horizontal angle was accurately determined by the theodolite.

The last and more probable error came from the crosshair positioning error. This study showed that the observer was able to accurately determine the general position of the object, described with an accurate horizontal angle, but what appeared to be difficult was to establish the exact vertical angle, the position where the object met the waterline. As the object became smaller with distance, it was harder for the observer to define the waterline. Moreover, the large size of the theodolite crosshair made it difficult to position it on small objects. In conclusion, with increasing distance, observers tended to place the theodolite crosshair on the object instead of on the waterline, creating a bias in the positioning crosshair. Positioning the crosshair on the object rather than the waterline will overestimate the distance and may cause the positive bias in distance estimation we observed.

During our study it was not possible to have constant objects found at different distances within our study area and collecting opportunistic vessel positions was the only approach to estimate positional error. Thus, the protocol we propose could be improved by using objects at constant positions, such as buoys. The difficulty will be to have enough such objects across the study area.

2.6. Conclusion

This study revealed the necessity of calibrating theodolite measurements when tracking animals at sea. Known GPS positions of objects within the study area should be used in all theodolite studies in order to correct the error with distance. One of the most important applications of this technique is its potential to improve the use of shore-based stations for habitat and abundance studies at the limit of visual detection.

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3. Estimating sperm whale (*Physeter macrocephalus*) daily abundance from a shore-based survey within the Kaikoura submarine canyon, New Zealand

3.1. Abstract

The Kaikoura submarine canyon (New Zealand) is one of the few places in the world where male sperm whales (*Physeter macrocephalus*) can be found year round close to the shore. The objective of this study was to estimate the daily abundance of sperm whale within the study area. Positions of sperm whales were measured from a shore-based station over a two year study (2010-2012) which included information from 4,613 sperm whale sightings. Distance sampling and mark-resight models were used to estimate daily abundance. Results showed an average of 4 (SEM = 0.13) individuals present in the study area at any given time. These results differ and are much lower than the ones from previous studies. A decline in the daily number of individuals suggests that a cautious management approach is necessary. Our study illustrated the application of distance sampling and mark-resight methods from a shore-based station.

3.2. Introduction

Estimating animal abundance is crucial for effective management and conservation (Soulé 1986). In order to obtain reasonable estimates of animal abundance, methods such as distance sampling have been developed. Distance sampling estimates the absolute density of a population based on the distance between observer and animal (Buckland *et al.* 1993). Central to this technique is the detection function which is the probability to detect an object, given that it is at a certain distance from the random line transect or point transect (Buckland *et al.*

1993). An alternative method uses mark-recapture techniques to obtain population estimates (Hammond *et al.* 1990, Whitehead *et al.* 2000; Forcada *et al.* 2004).

At this time, the most commonly used platforms to determine marine mammal abundance are ships or planes (Barlow 1988, 1995, Barlow *et al.* 1988, Vidal *et al.* 1997, Borchers *et al.* 1998, Buckland *et al.* 2001, Calambokidis and Barlow 2004, Dawson *et al.* 2004, Evans and Hammond 2004, Forcada *et al.* 2004, Mullin and Fulling 2004, Zerbini *et al.* 2006, Williams and Thomas 2007, 2009). However, such studies can be limited by weather conditions, availability of boats/planes and cost (Giacoma *et al.* 2013). Alternatively, shore-based surveys are generally less costly to complete, which allows the possibility to undertake them at a higher frequency or for longer time periods. Shore-based stations also lack the error introduced by movement of boat or plane. The major disadvantages of shore-based surveys are the limited area of coverage, which is restricted to the area visible from shore, and that this method is only applicable for species with at least a temporary coastal distribution (Evans and Hammond 2004).

In this study, we undertook two years of intensive data collection of sperm whale positions within the Kaikoura submarine canyon (New Zealand) from a single shore-based station. The objective was to determine the daily abundance of sperm whales within the canyon. The Kaikoura submarine canyon is one of the few places in the world where male sperm whales are found close to the shore year round (Gordon *et al.* 1992, Jaquet *et al.* 2000). Knowing the abundance of sperm whales within the submarine canyon is of particular importance since this is an area where anthropogenic activities are growing (Te Korowai 2008). The Kaikoura submarine canyon is the focus of an important sperm whale watching industry, which began in the late 1980s and has grown considerably since that time (McAloon *et al.* 1998). Whale watching platforms of local operators include aircraft (both fixed wing planes and helicopters) and ships. Tours operate year round, all day, as long as weather permits. Consequently, there is an economic and biological interest in knowing the abundance of sperm whales.

This study proposes an alternative method to those used previously to assess the abundance of sperm whales within the Kaikoura submarine canyon. Two sampling methods were used to optimize the estimation of abundance under the limitations of observing animals from a shore-based station: conventional distance sampling (CDS/MCDS - point transect) and mark-resight sampling. Because many parameters can prevent the observer from seeing animals, parameters such as sea state and visibility were included using multiple covariate distance sampling (MCDS) (Marques *et al.* 2007).

3.3. Materials and methods

3.3.1. Study area

A shore-based station was established on the highest near-shore hill situated at the east end of the Kaikoura Peninsula, New Zealand (S 42°25’47, 1’’ E 173°41’54, 6’’), providing a good vantage point overlooking a study area encompassing the Kaikoura canyon (Fig. 1).

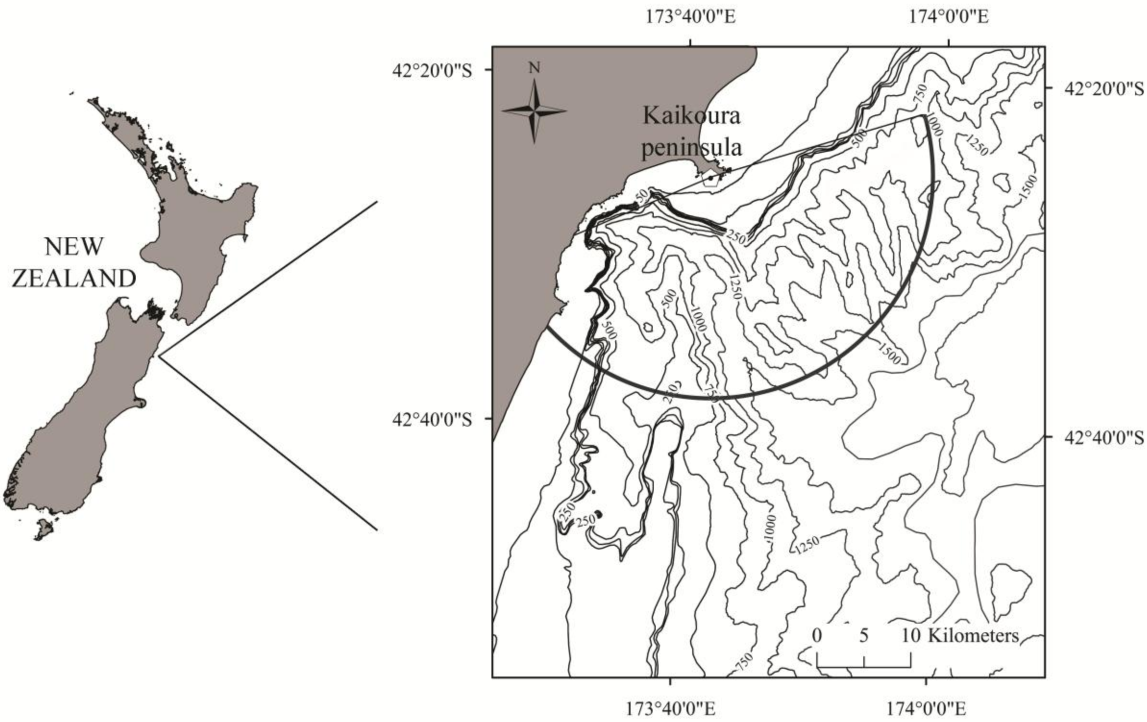

Figure 1. Bathymetry of the study area (25 km buffer/black dashes) and location of the shore based station (pentagon). Survey area is delimited by the black line.

Positions and movements of sperm whales were estimated using a theodolite (Sokkia Set4000) which measures horizontal and vertical angles (Würsig *et al.* 1991, Gailey and Ortega-Ortiz 2002). The theodolite was connected to a laptop running the tracking program Pythagoras (Gailey and Ortega-Ortiz 2002). The software transformed thedolite readings into latitude and longitude coordinates in real time. Coordinates were corrected for the curvature of the Earth and tide level and error associated with distance (Gailey and Ortega-Ortiz 2002, Sagnol *et al.* 2014).

During the day, the study area was scanned constantly with 20x80 binoculars to initially locate sperm whales; the visual coverage (angle from the observation point) was established using a Kestrel pocket weather tracker mounted on the binoculars to obtain compass readings. Whale positions were then recorded using the theodolite. We recorded the Beaufort sea state, an estimation of swell height/direction and of wind speed/direction and percent cloud cover. A visibility score (0-4) was recorded in relation to glare, fog, haze and possibility to see the horizon (with 4 = perfect visibility). All these factors can influence our ability to detect sperm whales. We recorded these weather data every hour and whenever conditions changed.

The seasons were described as:

Autumn: March, April and May.

Winter: June, July and August.

Spring: September, October and November.

Summer: December, January and February.

3.3.2. Analysis

Distance sampling data were analysed using the methods described by Buckland *et al.* (2001). Data were collected from a shore-based station, using a point count survey with radial distance estimated between the observer and the animals. Point counts involve counting the number of animals from a fixed point over a pre-defined time period. The analysis used whale counts restricted to the first hour of daily observations made during good conditions (visibility ≥ 3 and sea state ≤ 2). Previous studies off Kaikoura have shown that sperm whales spend between 7 and 14 min resting at the surface, and approximately between 30 and 49 minutes foraging underwater (MacGibbon 1991, Gordon *et al.*1992, Jaquet *et al.* 2000, Richter *et al.* 2003). So the one hour time window offered us the possibility to limit the risk of resighting an individual. We also tested other time window parameters such as one random hour during the day, all data collected during a 6 hour period and data collected three times during the day during a period of one hour.

Estimation of abundance by mark-resight sampling

Mark-recapture studies are based on sighting uniquely marked individuals and calculating abundance based on resightings of previously encountered individuals (Seber, 1982). If n_1 and n_2 are the numbers of animal captured during sampling periods t_1 and t_2, and m_2 is the number of animals marked on occasion 1 that are re-sighted at occasion 2, then the Chapman modification of the Lincoln-Petersen estimator may be applied to determine the estimated abundance (N) (Hammond 1986):

$$N = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

For the Chapman modification of the Lincoln-Petersen estimator we used whale counts restricted to the first hour (t_1) of daily observations for n_1 and whale counts made during the second hour (t_2) of daily observations for $n_{2.}$

This method has been applied to data derived from photographic records of naturally marked individuals (Hammond *et al.* 1990), such as photographs of the trailing edge of sperm whale flukes (Arnbom 1987). When the assumptions of the technique are fulfilled, such as marks are not lost and all animals have the same survival probability then mark-recapture techniques can provide unbiased estimates (Calambokidis *et al.* 1990, Whitehead *et al.* 2000, Campbell *et al.* 2002, Chilvers and Cockeron 2003, Irwin and Würsig 2004).

From a shore-based station it is not possible to determine marks on individuals. In this study we established another way to estimate when the same animal was re-sighted from land. This is based upon the following assumptions.

a) It is possible to follow the same individual through his entire time at the surface, from the first blow when the whale is sighted to the onset of a dive indicated by "flukes up" behaviour). So the collected daily data correspond to the number of surfacings made by individuals within the study area recorded during the day.

These mark-resight sequences only apply to sequential dives of a whale within a single day and not across days.

b) The diving behaviour of sperm whales in the Kaikoura canyon is predictable and changes only slightly with the season (Richter *et al.* 2003). Previous studies showed that sperm whales spend between 7 and 14 min resting at the surface and approximately between 30 and 49 min underwater, moving as far as 3 km from their last surfacing (MacGibbon 1991, Gordon *et al.* 1992, Jaquet *et al.* 2000, Richter *et al.* 2003).

The above temporal and spatial data were used to set criteria for data extraction which optimized the probability that the same whale was re-sighted in a series of surfacings. A computer program was written (Python programming language) to extract the positions of individuals as they progressed over the canyon. Two criteria were applied to extract sequential position data for a whale:

a) The elapsed time between a given fluke up and the first subsequent blow was limited to 30-60 min.

b) The distance between these two events was ≤ 3 km.

We chose a longer time window compared to the one described in the above studies, in order to include variation between individuals, and also to take into consideration that the first subsequent blow in the data sequence may not have been the first actual blow upon resurfacing. Any whale surfacing within this spatio-temporal buffer of 30-60 min and 3 km around a fluke up event was most likely the same individual that was sighted previously. We also tested other temporal and spatial selection criteria in order to evaluate the influence of these criteria on our analysis. The 30-60 min and 3 km criteria were deemed to be the most appropriate criteria. In order to assess the accuracy of our ID assignments based on the criteria, we correlated these results with photo-IDs of sperm whales taken by a simultaneous boat-based study. Time and position of sperm whale IDs photographed from the boat and sighted by the shore-based study were correlated. From a total of 55 days of data collected at the same time with the boat and the shore-based stations, 88 % of the computer-generated matches from the shore-based station correspond to the same individual's determined using photo-ID from the boat-based study (160 comparisons).

3.4. Results

3.4.1. Effort and Sightings

The shore-based point transect survey covered a field of view of 900 km^2 within the Kaikoura submarine canyon area (Fig. 1). The study area was delimited by our visual capacity to sight a whale, determined as a radius of 25 km around the shore-based station and which represents 88.9 % of canyon habitat for sperm whales (within a depth > 200m). We scanned the study area for a total of 2014 hours over a two years period (2010-2012). For this analysis only days with good sighting conditions were used (visibility $\geq$ 3 and sea state $\leq$ 2). A total of 4613 sperm whale surfacing events were recorded during good sighting conditions, and 98 % of sightings were of solitary individuals.

3.4.2. Detection probability

We calculated abundance estimates using the standard point transect formula in DISTANCE 6.0 (Buckland *et al.* 1993, Thomas *et al.* 2009). Analyses were carried out using conventional points counting distance sampling methods (Buckland *et al.* 2001). We selected the model that minimized the Akaike Information Criterion (Δ_i (AIC)), which is a measure of model fit. In order to quantify the likelihood of each model given the data, the Akaike weight (w_i) was calculated:

$$w_i = \frac{\exp(-\frac{1}{2}\Delta_i\,(AIC))}{\sum_{r=1}^{R}\exp\,(-\frac{1}{2}\Delta_r\,(AIC))}$$

The hazard-rate key function presented the best fitting plotted detection function (lowest AIC) and was selected for subsequent models (Table 1). Following the recommendation by Buckland *et al.* (2001) we removed 5% of the sightings collected at the largest distances from the shore-based station, allowing a better model fit. No observations were recorded near the station (< 5000 m) due to the preference of sperm whales for deep water. Accordingly, the data were left-truncated at 5000 m during analysis in order to shift g(0) = 1 to g(5000) = 1 with the assumption that at the 5000 m distance all individuals present were observed. The probability of detecting all individuals at g(0) is affected by both availability bias and perception bias (Marsh and Sinclair 1989). In this study we treated the availability bias by using a scanning time window of 60 min. This time window offered the possibility to detect all the individuals present in the study area given that it was slightly greater than the average time a sperm whale was submerged (Barlow *et al.* 1988). Additional variables (habitat, behaviour, observer, weather condition) can also impact the probability to detect animals. To account for these covariates we also used multiple covariate distance sampling (MCDS) on the dataset. Beaufort sea state, visibility and bottom depth at which the animals were detected were included as covariates.

The CDS and MCDS estimates of abundance were not different but on the basis of AIC the MCDS with two covariates, Beaufort sea state and visibility, was preferred (Fig. 2).

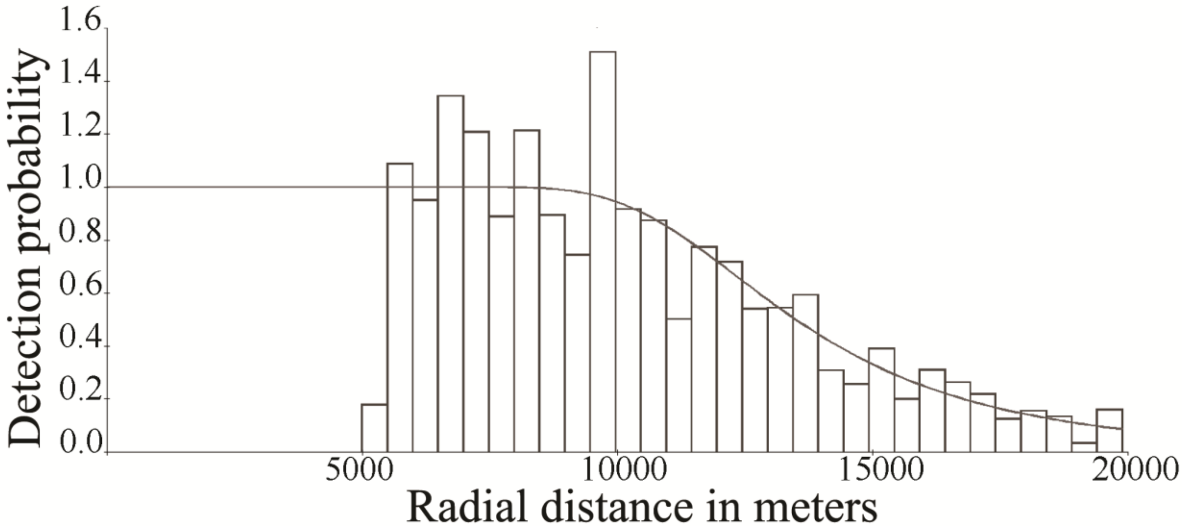

Figure 2. Detection probability for whales sighted from shore-based station using a MCDS harzard function with a cosine adjustment term. Left truncated at 5000 m, due to no sightings between 0-5000 m, and 5% right truncated.

The results of models with an Δ_i(AIC) < 9 that used distance, visibility, Beaufort sea state and depth as potential covariates in a distance sampling analysis are presented in Table 1. The w_i(AIC) can be interpreted as the probability that *i* was the best model, given the data and set of candidate models. Analysis of AIC values revealed that three models, all including visibility as an important covariate, provided more information than the remaining models (Table 1). From an inspection of the Akaike weights in Table 1, the model with the highest Akaike weights is model 5 with the hazard function and two covariates (Beaufort sea state and visibility). As expected, with good visibility, which is an important covariate in our models the detection probability increased.

Table 1. Model-selection results for distance sampling detection probability function for sperm whale survey data with left truncation = 5000 m (n = 586).

# Model	Key + adjustment	Covariate	AIC	Δ_i (AIC)	w_i(AIC)	N	CV(%)	D	CV(%)	P	K-S *p*
1	Hazard + cosine	no	11161.02	8.53	0.006	4	5.030	0.005	5.030	0.495	0.127
2	Hazard + cosine	Beaufort sea state	11157.74	5.25	0.033	4	3.140	0.005	3.140	0.456	0.721
3	Hazard + cosine	Visibility	11153.51	1.02	0.273	4	3.150	0.005	3.150	0.464	0.650
4	Hazard + cosine	Depth	11159.93	7.44	0.012	4	3.130	0.005	3.130	0.456	0.739
5	**Hazard + cosine**	**Visibility + beaufort sea state**	**11152.49**	**0.00**	**0.456**	**4**	**3.190**	**0.005**	**3.190**	**0.459**	**0.740**
6	Hazard + cosine	Visibility + beaufort sea state + depth	11154.39	1.90	0.176	4	3.200	0.005	3.20	0.455	0.716

Note: AIC = Akaike Information Criterion; Δ_i (AIC) = AICi – min AIC; w_i(AIC) = Akaike weights; N = abundance estimate; D= density estimate whale/km²; CV = Coefficient of Variation; P = detection probability; K-S *p* = Kolmogorov–Smirnov goodness-of-fit *p*-value.

3.4.3. Daily abundance

We used the optimum modeling procedure in the program DISTANCE 6.0 to generate encounter rate, density and daily abundance. The results gave an estimated daily abundance of 4 sperm whales (CV = 3.9%, 95% CI = 4-5) and density for the study area of 0.005 whales/km² (CV = 3.9%, 95% CI = 0.0046-0.0052). A detection probability of 0.46 (CV= 3.12%, 95% CI = 0.431-0.488) occurred within the study area. These results were made using the first hour of each day of data collection; The mean estimated daily abundance for the three other methods (one random hour/ 6 hour period/ three times count) was 4.5 sperm whales (± 0.72).

We also investigated g (0) = 1 by pooling the data into categories (0-5, 5-10, 10-15, 15-20 and 20-25 km). We could not directly compare the AIC between the models determined by pooling categories and the ones using a left truncation due to different data being used. The results demonstrated that pooling the sightings tended to slightly decrease the estimated daily abundance (N = 3 sperm whales, CV = 3.23 %, 95% CI = 3-4). The modeling of data close to the point transect should have the greatest impact on density, however in our case the lack of sightings close to the shore is directly influencing the abundance and the left truncation at 5000m seemed more appropriate in our study.

We compared the distance sampling results with two other methods: the mark-resight analysis and the mean number of sightings/hour (Fig. 3). In order to determine the number of sightings/hour, we calculated the ratio of the total number of sightings collected during the day and the number of hours spent collecting data during this day. The mark-resight method estimated the highest abundance with a mean of 5.5 sperm whales (± 0.20) at all times during our data collection and the number of sightings/hour estimated the lowest abundance at 2.5 (± 0.10) individuals (Fig. 3). There was no statistical difference between the abundance extracted using distance sampling and the other two methods (Mann-Whitney, NS). The abundance results for the mark-resight and the number of sightings/hour methods differed significantly (Mann-Whitney, P = 0.012). The number of sightings/hour method underestimated the number of individuals; this underestimation can be explained by the fact that this technique extracted raw data, without being corrected by distance and perception bias.

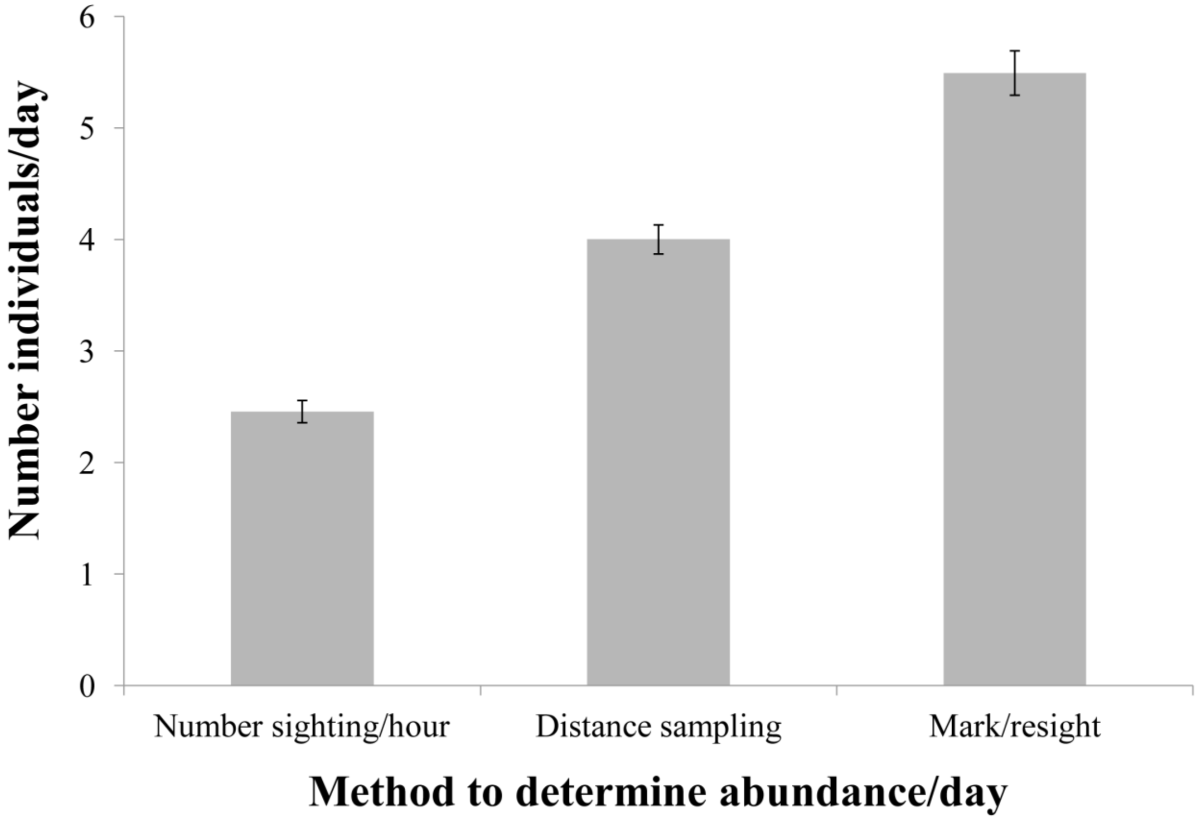

Figure 3. Mean (± SEM) daily abundance of sperm whales within the Kaikoura submarine canyon determined using 3 methods.

We compared the three methods of estimating seasonal mean number of sperm whales occupying the submarine canyon (Fig. 4).

The abundance varied significantly between the seasons (Kruskal-Wallis, $P < 0.0001$). All three methods displayed the same pattern for spring with a lower number of whales in the study area, correlated with the absence of sperm whales for a couple of weeks during this season. The difference of abundance with the mark-resight method can be related to the range of error inserted by our spatio-temporal model. During the day, if we missed the surfacing of an individual already recorded, when resighted later during the day the computer program will determine this whale as a new individual.The accuracy of the computer program was dependent of our capacity to record all the surfacing of each individual during the day. 11 % of the matching errors corresponded to an already observed whale recorded as a new individual, which resulted in an overestimation of the abundance using this method.

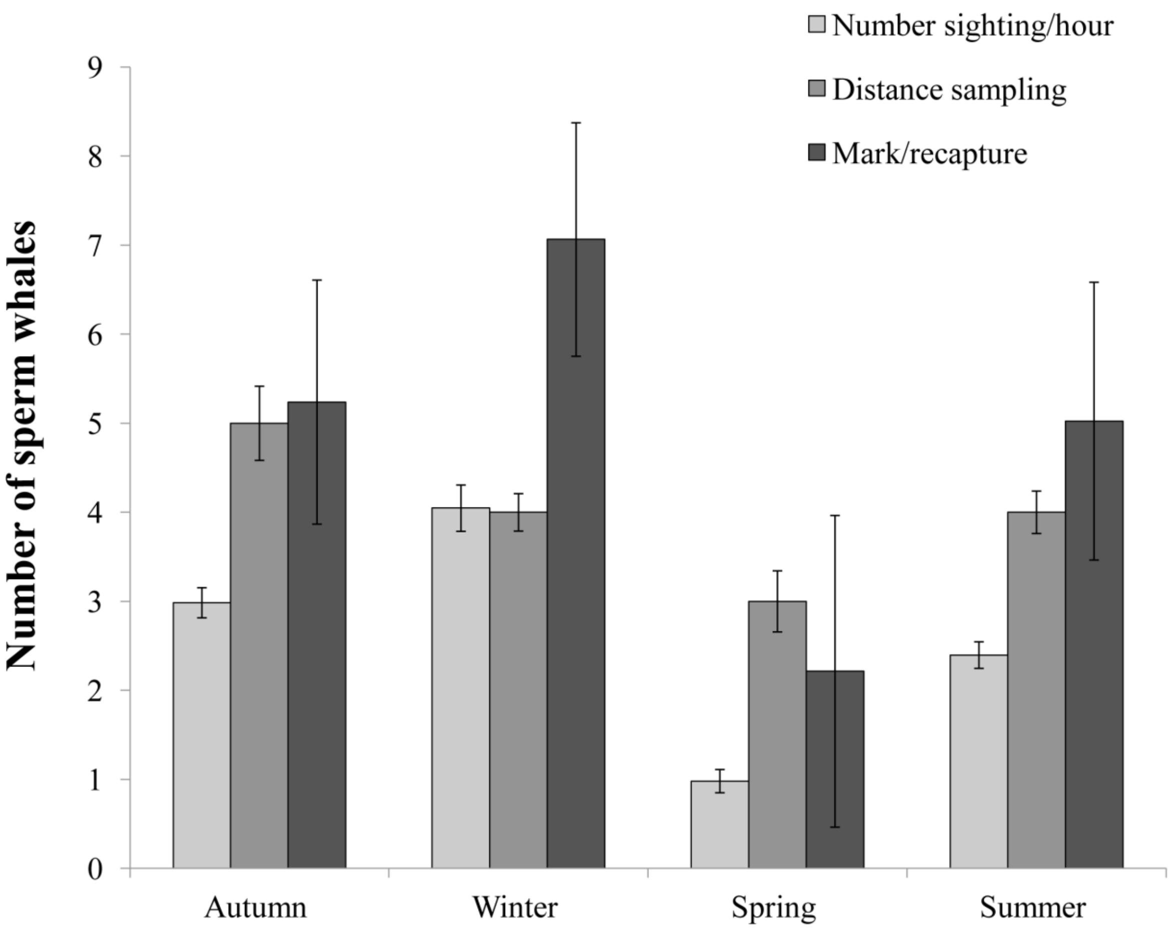

Figure 4. Mean seasonal abundance of sperm whales within the Kaikoura submarine canyon using three different methods (± SEM).

3.5. Discussion

The objective of this study was to estimate the abundance of sperm whales within the Kaikoura submarine canyon by pooling sighting data from a shore-based station using distance sampling and alternative mark-resight analysis. This study has provided the first daily abundance estimates of sperm whales within the Kaikoura submarine canyon collected from a shore-based station. Determining marine mammal abundance is fundamental for management procedures, where cost becomes important. This study indicated that low-cost shore-based methods to estimate abundance are efficient. In our study we used alternative methods to record abundance information from a shore-based station. By using three different methods to determine the daily abundance we optimized the analysis performances and our ability to critically evaluate this information.

We estimated that the Kaikoura submarine canyon hosts between 4 and 5 sperm whales on a daily basis using distance sampling. Numbers of individuals of sperm whales in the present study area were lowest during spring. This is not surprising as we observed many individuals leaving the survey area during this period, resulting in a total of 35 survey days (during the two years of field work) without sighting any individuals. It would be an interesting future research project to attempt to understand why this movement out of the canyon occurred, as it could help to understand the variation of abundance over the years.

Previous studies using photo-identification mark-recapture, estimated the general abundance of sperm whales off Kaikoura. Childerhouse *et al.* (1995) estimated that 60 to 108 sperm whales visit the study area during any one field season and Van der Linde (2010) estimated 57-97 individuals. These studies looked at the general abundance of sperm whales within the study area during any field season. In our case, we focused on determining the number of sperm whales within the area on any given day, as it is not possible from a shore-based station to determine which individual is present during consecutive days. Therefore, it is not possible to compare the above studies with our results. However, a third study determined that there are on average 13.8 (± 1.3) whales in the study area on any given day using the lagged identification rate, which is based on fluke ID data from boat-based surveys (Lettevall *et al.* 2002). For this study, they used data collected during previous studies between 1990 to 2001 each summer and some winters within a study area of 10 x 20 and 10 x 15 naut. mi (1 naut. mi = 1.853 km). Our results using distance sampling showed a much lower number of whales within our study area of 900 km^2, with 4 (± 0.13) individuals at any given time. A couple of factors can explain the difference between both studies. Our study was done on a smaller temporal scale, with data being collected on a daily basis over a two years study, with the data collected equally (only weather dependant) through the months and encompassing a larger survey area. However, the study of Lettevall *et al.* (2002) only used data collected in summer and winter, thus possibly overestimating the abundance of sperm whales by using data collected during months where the number of individuals is larger. This result could also be related to the difference in photographic effort between seasons. In conclusion, our results introduce the possibility of a large reduction in sperm whale occurrence within the Kaikoura submarine canyon compared to the one determine by earlier work and this difference can be explained by a decrease of the use of this particular area by sperm whales. However, the alternative methods used in this study make it difficult to compare our numbers with previous studies.

Van der Linde (2010) detected a decline from 97 individuals (95% CI: 62-153) in 1991 to 46 individuals (95% CI: 36-60) in 2007. In addition to observing a long-term decline in abundance of the total number of sperm whales that visit Kaikoura, a similar significant decline was found when only returning resident whales were considered (Van der Linde, 2010). This change could be due to human activities (Norris and Dohl 1980). For example, Wells (1993) showed that the presence of bottlenose dolphins in Sarasota Bay, Florida, decreased during the weekend in relation to an increase in boat traffic. It is likely that this decline is caused by avoidance behaviour. The whales within the Kaikoura canyon are frequently visited by tour boats, airplanes and helicopters, which may cause individual whales to reduce their time spent in the area.

These results could also arise from a redistribution of animals to offshore waters, or from individuals moving to other areas in response to environmental variations influencing food availability. Food is the main factor influencing species distribution; thus cetacean distribution is positively correlated with presence/absence of prey (Davis *et al.* 2002).

Current whale watching conservation procedures (limit number of tours, restricted distance from whale and number of vessels around one individual) appear to appropriately managed and minimize the influence of vessels on sperm whales (Markowitz *et al.* 2011). We still have a lot to learn concerning the sperm whales population off Kaikoura. Reliable information is necessary to determine which other feeding grounds these sperm whales are using when out of the study area and how important the Kaikoura submarine canyon is for the sperm whale population in the South Pacific.

Consequently, it is important that this population is properly managed to assure that the occurrence of sperm whales so close to shore continues to provide a unique opportunity for the local tourism industries and for ecological research.

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4. A spatio-temporal model to track individuals from a shore-based station: A case study for sperm whales (*Physeter macrocephalus*) off Kaikoura, New Zealand

4.1. Abstract

The sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon (New Zealand) show regular spatio-temporal patterns in the time they spend at the surface and the time spent diving for food. Our objective was to build a spatio-temporal model in order to track the identity of individuals from a data set of sperm whales sightings collected from a shore-based station. The main hypothesis to build the model was that an individual should surface again inside a spatio-temporal buffer of 30-60 min and 3 km around the last dive position of this same individual. In order to support the model, we correlated photo-identification of sperm whales collected from a boat-based station with the identification made by the model. We recorded simultaneously from the shore-based and the boat-based station a total of 160 sightings of sperm whales. 88% of the modeled identifications corresponded to the photo-identification database.

4.2. Introduction

Management and conservation of wildlife populations often require the recognition of individual animals so that such animals can be followed through time (Lebreton *et al.* 1992, Caughley and Gunn 1996). Individual recognition is typically achieved either by applying an artificial mark to an animal or by using an animal's natural markings (Whitehead *et al.* 2000). The natural marking of animals has become a major tool to identify individuals and study populations of animals from badgers to whales (Sears *et al.* 1990, Stevick *et al.* 2001). The most popular technique of recording such markings is photo-identification (Fujiwara and Caswell 2001, Dixon 2003, Meekan *et al.* 2006).

For marine mammal research, photo-identification techniques were introduced in the 1970s. Most cetaceans exhibit individually distinctive patterns of skin coloration, scars and particular curved edges of flukes and dorsal fins which accumulate over their lifetimes through interaction with other cetaceans, predators and the environment (Hammond *et al.* 1990). Unfortunately, some studies of marine mammals do not allow the scientist close access to those mammals in order to take an identifying photograph. This is the case for shore-based studies, where it is not possible to determine marks on individuals as the animals are identified at a considerable distance from the observer (from 5km from shore up to 25 km). When it is not possible to identify a particular individual from a population using photo-identifications, other techniques need to be explored.

From a shore-based station it is not possible to identify individuals using their natural markings. The objective of this study was to establish an alternative method to determine when the same animal was resighted from a shore-based station using a spatio-temporal model based on the well known feeding behaviour of sperm whale within the Kaikoura submarine canyon. Knowing the future behaviour of the sperm whale through a learned model of previous behaviour which occurs in predictable patterns will offer us the possibility to build a model that allows us to simulate these regular behaviours through time. Photo-identifications of whales from a boat-based station were used to quantify the error rate of the model. Sperm whales have a very predictable behaviour when observed in a feeding ground and are known to continuously conduct deep foraging dives, so it is possible to predict the likely future location of an individual in order to create a continuous record of the same sperm whale through multiple surfacings.

The Kaikoura region in the South Island of New Zealand is the ideal place to study sperm whales from a shore-based station with the proximity of the Kaikoura submarine Canyon making it one of the only places in the world where male sperm whales are found close to the coastline (Gordon *et al.* 1992, Jaquet *et al.* 2000). The sperm whales off the Kaikoura coast are almost exclusively adult and sub-adult males (Dawson *et al.* 1995), consistently using this area as a feeding ground (Jaquet *et al.* 2000).

4.3. Materials and Methods

We measured the positions and movements of sperm whales using a theodolite (Sokkia Set4000) established on the highest near-shore hill situated at the east end of the Kaikoura Peninsula, New Zealand (Fig. 1) (S 42°25'47, 1'' E 173°41'54, 6'') at a height of 99.88 m (± 0.04 m) above sea level.

During the day, we constantly scanned the study area with 20 x 80 binoculars to locate sperm whales, for which we recorded the positions using a surveyor theodolite (Table 1). Behaviours were recorded and described as follows (Whitehead and Weilgart 1991):

- Blow: visible each time air is expelled through the blowhole
- Fluke up: whale tail is above the water surface, indicating the beginning of a dive.

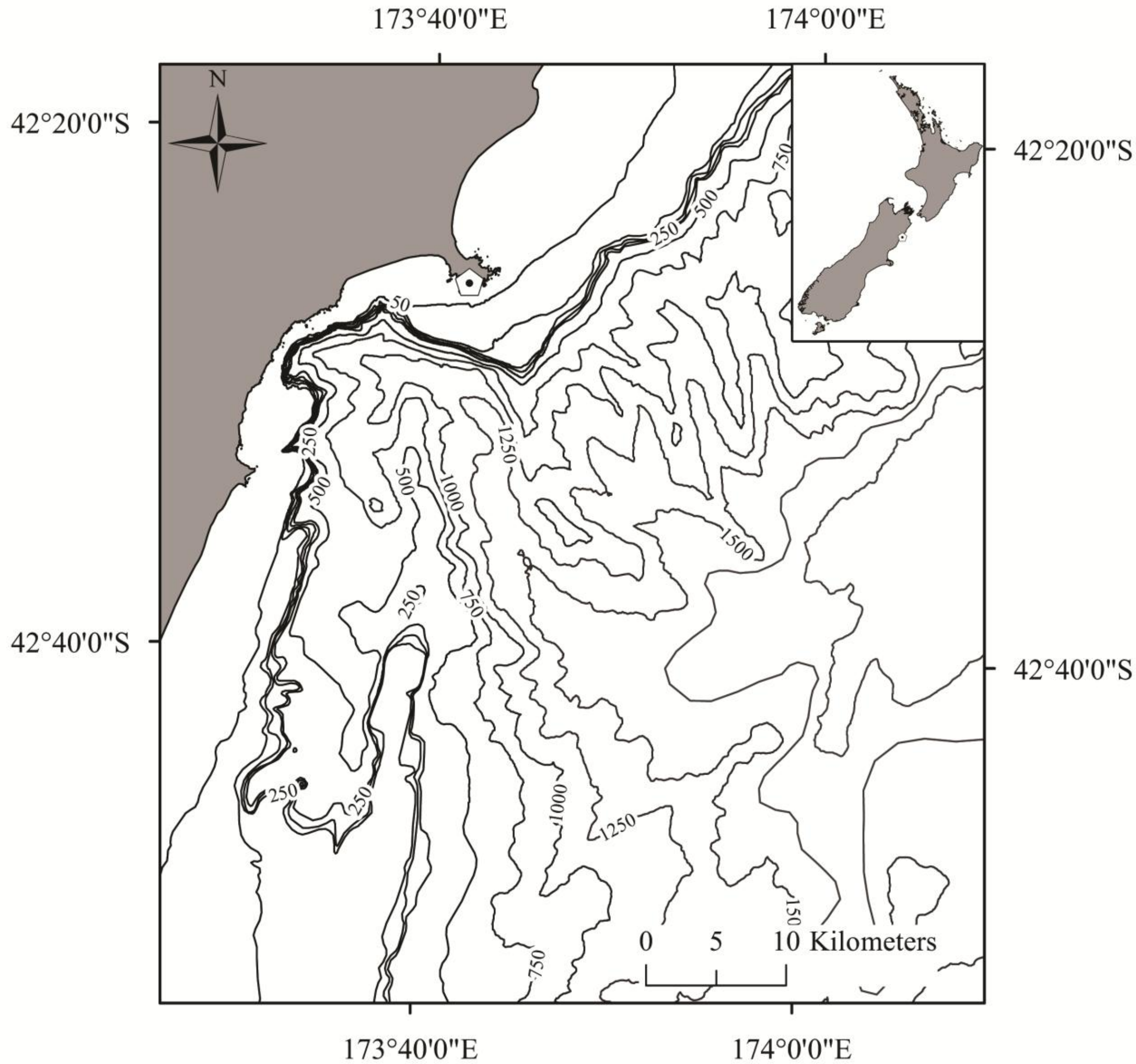

Figure 1. Bathymetry of the study area and location of the shore based station (pentagon).

We followed the same individual through his entire surface period, starting from the first blow sighted from the shore-based station until the fluke up of this individual indicating the beginning of a foraging dive. Most of the sperm whales encountered during the study were feeding, making long dives with periods of recovery at the surface. An exception was observed twice for a whale which spent over two hours breathing slowly at the surface that is, appearing to be resting. We observed at rare occasions other behaviour such as shallow dives, whale making short dives ending without fluke up. Data from these unusual encounters have been excluded from the analyses and we only used surface peridos finishing with observation of the fluke up. We associated a group number for each surfacing (first blow to fluke up), so each group corresponded to a different encounter but we did not know if they were from the same whale (Table 1).

Table 1. Sample of data recorded using the theodolite.

Time	Fix Type	Group Number	Behaviour	Longitude	Latitude
08:48:27	Sperm Whale	1	Blow	173. 666	-42. 519
08:56:58	Sperm Whale	1	Fluke up	173.667	-42.515
09:18:09	Sperm Whale	2	Blow	173.686	-42.505
09:20:07	Sperm Whale	2	Fluke up	173.686	-42.506
09:42:37	Sperm Whale	3	Blow	173.683	-42.530
09:43:24	Sperm Whale	3	Fluke up	173.683	-42.530
10:05:08	Sperm Whale	4	Blow	173.684	-42.539
10:27:52	Sperm Whale	4	Fluke up	173.694	-42.540

Previous studies have shown that the majority of sperm whales off Kaikoura spend between 7 and 14 min resting at the surface, and between 30 and 49 minutes underwater, foraging, and moving as far as 3 km from their last surfacing (MacGibbon 1991, Gordon *et al.* 1992, Jaquet *et al.* 2000, Richter *et al.* 2003). This pattern may lightly vary between transient and resident individuals and between seasons (Richter *et al.* 2003).

We developed a spatio-temporal model knowing the specific behaviour of the sperm whale within the Kaikoura submarine canyon to capture this behaviour and to track the identity of individual sperm whales. We wrote the model in *Python* 2.7.2 on win32. The *Python* programming language offered an efficient coding style and an excellent choice as the preferred scripting language (Sanner 1999, Oliphant 2007). We choose the simple syntax of *Python* because it results in a language that is easy to learn for people without particular knowledge of programming and used by researchers who want to construct environmental models (Karssenberg *et al.* 2007).

The model considered the sperm whale as a system whereby we described each component using thresholds derived from scientific knowledge related to sperm whale behaviour in this particular area. Given the regularity of sperm whale behaviour it was then possible to create a model to assemble all of the observations in the data that relate to one individual. The main approach was to determine a buffer of 30-60 min for the temporal scale and 3 km for the spatial scale around the fluke up of the individual (Fig. 2). A larger temporal scale than the one determined from previous studies was used for this model in order to cover the variation between individuals but also to take into consideration that from a shore-based station it is more complicated to sight the first blow when the whale come to the surface that is, the temporal buffer must include the fact that the whale was possibly already at the surface when sighted.

The main hypothesis was that if within this spatio-temporal buffer there is another sperm whale sighting it is more likely to be the same individual than a new individual (Fig. 2). The model was then run through the entire database of observations made over two years, and sightings corresponding to the same whale during each day where then extracted.

We presented the pseudo code for the model:

1. For each measurement
2. Get the whale time, latitude and longitude value
3. For each whale measurement
4. Get the next whale measurement's time value
5. If the difference between whale time and next whale time was between 30-60 min
6. Get the next whale latitude and longitude vale
7. If distance between first whale and next whale position was ≤ 3 km
8. It was the same individual
9. Else it was a new whale

We also tested other models with different temporal and spatial scales in order to evaluate the variation of errors depending of the parameters (time/distance) used and determined the best algorithm.

Model A: ≥30 ≤ 60 min and ≤ 3 km

Model B: ≥25 ≤ 60 min and ≤ 3 km

Model C: ≥30 ≤ 60 min

Model D: ≤ 3 km

Model E: ≥30 ≤ 60 min and ≤ 2 km

Model F ≥30 ≤ 60 min and ≤ 4 km

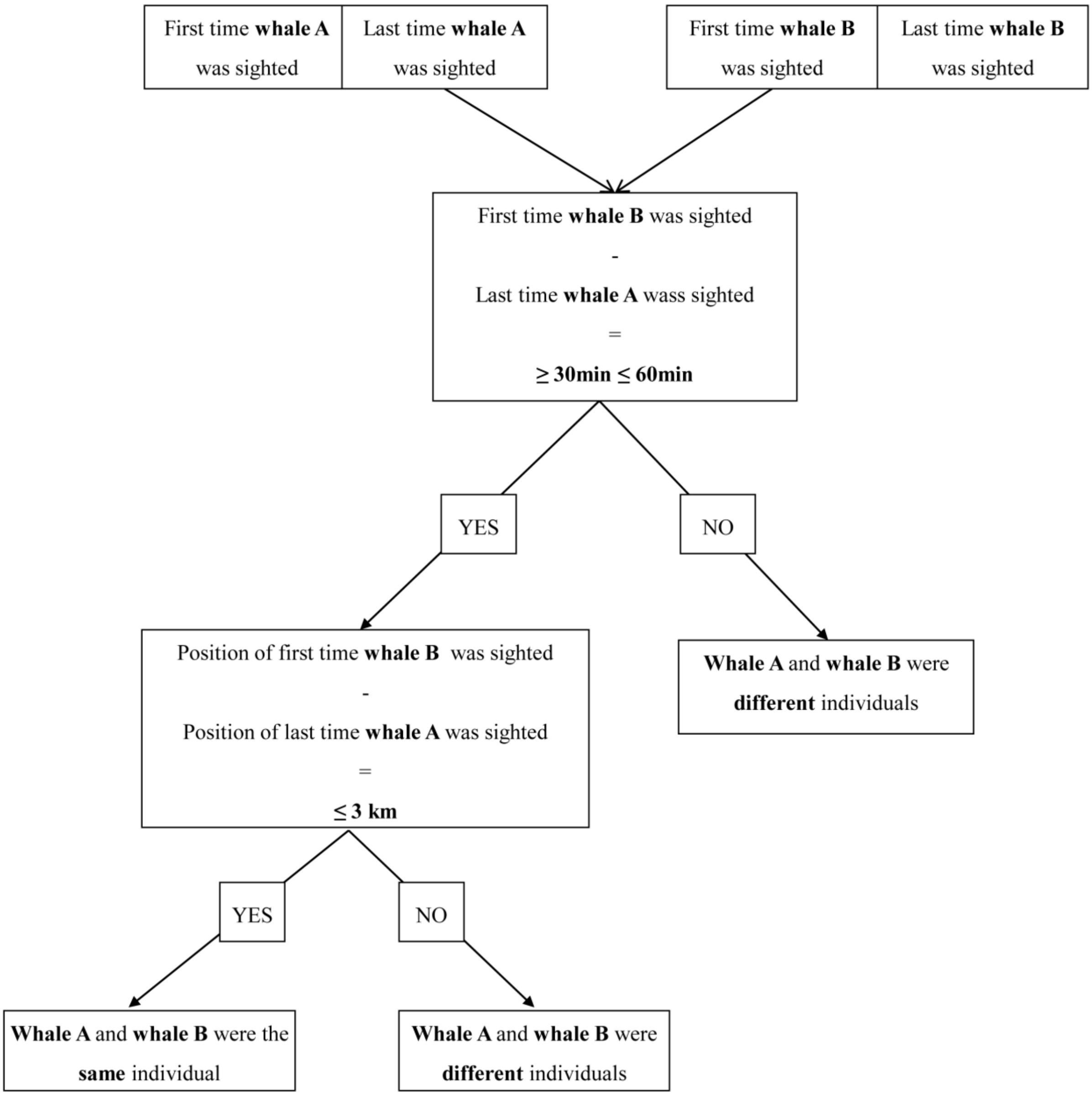

Figure 2. Graph explaining the model used to determine if two individuals are the same whale.

In order to confirm the validity of the algorithm, we compared the predictions from the computer model and the photo-identification data collected at sea from a boat. This photo-identification data set was created through another study, which used a research vessel (6m, aluminium monohull Stabicraft 2050 Supercab, powered by a 100 hp four-stroke Yamaha engine) to record behavioural observations of sperm whales. The observers onboard the research vessels were tracking sperm whales throughout their dives with a towed hydrophone, and recorded the behaviour and a series of photos of the fluke with a Nikon D300 camera and a AF-S VR 70-300mm f/4.5-5.6 Nikkor lens. Matched flukes were given the same identifier name. If no match was made, the whale was recorded as a new individual.

In order to assess the best parameters in our pseudo-code we used Receiver-Operating-Characteristic analysis (ROC) (Swets 1988). ROC analysis investigates the relationship between sensitivity and specificity of a binary classifier (Flach 2010). Sensitivity measures the true positive rate, that is, where our algorithm concluded that two sightings were the same whale and this was then confirmed with photo-id data set. Specificity, or true negative rate, measures the proportion in which our algorithm concluded that two sightings were from different whales and this was confirmed by photo-id. A false positive error would be two sightings concluded to be the same whale using the algorithm but not confirmed by the photo-id. A false negative was determined as the error in which the algorithm concluded that two sighting were from different whales, but photo-id showed that they were the same individual. In order to determine sensitivity, specificity and accuracy we used a confusion matrix and equations as described by Fawcett (2006) (Fig. 3).

Sensitivity = true positive / (true positive + false negative)

Specificity = true negative / (true negative + false positive)

Accuracy = (true positive + true negative) / (true positive + false negative + true negative + false positive)

		Photo-id match	
		Same whale	Different whale
Algorithm match	Same whale	True positives	False positives
	Different whale	False negatives	True negatives

Figure 3. Confusion matrix. False positive = two sightings recorded as same whale when they were not. False negative = two sightings recorded as different when they were not. True positive = two sightings recorded as same whale by algorithm and photo-id. True negative = two sightings recorded as different whale by algorithm and photo-id.

We then plotted a two-dimensional ROC graph with the true positive rate (sensitivity) plotted on the Y-axis and the false positive rate (1-specificity) plotted on the X-axis. On a ROC graph, the point on the left upper side of the diagonal line represents the classifier that performs the best (Fig. 4).

4.4. Results and Discussion

We simultaneously recorded a total of 160 sperm whale observations from the shore-based and the boat-based station corresponding of 28 different individuals. Two individuals were sighted more often than the others, their number of surfacings recorded representing 20 and 11% of the total.

We correlated the photo-identifications of sperm whales collected from the boat with their matching surfacing recorded from the shore-based station. Then we correlated the photo-identification catalogue with the individuals extracted from the model. ROC analysis showed that when using the computer algorithm A, with a temporal buffer of 30-60 min and a spatial buffer of 3km, the accuracy in matching properly individual is 88% (Table 2).

Table 2. Confusion matrix for the six models

	A	**B**	**C**	**D**	**E**	**F**
Sensitivity	**0.87**	0.85	0.69	0.78	0.64	0.75
Specificity	**0.93**	0.90	0.84	0.69	0.90	0.87
Accuracy	**0.88**	0.86	0.72	0.76	0.69	0.77

Point A represented a true positive rate higher and a false positive rate lower than all the other points. A total of 88% of the modeled identifications were accurately correlated with the boat-based study photo-identification catalogue (Table 2). The temporal scale choosen in our model appeared to be the major parameter responsible for the error of matching individuals in the model. We observed that 80 % of the error can be explained by missing a surfacing of an individual previously encountered when tracking another one. Then the individuals were sighted again later in the day and mismatched by the model. Our models resulted in few false positive cases with sightings mostly matched as a new individual when it was in fact the same whale.

We used two other temporal and spatial scales (20-60min/25-50min, 2km/4km) (Table 2, Fig. 4), still following the known surfacing behaviour of sperm whales off Kaikoura, in order to look at the impact of this change on model accuracy. Alternative temporal models did not perform better in matching individuals throughout the day. When we looked more closely at the matching errors, we observed that two individuals were particularly difficult to match correctly by the spatio-temporal model. Based on communication with whale watching skippers, we know that these two resident sperm whales, often exhibit unusual behaviours such as short or long dives and long periods at the surface, which may explain the frequent mismatch of these two individuals.

Figure 4 showed a ROC graph with six classifiers representing the different algorithm used. As expected all the classifier appeared on the left side of the diagonal line explained by the fact that our six algorithms followed the particular behaviour of sperm whale off Kaikoura

(Fig. 4). The point (0, 1) represents perfect classification, in our case, the point closer to the left side of the graph is A, confirming that the first algorithm tested (30-60min/3 km) performed the best.

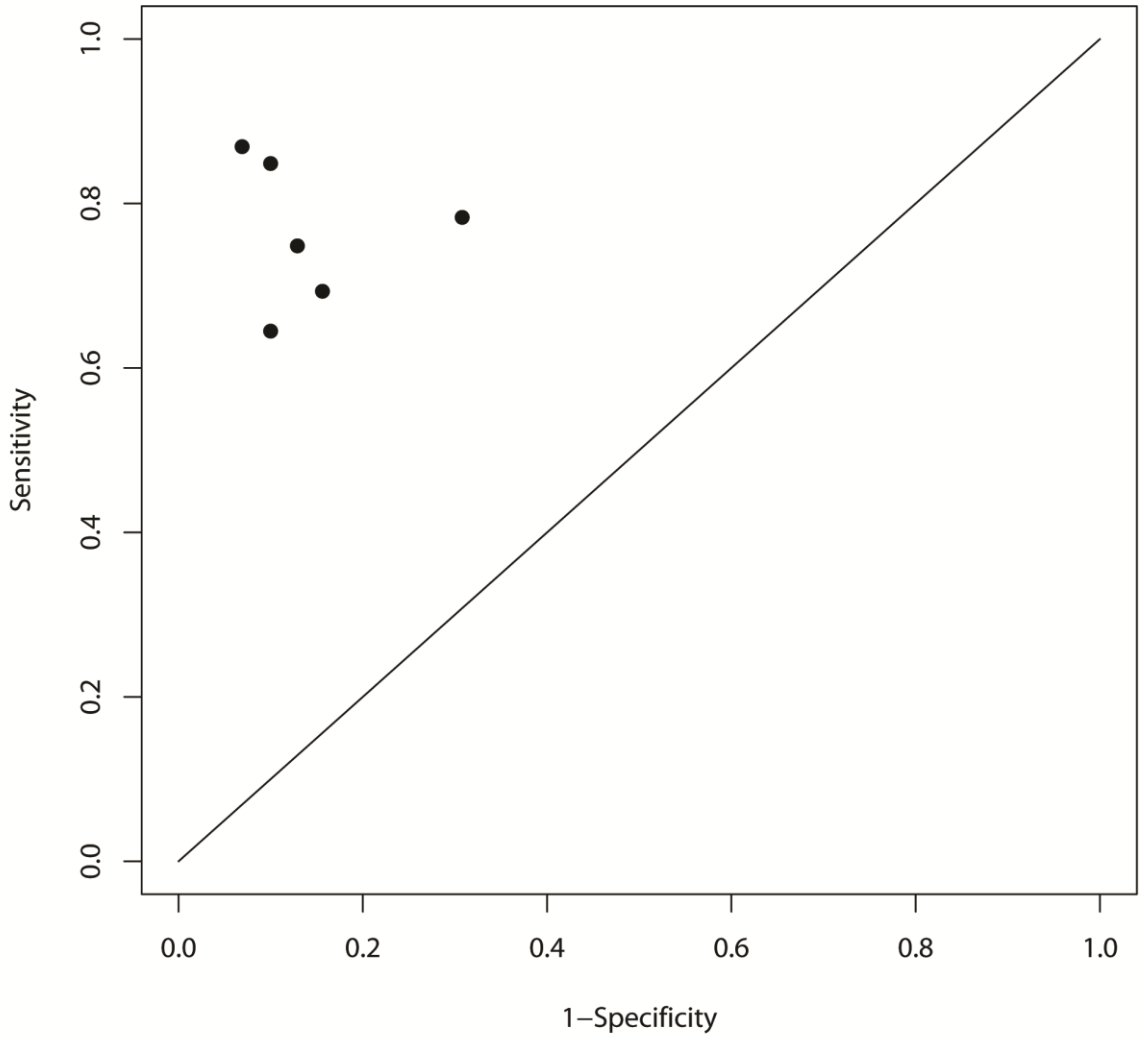

Figure 4. ROC graph showing six classifiers representing the different algorithms. The line indicates the diagonals of the ROC.

4.5. Conclusion

Modeling animals with unique behavioural patterns holds promise for research where the proper identification of individuals is not possible. Using a model is well suited to organisms that have well known behaviour patterns and display minimal inter-individual variation. The benefits of this approach were to determine whether or not we were following the same individuals through the day to understand their movement patterns at an individual level. These spatio-temporal models can also be very useful in order to determine the daily abundance of a species and to establish, from a shore-based station, the effect of whale watching industries by using a before/during/after comparison (Bejder and Samuels 2004). And the model could be expanded to include different types of behaviour for different species.

The limits of this approach were mostly related to the time scale at which we were able to link sightings to probable individuals from the population. This model only gave an indication of the individuals on the particular day where the sightings were made so it was not possible to follow these individuals over multiple days. In order to decrease the matching errors, future research is needed to improve the model. Increasing the amount of data collected simultaneously from boat-based and land-based station will improve the factors (spatial and temporal scale) used in our model.

In this study we introduced a way to extract information on sperm whale individuals from a shore-based station dataset by using a spatio-temporal model of behaviour. We based our approach on a good understanding of the animal behaviour within a particular area. This study opens up new opportunities for future research on spatial-temporal models used for marine mammal's individual identification in areas where their behaviour is already well documented, suggesting a new approach to determine their identity from a shore-based station.

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5. Spatial and temporal distribution of sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon, New Zealand in relation to bathymetric features

5.1. Abstract

Using a shore-based station we monitored the position of sperm whales (*Physeter macrocephalus*) within the Kaikoura submarine canyon from 2010 to 2012. We tracked sperm whales using a theodolite station for a total of 290 days. We extracted the distance from the nearest coast, the depth and the bathymetric slope using ArcGis 10.1. We estimated the seasonal spatial distribution of sperm whales using general additive models (GAM). The distribution varied significantly between seasons with individuals found further offshore and at deeper depth in spring and closer to shore in winter. This study improved our understanding of the variability of sperm whales distribution patterns off Kaikoura. We determined that the distribution was linked to the bathymetric features and we hypothesized that whales adapted their use of the submarine canyon in relation to food aggregation. We encouraged further studies to evaluate the sperm whale relationship with oceanographic variables off Kaikoura.

5.2. Introduction

The Kaikoura region on the east coast of the South Island, New Zealand, is the ideal place to study male sperm whales (*Physeter macrocephalus*) and their distribution. The proximity of the Kaikoura submarine canyon to the coast of the South Island makes it one of a few places in the world where male sperm whales are found close to shore and present year round (Gordon *et al.* 1992, Jaquet *et al.* 2000). The particular bathymetry of the submarine canyon directly influences the hydrological system of the coastal waters off Kaikoura. The mixing of the warm northern water from the East Cape current and the cooler water from the Southland current leads to a local upwelling (Garner 1953, Hart *et al.* 2008). This upwelling brings deep nutrient-rich waters to the surface, causing very high productivity. Due to this high productivity, the Kaikoura canyon offers a valuable feeding spot for sperm whales (Gaskin and Cawthorn 1967, Bradford 1972, Heath 1972, Farrell *et al.* 1991, De Leo *et al.* 2010).

The presence of sperm whales close enough to shore allows for non-invasive research and commercial whale watching. The Kaikoura region is one of two places in the world where sperm whales are the main focus of a year-round whale watching industry. As a consequence, during the past few decades, sperm whales off Kaikoura have been the focus of scientific investigation in order to determine the effect of whale watching vessels on sperm whales (Gordon *et al.* 1992, Richter *et al.* 2003). One of the major issues in managing whale watching activities is the interpretation and management of effects on the species. To assist effective whale watching management, a general understanding of the effects of environmental variables on distribution and abundance is necessary.

A great number of studies have examined the correlation between cetacean distribution and bathymetric features (e.g. Whitehead *et al.* 1992, Cañadas *et al.* 2002, Gannier *et al.* 2002, Croll *et al.* 2005, Panigada *et al.* 2005, Laran and Gannier 2008, Praca *et al.* 2009). Studies focusing on sperm whales have shown they occur in greatest numbers near the lower continental slope and deep water (Baumgartner *et al.* 2001, Gregr and Trites 2001).

A previous study by Jaquet *et al.* (2000) from 1990 to 1997 observed a seasonal difference in sperm whale distribution between summer and winter. To determine this change in the distribution they divided there study area in three blocks and observed if the number of sightings between blocks differed between summer and winter (Jaquet *et al.* 2000).

The purpose of this study was to investigate the distribution of sperm whales off Kaikoura in relation to the depth, distance from the nearest coast and slope. The importance of this study was to determine if the relation between sperm whale distribution and bathymetric feature could be determined at a small spatial scale (study area 900 km^2). This study will add valuable knowledge which could greatly improve management efforts.

5.3. Method

A shore-based station was established on a hill at a height of 99.88 m (± 0.04 m) above sea level, situated at the east end of the Kaikoura Peninsula (42°25’47.1 S’’ 173°41’54.6’’ E) (Fig. 1). This location provided a good vantage point overlooking the study area encompassing the Kaikoura Canyon with a limit of visual detection of 25 km.

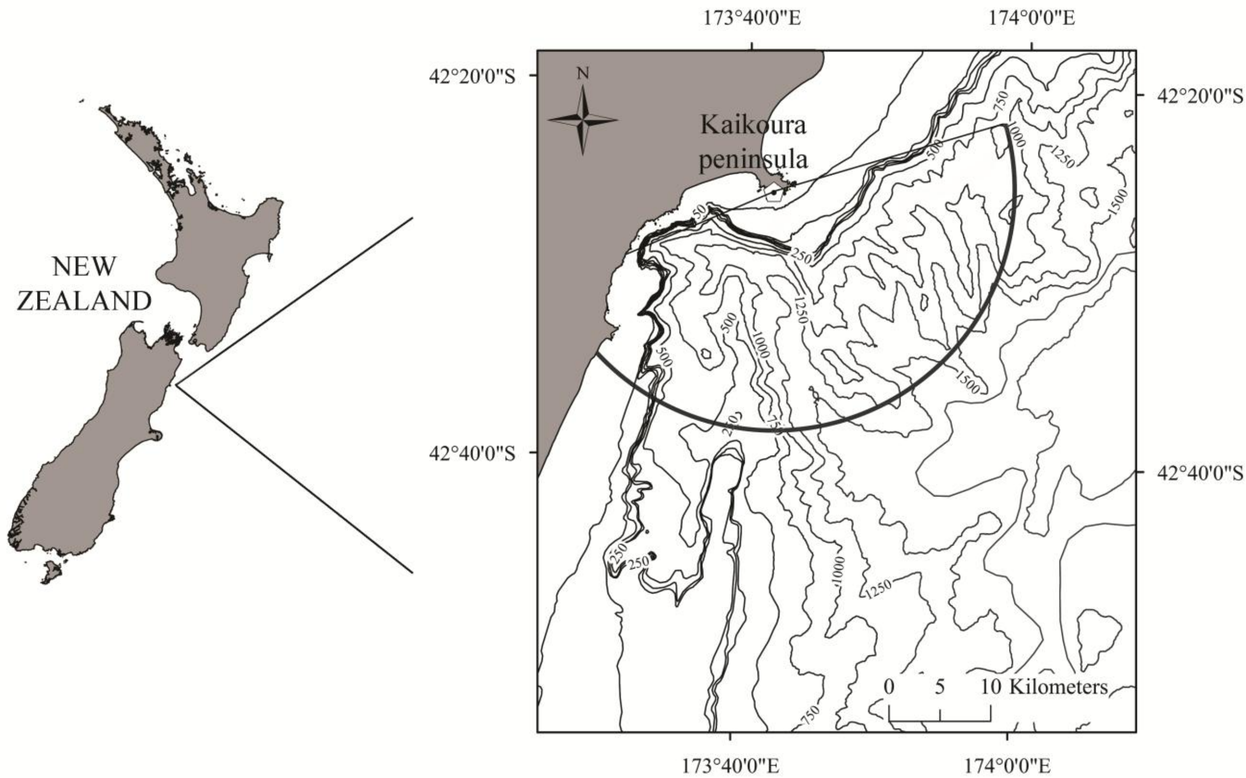

Figure 1. Map of the Kaikoura submarine canyon bathymetry and showing the location of the shore-based station (pentagon) and study area (black line).

5.4. Data collection

We recorded the positions and movements of sperm whales using a Sokkia Set 4000 theodolite. To determine station height above sea level (99.88 ± 0.04 m), we used methods detailed by Würsig *et al.* (1991). We ran the tracking program Pythagoras which transformed thedolite readings into GPS coordinates in real time with corrections for curvature of the Earth and tide level (Gailey and Ortega-Ortiz 2002). We also logged whale positions and behaviours (as described by Whitehead and Weilgart 1991) and environmental parameters in Pythagoras. All information was automatically stamped with date and time.

Monitoring typically started right after sunrise and during the day we constantly scanned the study area with 20 x 80 binoculars. We recorded environmental conditions such as: Beaufort sea state, swell height and direction, percent cloud cover and a visibility score of 0 to 4 (4 = perfect visibility and 0 = dense fog). When a whale was spotted, we tracked the whale during the entire time at the surface, from the first blow spotted until the fluke up.

We defined seasons as follows:

Autumn: March, April and May.

Winter: June, July and August.

Spring: September, October and November.

Summer: December, January and February.

5.4.1. Data analysis

We carried out all mapping and spatial analyses using ArcGIS 10.1. In order to avoid pseudo-replication, we only used the fluke up position which clearly identified the end of a surfacing.

To determine the spatial structure of the sightings we used nearest neighbour analyses to test for complete spatial randomness (CSR) of sperm whales sightings, whether sightings were clustered ($R < 1$), random ($R = 1$) or dispersed ($R > 1$) (Rogerson, 2001).

The fluke up positions were correlated with three different variables: distance from the nearest coast, water depth and bathymetry slope. To analyze the distance of sperm whales to the coastline, we performed a spatial proximity analysis using the near analysis in the ArcGIS tool box, which determined the distance from our database to the closest point of the coastline shape file. The bathymetric chart was supplied courtesy of the National Institute of Water and Atmospheric Research, New Zealand (NIWA). The resolution of the bathymetry map was of 10 m at shallow depths (< 200 m) followed by increments of 50 m at depth > 200 m. We again used the near-analysis tool to determine the closest isobath bin to each position. Finally, we calculated the maximum change in bathymetry between cells which determined the inclination of the slope in degrees.

We performed standard deviation ellipse analysis to determine the distribution patterns of sperm whales. Standard deviational ellipses summarize central tendency, dispersion (area km^2) and directional trends of the fluke up positions.

In order to analyze the data, we determined for each grid cell (1 km x 1 km) the presence (1) or absence (0) of sperm whales within the study area. We analyzed the data in R 2.15 using General generalized additive models (GAM) in the mgcv package (Wood 2001). We used GAMs in order to capture non-linear relationships. To account for temporal influences on sperm whale distribution, we included year and month as factors. We also included the survey effort, measured as the number of hours scanning the study area to account for the variability between seasons. We modeled all variables and we replaced smooth terms with linear terms if the Un-Biased Risk Estimator (UBRE) score dropped and the deviance explained increased when removed (Wood 2001). We dropped linear terms if the UBRE score dropped and the deviance increased when removed. We kept non significant variables if it resulted on a drop in the UBRE score and an increase in the deviance. During the figure interpretation, values greater than zero on the y-axis indicate positive correlation, zero corresponds to no effect, and less than zero indicates negative correlation.

5.4.2. Research effort

We collected data during 290 days from April 2010 through March 2012, encompassing a total of 1720 h effort. Scanning effort by season is described in Table 1. The difference in effort between seasons was due to changing weather conditions limiting data collection. Within the 1720 hours of scanning, we tracked sperm whales for a total of 354 hours corresponding to 4484 surfacing events (surfacing = same individual followed from the first blow spotted until the fluke up). Tracking effort and number of surfacing per hours are given in Table 1.

Table 2. Summary of monitoring effort from the shore-based station by year and season.

Year	Season	Effort (h)	Tracking effort (h)	Number of surfacings/ h
2010	Autumn	244.95	46.90	1.78
	Winter	88.53	17.52	2.24
	Spring	136.13	14.23	1.16
	Summer	70.13	14.03	1.74
	Total	**539.74**	**92.68**	**1.69**
2011	Summer	174.37	40.60	2.78
	Autumn	212.33	57.60	3.65
	Winter	241.35	71.62	4.64
	Spring	187.00	16.23	1.33
	Summer	101.42	19.43	2.43
	Total	**916.47**	**205.48**	**3.14**
2012	Summer	169.17	32.22	2.56
	Autumn	95.00	24.05	2.75
	Total	264.17	56.27	2.63
Total		**1720.38**	**354.43**	**2.61**

5.5. Results

To start we tested for Complete Spatial Randomness (CSR) of sperm whale distribution to test the hypothesis that distribution within the study area was random. Seasonal sperm whale distribution was clumped (R <1) and this did not change across season or year (Table 2).

Table 2. Nearest neighbour ratio values indicating that the distribution of sperm whale is clustered during the seasons.

	Season	**Nearest neighbour Ratio**
2010	**Autumn**	0.572
	Winter	0.553
	Spring	0.679
2011	**Summer**	0.535
	Autumn	0.619
	Winter	0.648
	Spring	0.639
2012	**Summer**	0.727
	Autumn	0.458

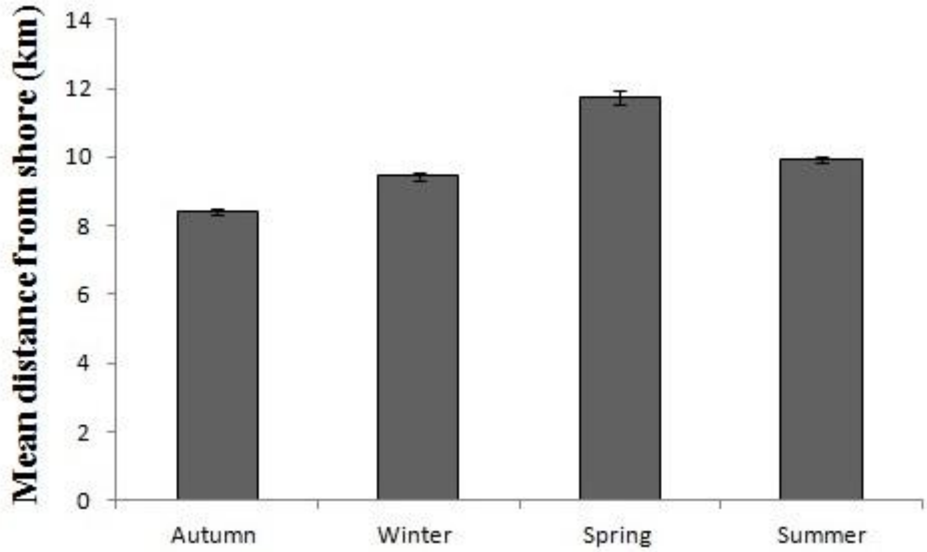

Figure 2. Mean distance from shore (mean km ± S.E.) of sperm whale positions by season.

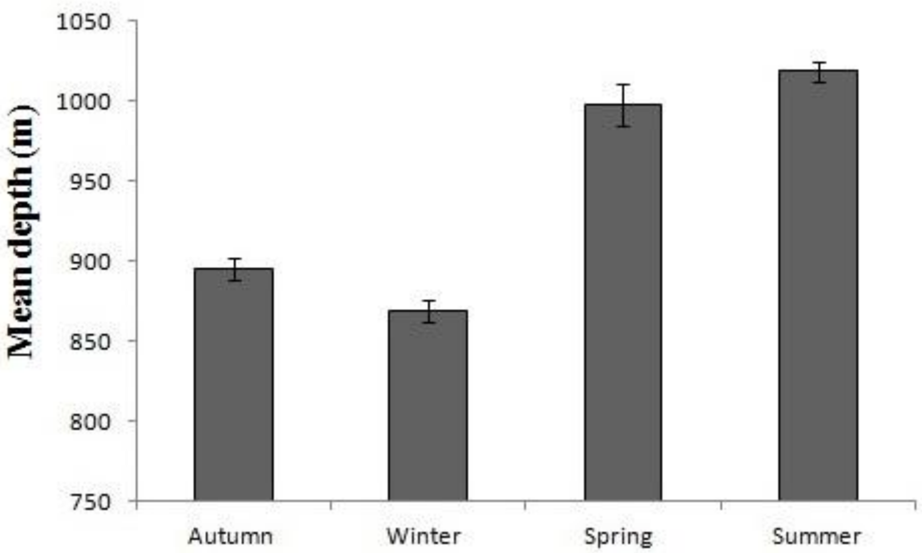

Figure 3. Mean depth (mean m ± S.E.) at which sperm whales were sighted by season.

We observed sperm whales closer to shore in autumn and further offshore in spring, during spring the whales left the study area altogether for a couple of weeks (Fig. 2). Regarding the mean depth at which we found sperm whales, in winter they used areas of lowest depth (< 900 m), and deepest water in summer (Fig. 3). Estimated mean distance and mean depth varied significantly between seasons ($F(3, 4480) = 104.355$, $p < 0.0001$; F(3,

4480) = 100.064, $p< 0.0001$) (Figs. 2–3). Post-hoc comparisons using the Tukey HSD test indicated that all pair wise differences for the mean distance from the nearest coast were significant between seasons, $p < 0.05$. Concerning the mean depth, post-hoc comparisons using the Tukey HSD test indicated that the comparison between summer and spring were not significant, all other comparison were significant, $p <0.05$. Examination of standard deviation ellipses indicated that the distribution of sperm whales is highly scattered during spring and tightest in summer and autumn (Figs. 4, 5). Whales ranged not only furthest offshore but were also tracked further to the north during spring (Fig. 5).

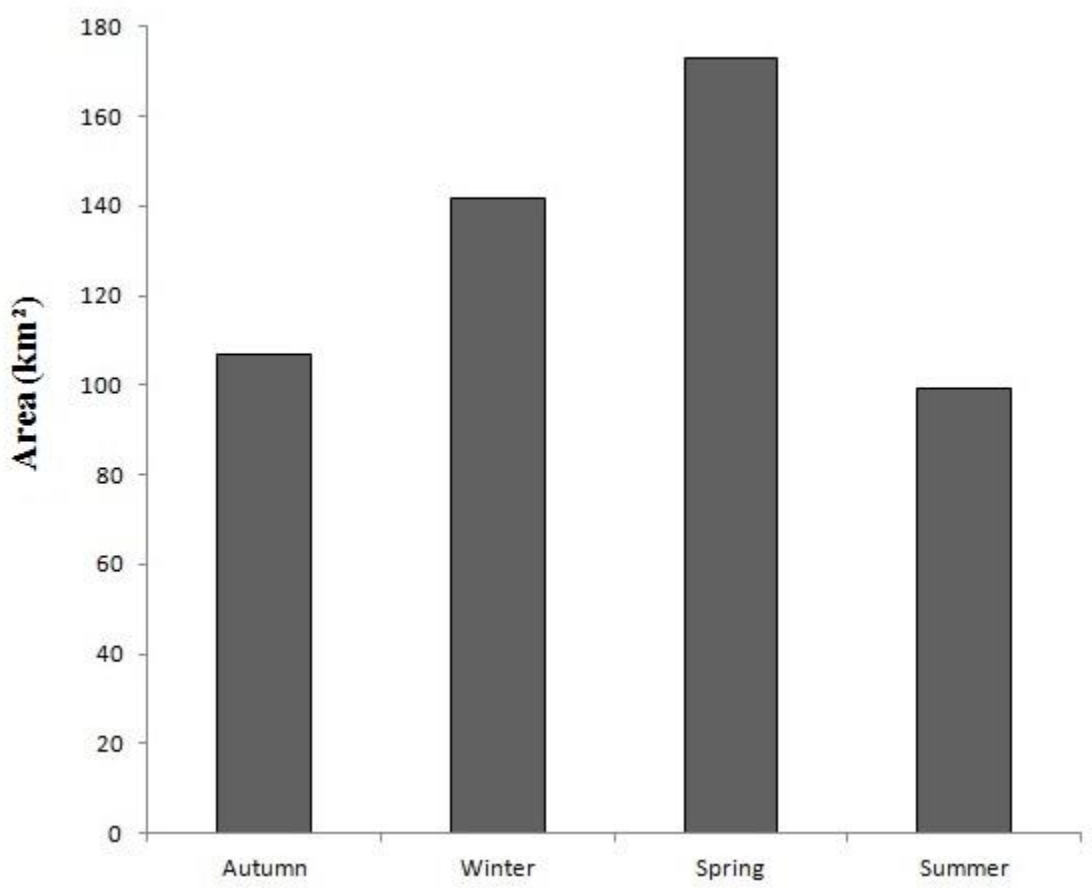

Figure 4. Monthly area in km² of standard deviation ellipses for sperm whale locations between seasons.

We used the variance inflation factors (VIFs) to measure the possibility of collinearity between the variables. No collinearity between variables was detected with all the variables having a variance inflation factor (VIF) < 3, so we used all the variables in the models. For the GAM models, all three variables (depth, distance from shore and slope) had a significant relationship with whale presence (Table 3).

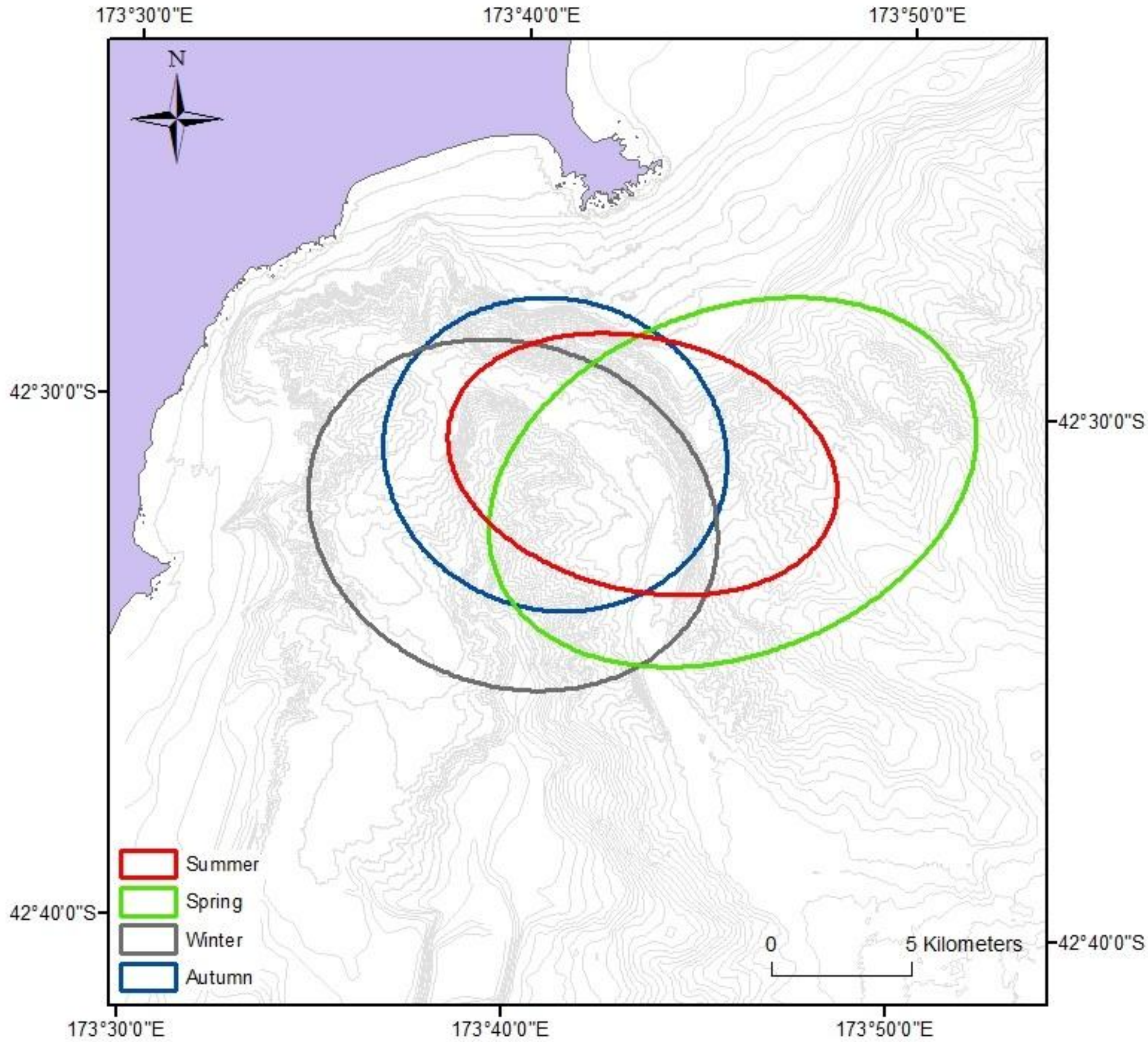

Figure 5. Areas of standard deviation ellipses for sperm whales locations are compared by seasons.

Table 3. Summaries for generalized additive models for the seasonal models based on bathymetric features. The selected explanatory variables in each model are identified as factor (top) or smooth functions (bottom) along with their estimated degrees of freedom in parentheses and approximate p-value significance.

		Summer (n= 2335)	**Autumn (n=2399)**	**Winter (n=1578)**	**Spring (n=1547)**
			Estimate (± SE)		
Intercept		-5.524 (±0.460) ***	-4.053 (±0.338) ***	-3.822 (±0.410) ***	-1.416 (±0.433) **
Effort		0.018 (±0.006) **	-	0.024 (0.008) **	-0.030 (0.009) ***
FACTOR					
Year					
2011 (vs. 2010)		1.220 (±0.291) ***	1.718 (±0.168) ***	0.955 (±0.304) **	0.826 (±0.202) ***
2012 (vs. 2010)		1.109 (±0.328) ***	0.218 (±0.281)	-	-
Month					
January (vs. December)	April (vs. March)	0.150 (±0.290)	-0.611 (±0.235) **	-	-
February (vs. December)	May (vs. March)	-0.274 (±0.238)	0.436 (±0.162) **	-	-
SMOOTH FUNCTIONS			**X^2 (edf)**		
Depth		229.500 (1.000) ***	157.260 (3.699) ***	102.290 (4.930) ***	54.710 (1.656) ***
Distance from nearest coast		289.900 (1.156) ***	67.680 (8.778) ***	111.580 (6.586) ***	94.720 (4.610) ***
Slope		124.800 (5.379) ***	242.220 (2.273) ***	42.970 (4.341) ***	16.030 (1.000) ***
% Deviance		40.6	38.2	34.2	21.9
R^2adj		0.414	0.387	0.368	0.173

**p<0.01, *** p<0.001, -: parameter not included in final model

Concerning the factors we used in the models, the year appeared relevant for all the models, with more sperm whales sighted in 2011 for all four seasons. The difference between months in each seasons appeared not significant for winter and spring so the month factor was not included for these two seasons. Regarding summer, the difference between months was not significant but we kept the factor in the model as it improved the percentage of deviance and the UBRE score. Concerning the effort, as expected the number of sightings was correlated with the number of hours spent scanning the study area, so the effort was a variable in the models except for autumn (Table 3). The linear relationship for spring was negative, described as a lower number of sightings with an increase of effort. This could be explained the fact that sperm whales were absent of the study area for a couple of weeks during this season and by a lower number of individuals in spring than during the other seasons. The fitted residuals for the four GAM models displayed no pattern, indicating that the four models fitted the data well.

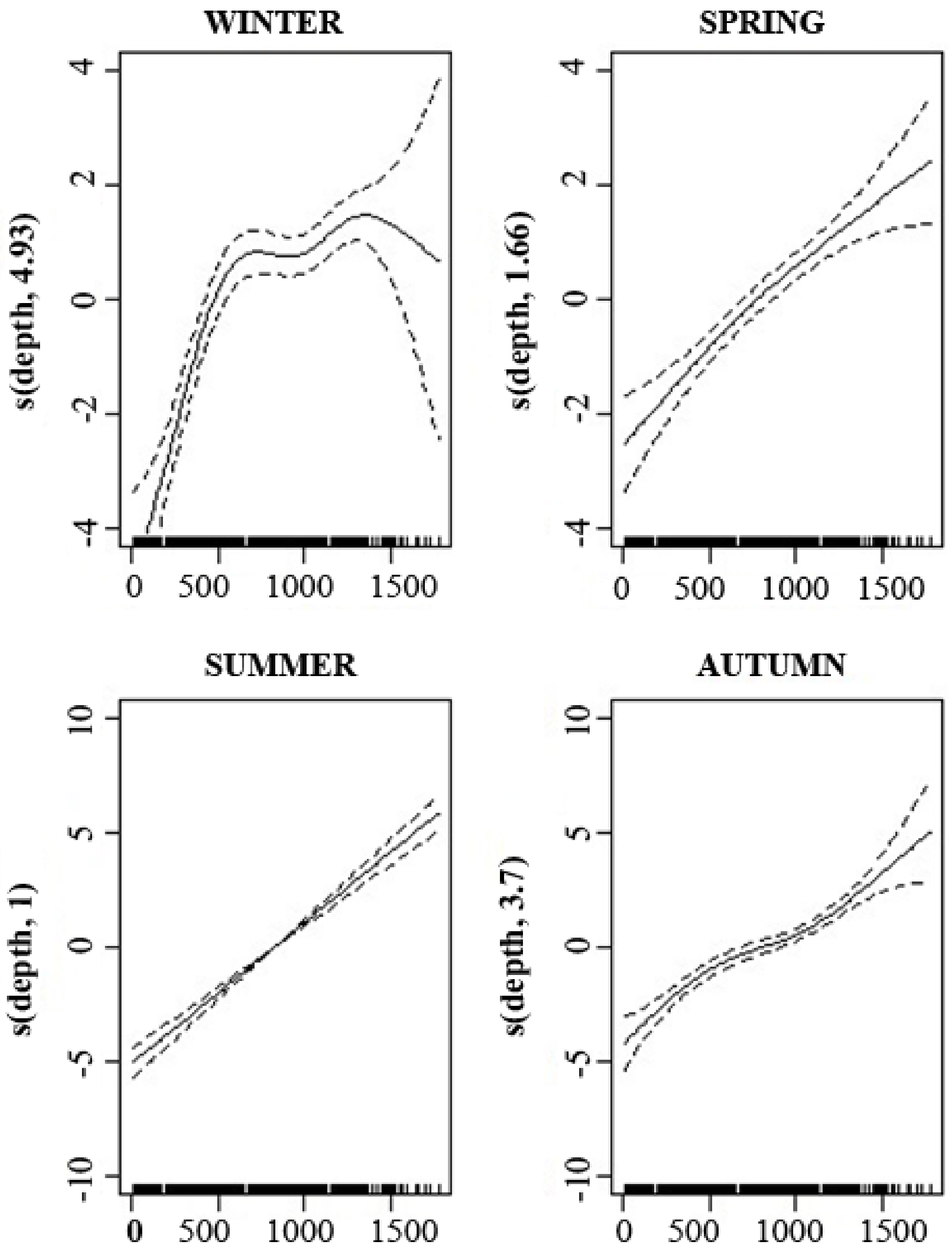

Figure 6. Genealized additive model smoothing curves of depth (in meters) explaining the presence of sperm whales for the seasonal models. Y-axis = fitted function with estimated degree of freedom. Dashes on X-axis = distribution of the depth in meters. Dashed lines = 95% confidence bands.

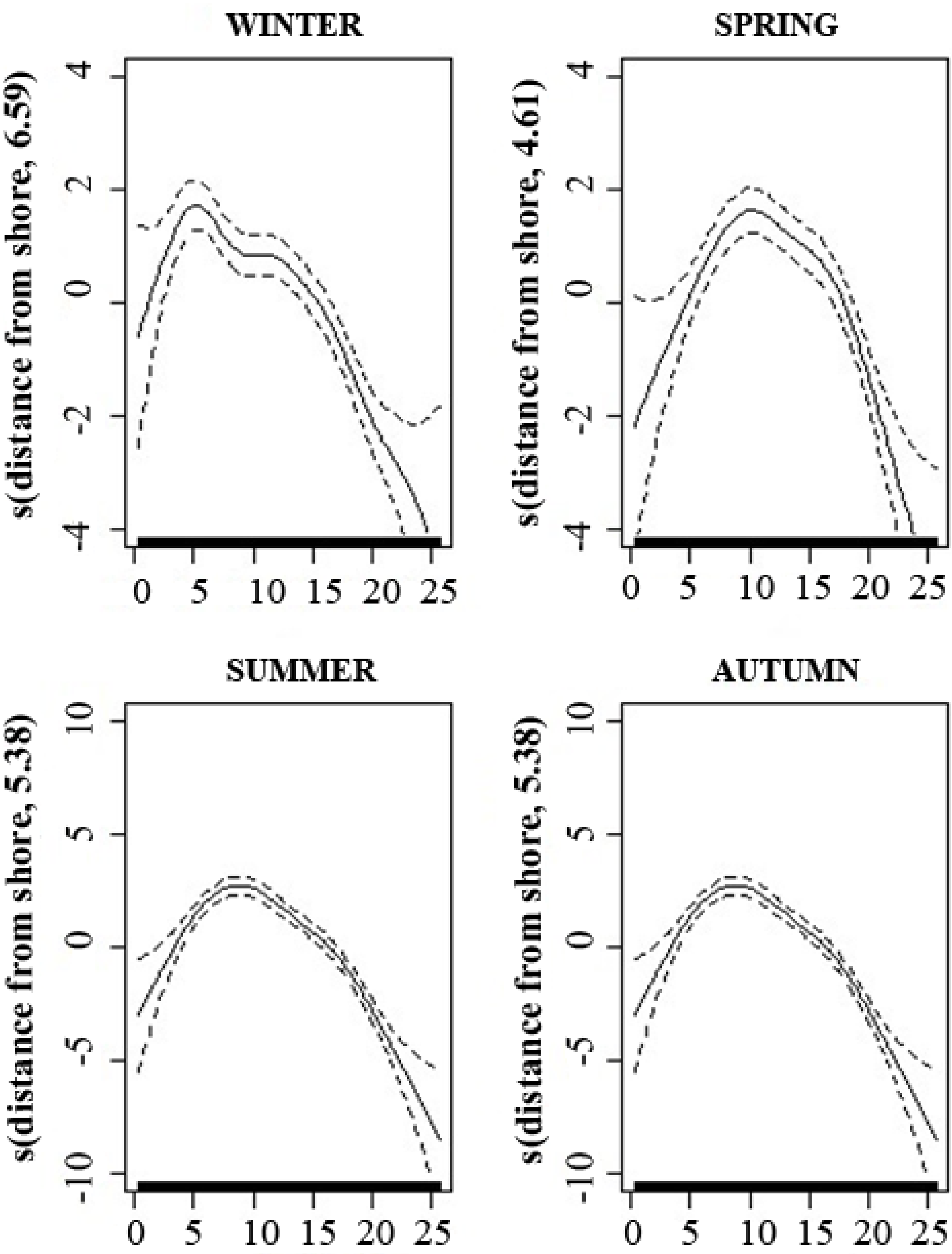

Figure 7. Genealized additive model smoothing curves of distance from shore (in km) for the seasonal models. Y-axis= fitted function with estimated degree of freedom. X-axis = distribution of the distance from shore in km. Dashed lines = 95% confidence.

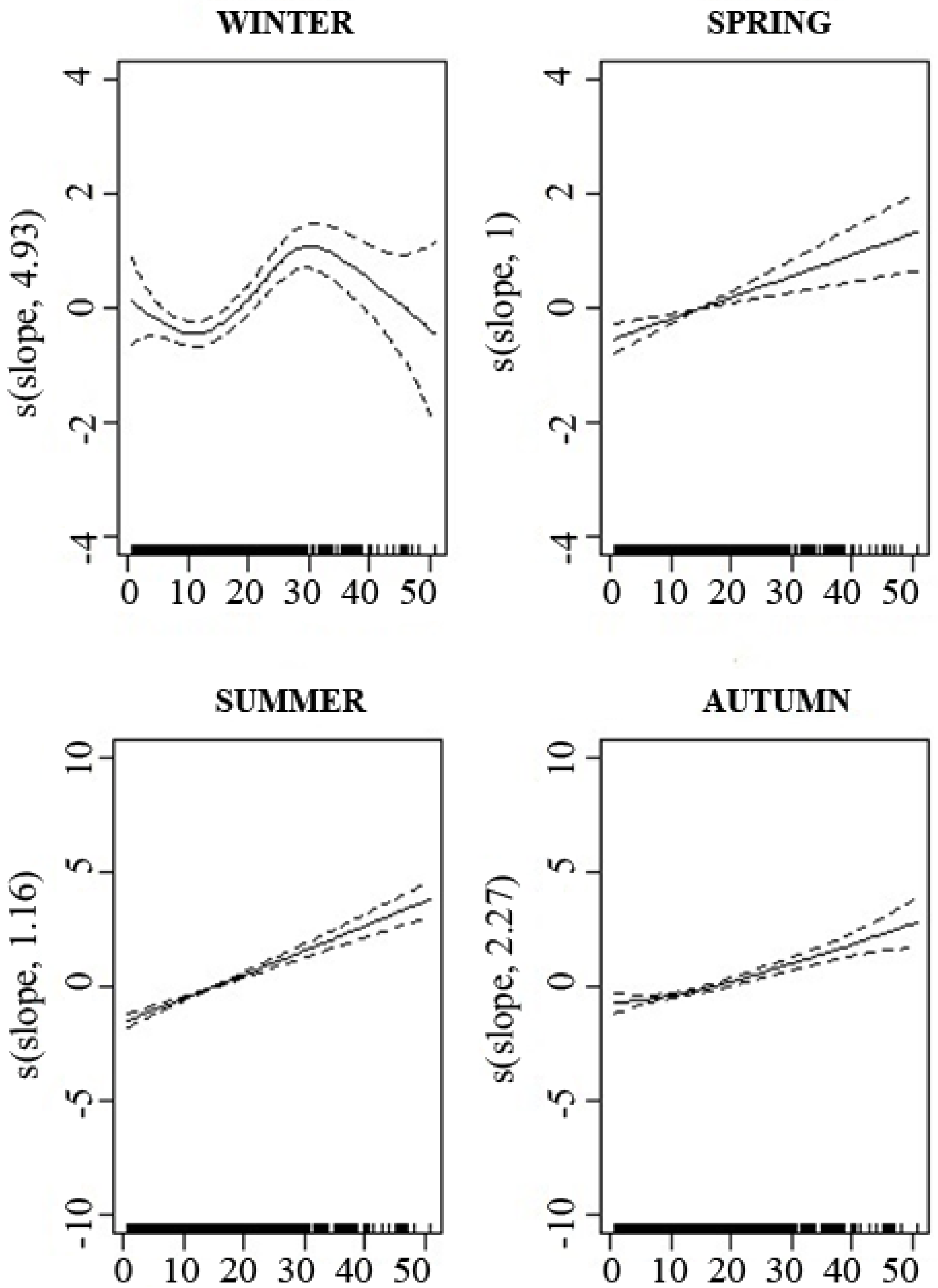

Figure 8. Genealized additive model smoothing curves of the slope (in degree) for the seasonal models. Y-axis= fitted function with estimated degree of freedom. X-axis = distribution of the slope in degree. Dashed lines = 95% confidence.

Sperm whales appeared to be strongly associated with bathymetry. Response curves suggested that in winter, sperm whale presence was higher at low depth, with a peak at 500 m and dropped around 1500 m which can be influence by a much smaller sample sizes for the depth > 1500 m given the wide confidence interval. For the three other months, a nearly linear relationship between the presence of whales and the depth emerged, with sperm whale presence increasing with an increase of depth (Fig. 6). Concerning the distance from shore, response curves presented a non-linear relationship (Fig. 7). The curve decreasing at larger distance can be mainly due to a lower probability of sighting whales at larger distance from the shore-based station, limiting robust conclusion for the extreme right side of the curves. The smooth curve for distance from nearest coast appeared to indicate an increase in sighting with increasing distance values. We observed a peak at a distance of 5 km in winter, and then the number of sightings decreased rapidly, with the majority of sightings made between 5 and 10 km from the nearest coast (Fig. 7). In spring we sighted sperm whales at the largest distance from the shore than from the other seasons. For summer and autumn, the peak of sperm whale occurred around 8 km, and at 10 km for spring, with the presence of sperm whales found further offshore (Fig. 7). Finally, associations with the slope were consistent across spring, summer and autumn with a near positive linear relationship, indicating a relationship between presence of sperm whales and a steeper slope (Fig. 8). The non-linear relationship for the slope in winter showed a peak at slope of 30° (Fig. 8).

5.6. Discussion

For the first time we modeled the distribution of sperm whales off Kaikoura in relation to bathymetric features. We established that sperm whales within the Kaikoura submarine canyon displayed a predictable seasonal pattern of habitat association. Our study showed that the seasonal distribution of sperm whales was strongly associated with bathymetric features, such as depth, slope and distance from the nearest coast. In winter, sperm whales were present at shallower waters than during the other seasons. We also noted that in spring, sperm whales occurred at greatest distance from the nearest coast, mainly north-eastwards from the shore-based station within the Hikurangi Trough.

Previous studies off Kaikoura principally focused on the sperm whale behaviour (diving/surfacing patterns and residency) and the effect of the whale watching activities (Gordon *et al.* 1992, Childerhouse *et al.*1995, Jaquet *et al.* 2000, Richter *et al.* 2003). These earlier works briefly described the general trend of the distribution without analysing the bathymetric features. Our study adds valuable knowledge on the sperm whales distribution off Kaikoura in relation to bathymetric features. Our work provided the first long term data collection for sperm whales off Kaikoura from a shore-based station. The advantage of the shore-based station was to have an overview of the whole submarine canyon area.

Our results are in accordance with previous studies showing that sperm whales are known to inhabit shallower waters (Rice 1989, Baumgartner *et al.* 2001, Gregr and trites 2001, Hamazaki, 2002). Our results suggested that the sperm whales within the Kaikoura submarine canyon were found principally at depths between 500m to 1250m, which agrees with previous results reported by Jaquet *et al.* (2000). Only 7.65% of the total of sperm whales sightings occurred at depths < 500 m and 7.48% at depth > 1250 m. However, there is some discrepancy between previous studies that did not found any significant preference by sperm whales for any particular bathymetric features in other parts of the world (Gannier 1999, Gannier *et al.* 2002). These differences between studies demonstrated that the factors influencing the sperm whales distribution may vary between region and individuals (Baumgartner 1997, Hastie *et al.* 2005).

Jaquet (1996) reviewed studies on sperm whale distribution in relation to environmental variables and explained that the main uncertainty between results was mainly due to inadequate spatial and temporal scales. By collecting data on a daily basis during two years, we were able to determine at which temporal scale the correlation with bathymetric features occurred. The seasonal distribution described in our study is supported by previous results by Jaquet *et al.* (2000) describing that two-thirds of the sperm whales identified off Kaikoura are seasonally resident. Moreover, seasonal movements of sperm whales have been documented for the North Pacific (Gosho *et al.* 1984) and off southern California (Dohl *et al.* 1980, Carretta *et al.* 1995). These results showed the need to collect data continuously through the year, in order to determine any natural fluctuation in distribution that could be missed or misunderstood if presented at a larger time scale. Concerning the spatial scale, our results demonstrated that correlation between sperm whale distribution and bathymetric features can also be explained at a coarser spatial scale than previously described (Jaquet *et al.* 1996, Jaquet 1996, Whitehead 1996, Jaquet and Gendron 2002). We were able to extract that bathymetric features influence the sperm whales distribution and the importance of the Kaikoura submarine canyon for the sperm whales. Therefore, our results established that sperm whales within the Kaikoura submarine canyon are associated with bathymetric features at a small spatial scale.

The seasonal distribution pattern of the sperm whales is more than probably link with food availability. Previous studies have related bathymetric features with prey availability; the main reason for this is that presence of upwelling in these areas enhances productivity. Best (1969) postulated that if most Sperm Whales are found at the edge of the continental shelf, it is because oceanographic factors promote the abundance of food supply in these regions. Foraging theory predicts that predators should spend more time in areas of abundant accessible prey (Macarthur and Pianka 1966). Our results also suggested that the distribution of sperm whales was highly scattered during spring and more aggregated in summer and autumn. Studies have shown that sperm whales aggregate more in areas and at times of greater food abundance (Whitehead and Kahn 1992). This can be explained by a possible change in prey between these seasons. Stomach contents (Gaskin and Cawthorn 1967) showed that gropers were frequently found in sperm whale stomachs between end of April and the end of June. Groupers are usually found in waters between 10 to 800 m. These results correlated with our distribution, with the sperm whales found at lowest depth during these months and more aggregated. Another sperm whale prey, the deepwater squid Onychoteuthidae (*Moroteuthis ingens*), are found at depths between 500 and 1450 m (Jackson 1997). Jackson (2001) confirmed a winter spawning of *Moroteuthis ingens* off the Chatham Rise between May and August; this can explain the distribution change of sperm whales during autumn and winter, with a possible shift of their main prey because of a decrease of the squid population in the area.

It is apparent that the bathymetric features are not the only factor affecting the distribution of sperm whales. Other parameters may influence the presence of sperm whales in particular area of the canyon such as oceanographic variables and anthropogenic pressure. Future work will include the construction of predictive model of sperm whale distribution in relation to oceanographic variables such as surface temperature and chlorophyll a. In order to detect hot spots for sperm whales within the Kaikoura submarine canyon and to explain the shift in distribution with a possible seasonal change in food resources correlated with oceanographic variables. Management and conservation issues are addressed by providing preliminary identifications of areas of particular importance. These areas change over a temporal scale.

In conclusion, the bathymetric features investigated in this study greatly influenced the probability of sighting sperm whales within the Kaikoura submarine canyon. The new knowledge from this study filled the gap regarding the distribution of sperm whales off Kaikoura and could be considered in conservation efforts. Successful conservation of species will depend on our understanding of the relationship between the species and the habitats they use (Cañadas and Hammond, 2008). This is even more important in area such as Kaikoura, with the sperm whale being the center of the whale watching industry. The growth of the whale watching tourism industry in Kaikoura provided a significant boost for the town economy (Butcher *et al.* 1998). This supports our need to improve our knowledge of sperm whales to ensure their effective conservation.

5.7. References

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6. Seasonal distribution of sperm whales in relation to oceanographic features within the Kaikoura submarine canyon

6.1. Abstract

The objective of this study was to better define the habitat use of sperm whale (*Physeter marcocephalus*) off Kaikoura in relation to sea surface temperature (SST), fronts and chlorophyll a (Chl*a*). We collected data from a shore-based station from 2010 to 2012 over a study area of 900 km² and we used Modis remote sensing data to compute maps of oceanographic variables within the study areas. We used Generalized Additive Models (GAM) to identify significant oceanographic variables relating the presence of sperm whales off Kaikoura. Models indicated that SST, Chl*a* and distance from SST fronts were all important parameters in predicting sperm whales presence. Our study provided information concerning the oceanographic factors influencing the sperm whales' presence within the canyon. Future studies should focus on potential impacts of climate change on the sperm whales using the canyon as a feeding ground.

6.2. Introduction

It is well known that food availability is one of the factors influencing the distribution of a species. This is also true with cetaceans, where prey availability is an important factor affecting their distribution (Smith *et al.* 1986, Viale 1991, Griffin 1996, Jaquet and Whitehead 1996, Gannier *et al.* 2002, Littaye *et al.* 2004). For example, Davis *et al.* (2002) examined cetaceans of the northern oceanic Gulf of Mexico, and concluded that presence of prey and cetacean distribution was positively correlated. Sperm whales (*Physeter macrocephalus*), are generally found where productivity is high, foraging in these submarine canyon "hotspots" (Hunt and Schneider 1987, Whitehead *et al.* 1992, Jaquet 1996, Croll *et al.* 1998). Sperm whales are known to feed on medium- to large-sized mesopelagic squid which are generally in high concentrations in productive waters over the continental slope and ridges (Clarke 1966, 1980, Rice 1989). Within the Kaikoura submarine canyon sperm whales exhibit mainly foraging behaviours with little or no apparent behaviour (Jaquet *et al.* 2000, Lettevall *et al.* 2002). It is evident that the Kaikoura submarine canyon area is feeding ground for sperm whales (Gaskin and Cawthorn 1967, Gordon *et al.* 1992).

Submarine canyons play a significant role in local marine ecosystems. Their topography induces upwelling, which is a process of vertical water motion. Thus, bottom water moving towards the surface introduces a large quantity of nutrients to the surface water, enhancing primary production and consumer biomass (Freeland and Denman 1982, Hickey *et al.* 1986, Hickey 1997). The particular topography of the submarine canyon directly influences the hydrological system of the coastal waters off Kaikoura. Within only a few nautical miles off the coastline, the Kaikoura canyon drops off steeply to depths of 500 to 1500 m (Jaquet *et al.* 2000). Within the Kaikoura submarine canyon, the convergence of the warm northern water from the East Cape current and the cooler water from the Southland current produces upwelling of cold, nutrient-rich subsurface waters (Garner 1953, Hart *et al.* 2008). This mixing of this two water masses results an area of high productivity and a valuable feeding spot for marine mammals (Gaskin and Cawthorn 1967, Bradford 1972, Heath 1972, Farrell *et al.* 1991, Chiswell and Schiel 2001, De Leo *et al.* 2010). A recent study by De Leo *et al.* (2010) indicates that the Kaikoura Canyon is a hotspot of benthic biomass and that, no other submarine canyon contains a benthic biomass as rich as the Kaikoura Canyon.

The Kaikoura region is the ideal place to study sperm whales. The proximity of the Kaikoura submarine canyon to the coast of the South Island of New Zealand make it one of the only places in the world where male sperm whales are found close to the shore and present year round (Gordon *et al.* 1992, Jaquet *et al.* 2000). During the past few decades, sperm whales off Kaikoura have been the focus of both scientific investigation and the whale watching industry (Gordon *et al.* 1992, Childerhouse *et al.* 1995, Dawson *et al.* 1995, Jaquet *et al.* 2000, Richter *et al.* 2003). These studies determined that the whales can be divided in two groups. The residents who spend several weeks or months and come back in the area over the year, and the transients who only spend a few days or hours in Kaikoura (Childerhouse *et al.* 1995, Jaquet *et al.* 2000, Richter *et al.* 2003). Previous studies have found a difference in sperm whale distributions between summer and winter and also that during some periods of the year, sperm whales are more difficult to find close to shore (Jaquet *et al.* 2000).

Previous studies have established that cetaceans selectively use different habitats and are influenced by changes in prey availability in response to oceanographic variation (Davis *et al.* 1998, Cañadas *et al.* 2002, Hamazaki 2002). Correlations of sperm whale abundance with highly productive areas have been found in the Mediterranean (Viale 1991), the South Pacific (Jaquet and Whitehead 1996), and the tropical Pacific (Jaquet *et al.* 1996). During the 1970s and the 1980s, numerous studies attempted to relate sperm whale distribution to oceanographic features (Kenney and Winn 1987). Water temperature can also affect the richness and the density of zooplankton (Rutherford *et al.* 1999) which in turn influences the distributions of tuna, billfish (Worm *et al.* 2005) and seabirds (Stahl *et al.* 1985, Guinet *et al.* 1997). Whitehead *et al.* (2010) found that the abundance of sperm whales and northern bottlenose whales (Hyperodon ampullatus) was often more affected by sea surface temperature (SST) than high oceanic productivity. Similarly, Polacheck (1987) found that the distribution of cetaceans in the tropical Pacific is primarily explained by SST. Cetacean distribution also appears to be strongly influenced by SST in the Mediterranean Sea, off the coast of California and in the Gully (Hooker *et al.* 1999, Reilly *et al.* 1999, Laran and Gannier 2008). In contrast, Drouot (2003) used a large spatial scale without discerning between data collected offshore and the one collected near continental slope and Drouot (2003) did not find a significant relationship between sperm whale distribution and SST in the Mediterranean Sea.

Understanding the habitat use of cetaceans is of central importance for population conservation (Lack 1971, Schoener 1974, Redfern *et al.* 2006, Laran and Gannier 2008), considering that habitat degradation or loss of habitat are threats to the sustainability of many species (Macleod *et al.* 2004). In addition, knowing why species are more abundant in some habitats than in others is a central question in ecology (Huey 1991). This suggests that understanding the distribution of sperm whales off Kaikoura will require a detailed assessment of the presence of whales in relation to Chl*a*, SST and distance from SST fronts.

The study utilized an alternative method to study sperm whales distributions by focusing on data collected from a shore-based station. Our aim was to investigate the relationships between sperm whales positions and oceanographic variables such as chlorophyll a (Chl*a*), sea surface temperature (SST) and distance from SST fronts.

6.3. Materials and Methods

6.3.1. Study area

The study area included the submarine Canyon and the surrounding near shore habitat off Kaikoura (South Island, New Zealand). The demarcation of the study area was influenced by the ability of spotting whales from shore. Data were collected from a shore-based station established on the Kaikoura Peninsula (S 42°25’47.1’’ E 173°41’54.6’’) overlooking the study area with an observation radius of 25 km and a study area in the order of 900 km² (Fig. 1).

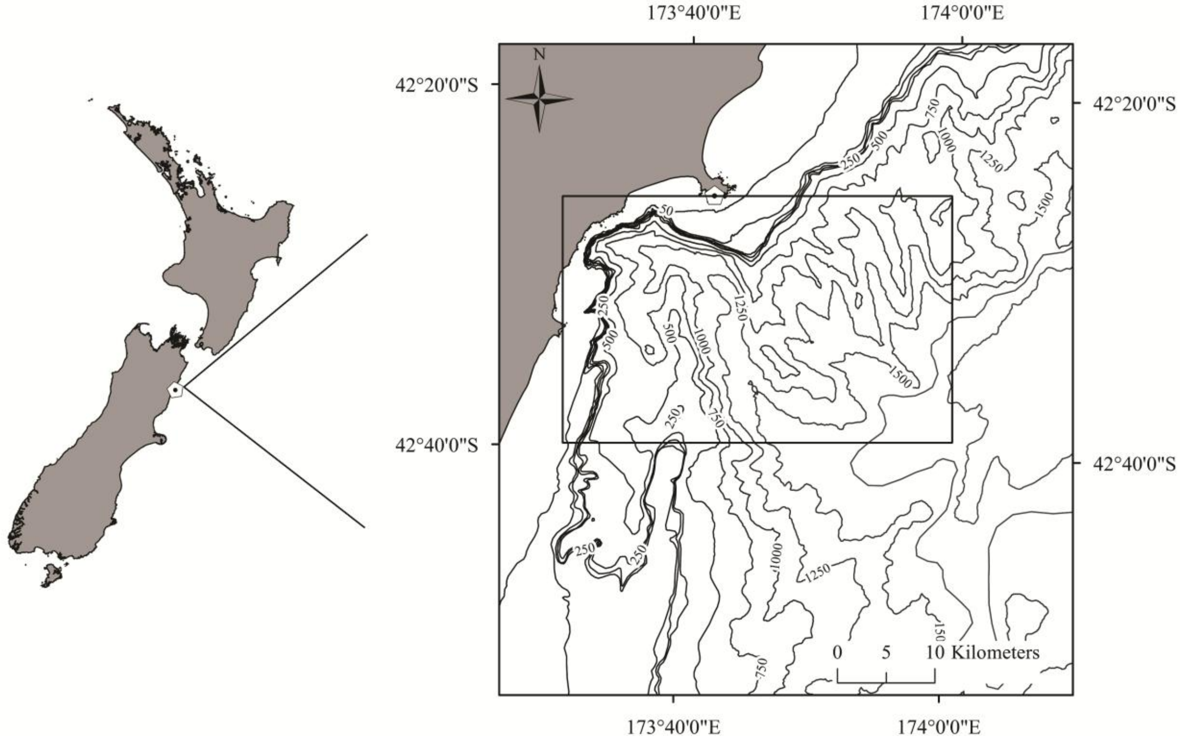

Figure 1. Map of the Kaikoura canyon, showing bathymetry and the study area (rectangle).

6.3.2. Data collection

We carried out our study between 2010 and 2012 from a shore-based station using a Sokkia Set4000 theodolite (Würsig *et al.* 1991, Gailey and Ortega-Ortiz 2002). We detected sperm whales visually using 20x80 binoculars, and when spotted, we tracked the individual with the theodolite during his entire time at the surface. The theodolite software Pythagoras transformed thedolite readings into GPS coordinates in real time with corrections for the curvature of the Earth and tide level (Gailey and Ortega-Ortiz 2002). All information such as whale positions and behaviours (blow, fluke up, tail slapping), were automatically stamped with date and time through the theodolite software Pythagoras.

6.3.3. Environmental data

To analyse all our oceanographic data we used ArcGIS 10.1. We downloaded SST (°C) and chlorophyll a (Chl*a*, mg/m^3) (as a proxy for primary production) data from the NOAA

National oceanographic data center NODC and were obtained by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the NASA Aqua satellite with a 1x1km/pixel resolution (http://www.nodc.noaa.gov/SatelliteData/ghrsst/accessdata.html). We choose a daily time-scale and we excluded cloudy days from the analysis, thus reducing the original dataset. We imported these data using NetCDF tables into ArcGIS, and then we imported each file to a point geodatabase and converted to raster. To obtain thermal fronts we used the open source ArcGIS toolbox Marine Geospatial Ecology tool (MGET) (Roberts *et al.* 2010). We used the Cayula-Cornillon fronts tools in MGET to identify the boundaries between different water masses. For our study, we identified frontal zones whenever a difference higher than 0.5°C existed between two cells. The fronts in the output rasters were converted to polylines in order to allow the calculation of the distance between the front and sperm whales fluke up positions. For each sperm whale position, we joined the GIS layers containing the environmental variables, and we extracted the distance from the nearest SST front.

6.3.4.Data analysis

We plotted sperm whale positions on a map using ArcGIS 10.1. Using the ArcView extension ET GeoWizards tool, the study area was divided into grid cells of 1km x 1km. We used presence data analyses and we determined for each grid cell the presence (1) or absence (0) of sperm whales.

To model the presence of sperm whales in relation to oceanographic features, we analyzed data using general additive models (GAMs), assuming a binomial distribution with a logarithmic link function using the mgcv library (Wood 2004, 2006) in R 2.15 (R Development Core Team, 2012). GAMs have the advantage of letting the data dictate how the shape of the dependent variable is affected by each covariate by fitting nonparametric smoothing terms (Hastie *et al.* 2005, Panigada *et al.* 2008).

We used presence and absence of sperm whales as response variable and SST, Chl*a* and distance from SST front (≥ 0.5°) as explanatory variables. Smoothness parameters were estimated with generalized cross validation (GCV/UBRE). The models with the lowest GCV/UBRE scores and an improvement in the overall deviance were selected. The covariate with the largest p-value was discarded in each step until the lowest GCV score was reached (Wood 2001). We retained non-significant variables in the model if they reduced the GCV/UBRE score. Multicollinearity between variables can create model performance issues by leading to the wrong identification of relevant predictors (Zurr *et al.* 2007). In order to avoid multicollinearity we identified the possibility of collinearity amongst covariates using pairplots. None of the variables appeared to be correlated ($r < 0.75$). We concluded that none of the variables needed to be excluded from the model.

To test model performance, we produced maps of predicted probability of sperm whale presence/absence by only using a part of the dataset to create the model and then to determine whether or not the predicted distribution matched the observed distribution on the excluded dataset. We made the prediction on the same scale as the model GAM, 1x1 km cell grid. We predicted the presence or absence of sperm whales for each grid using the prediction GAM tool in ArcGIS toolbox Marine Geospatial Ecology tool (MGET) (Roberts *et al.* 2010). We included years, months and observation effort as factors in order to assess the potential difference of sperm whales abundance during the different research seasons. The models residuals did not display patterns, indicating the model fitted the data well.

6.4. Results

Once we excluded cloudy days from the analysis, the final dataset used for this article corresponded to a total of 209 days of data collection between 2010 and 2012. This dataset corresponded to days where oceanographic variables were available. We defined a surfacing event when we tracked the whale during the entire time at the surface, from the first blow spotted until the fluke up (fluke raised above the water when preparing for a dive). We recorded a total of 3657 sperm whale surfacing event within the study area over a total search effort of 1295 hours (Fig. 1, Table 1). Table 1 describes the scanning effort by season. Variability in weather conditions during seasons influenced the data collection effort.

We defined seasons as follows:

Autumn: March, April and May.

Winter: June, July and August.

Spring: September, October and November.

Summer: December, January and February.

Table 1. Summary of monitoring effort from the shore-based station by year and season. Total number of recorded surfacings used in the analyses.

Year	**Season**	**Effort (h)**	**Number of Surfacings**
2010	Autumn	159.43	310
	Winter	43.18	100
	Spring	114.23	143
	Summer	64.58	108
	Total	**381.42**	**661**
2011	Summer	150.58	388
	Autumn	180.17	687
	Winter	202.1	1014
	Spring	78.5	114
	Summer	83.75	204
	Total	**695.1**	**2407**
2012	Summer	135.58	366
	Autumn	83.17	223
	Total	**218.75**	**589**
Total		**1295.27**	**3657**

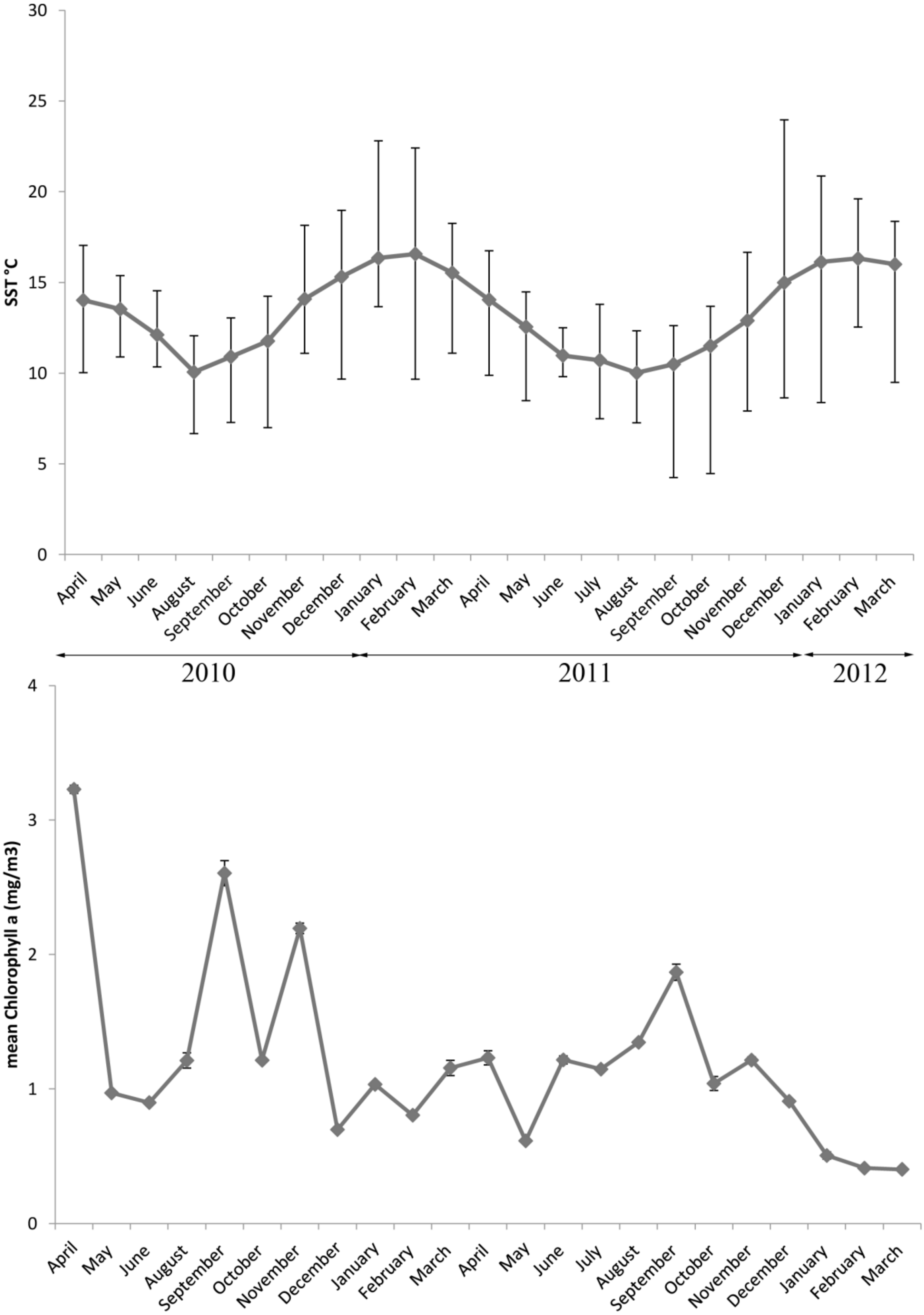

Figure 2. a) Average SST values (°C) from the study area from April 2010 to March 2012 maximum and minimum values indicates by bars. B) Average Chla values (mg/m^3) from the study area from April 2010 to March 2012 with SE bars.

Average SSTs throughout the study area displayed a variation of as much as 20°C between summer and winter months. An increase of sea surface temperature was apparent throughout the summer, reaching the highest in December/January then the temperature started to drop until reaching an annual low from August through October. Seasonal changes in primary productivity are related to the availability of nutrients. A Chl*a* peak appeared in the beginning of spring (Fig. 2).

6.4.1. Generalized additive models (GAMs)

All three oceanographic variables had a significant relationship ($p<0.001$) with whale presence/absence per cell through the seasons (Table 2). The factor years appeared relevant for autumn and winter with more sightings recorded in 2011 and 2012 than in 2010. As expected, the scanning effort was relevant for most of the seasons excepted for autumn (Table 2). The model that best explained sperm whale distribution was for winter and accounted for 56.5 % of the deviance (Table 2). Year was not significant for summer and spring but we kept the factor for the final model based on the percent of deviance and UBRE score. Smooth functions showed non-linear relationships (Figs. 3, 4, 5) indicating the need to use GAM models for our analyses.

Table 2. Summaries for final generalized additive models for the seasonal models. --: parameter not included in final model; na= not applicable for model. Month 1, 2, 3 correspond to first month in season, example for summer 1= December,2=January and 3=February). We bolded significant terms at p<0.05.

	Summer (n= 14858)	**Autumn (n= 11397)**	**Winter (n= 10880)**	**Spring (n= 4933)**
		Estimate(±SE)		
Intercept	**-10.285(± 1.413)**	**-9.748 (± 1.202)**	**-14.645 (± 1.828)**	**-80.597 (± 38.432)**
FACTOR				
Year				
2011 (vs.2010)	-0.227 (± 0.244)	**0.941 (± 0.169)**	**0.921 (± 0.214)**	-0.312 (± 0.202)
2012 (vs.2010)	-0.223 (± 0.309)	**-1.847 (± 0.316)**	-	-
Month				
2 (vs.1)	**1.934 (± 0.238)**	**1.958 (± 0.239)**	**1.720 (± 0.216)**	**-0.750 (± 0.360)**
3 (vs.1)	**0.571 (± 0.223)**	0.039 (± 0.212)	**1.025 (± 0.199)**	**1.056 (± 0.305)**
Effort	**0.092 (± 0.034)**	-	**0.425 (± 0.070)**	**0.185 (± 0.073)**
SMOOTH FUNCTIONS		**X^2 (edf)**		
Long,Lat	**374.50 (24.676)**	**567.42 (28.203)**	**553.02 (27.897)**	**160.29 (22.771)**
SST	**40.81 (7.844)**	**106.68 (6.102)**	**158.00 (8.877)**	**27.27 (4.542)**
LogChl*a*	**49.29 (7.359)**	**50.12 (8.282)**	**36.89 (6.667)**	**79.09 (7.119)**
Distance from front	**55.28 (5.000)**	**47.54 (8.891)**	**124.23 (6.634)**	**73.49 (8.970)**
% Deviance	47.6	46.9	56.5	42.1
R^2adj	0.352	0.376	0.487	0.324

Distribution of sperm whales appeared to be strongly associated with SST (Fig. 3). We observed a correlation between the absence of whale and an increase of SST in autumn and spring. During these seasons, sperm whales associated within the part of the canyon with colder SST waters. Sperm whales presence decreased with an increase of SST for autumn and spring. In winter, the SST curve suggested a lower presence of sperm whales for temperature below 8°C, with an uncertainty due to the low number of samples in these SST range, reaching a peak of presence at 8°C then with an apparent decrease of presence. A peak of sperm whale presence appeared at the upper range, around 13 °C (Fig. 3). The relation between presence of sperm whales and SST in summer was more uniform with a peak in presence at 14°C, this correspond to low temperature for the season. The wide confidence interval in both upper and lower range of the generalized additive model smoothing curves made the relationship difficult to interpret (Fig. 3).

Chl*a* was another significant oceanographic variable to determine sperm whales presence within the Kaikoura submarine canyon (Fig. 4). For summer, the curve suggested higher presence at both lower and upper ranges but with a wide confidence interval correlated with few sightings in these ranges. For spring, autumn and winter, Chl*a* played a role in sperm whale distribution with two peaks of presence with whales associated with areas of lower and higher Chl*a* concentrations. For winter and spring, the presence of whales peaked in low Chl*a* concentration and slowly declined to 3.16 mg/m^3. Presence rose again to larger concentration (Fig. 4).

The function of distance to the SST fronts suggested a positive correlation for winter (Fig. 5). We correlated the presence of sperm whales with SST fronts found at larger distances from the sperm whales positions. This correlated with whales found closer to shore in this season and the absence of a front nearby. In summer, sperm whale presence correlated with a nearby SST front with a decrease of whale presence with larger distance from the SST fronts. Autumn and spring showed a clear drop of sperm whales presence at large distances from the SST fronts.

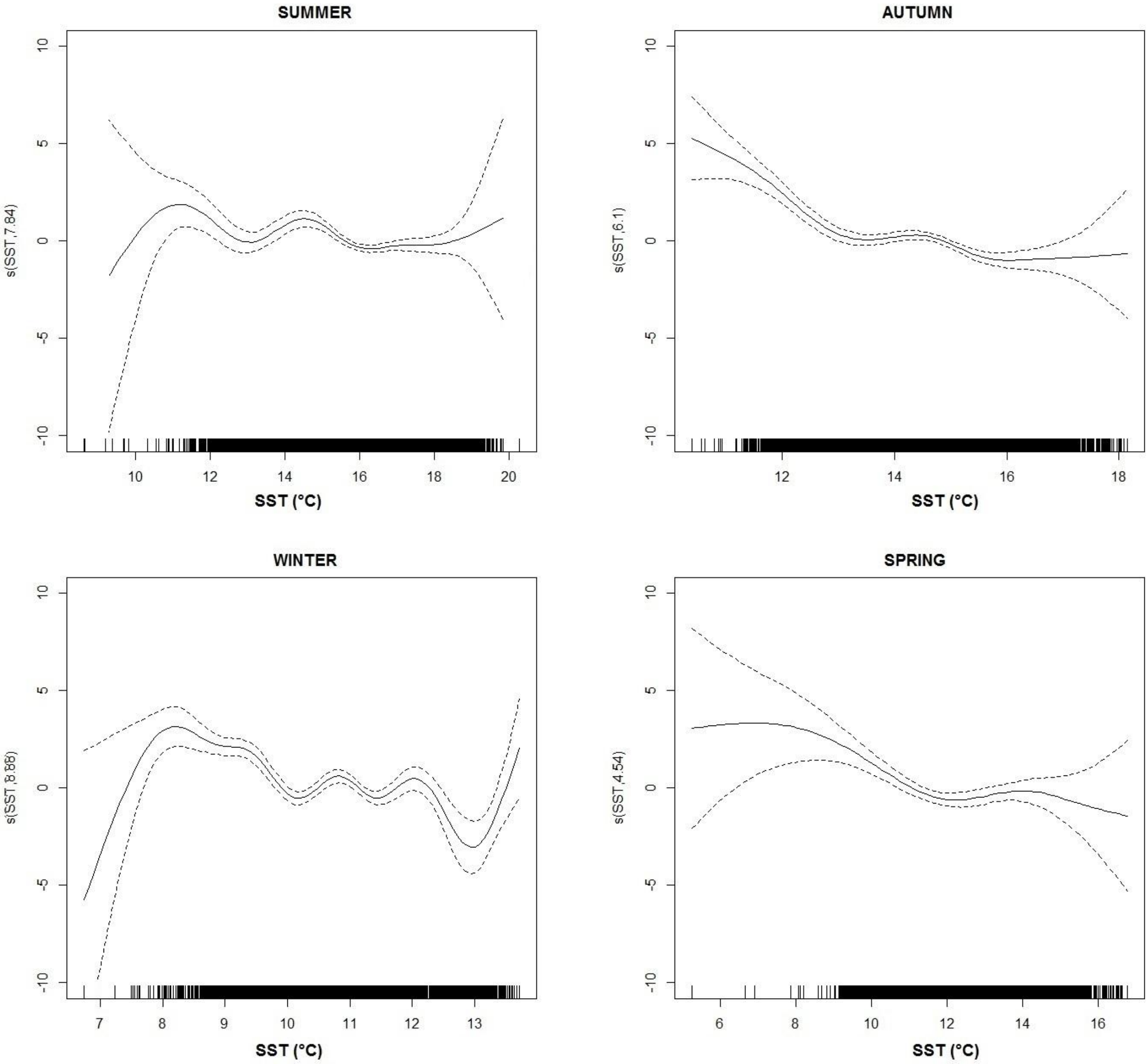

Figure 3. Genealized additive model smoothing curves of SST (°C) for the four seasonal models. Y-axis= fitted function with estimated degree of freedom. X-axis represents the SST range. Dashed lines represent 95% confidence. Values greater than zero on the y-axis indicate positive correlation, zero corresponds to no effect, and less than zero indicates negative correlation. Tick marks indicating the observations made for each value of the explanatory variable.

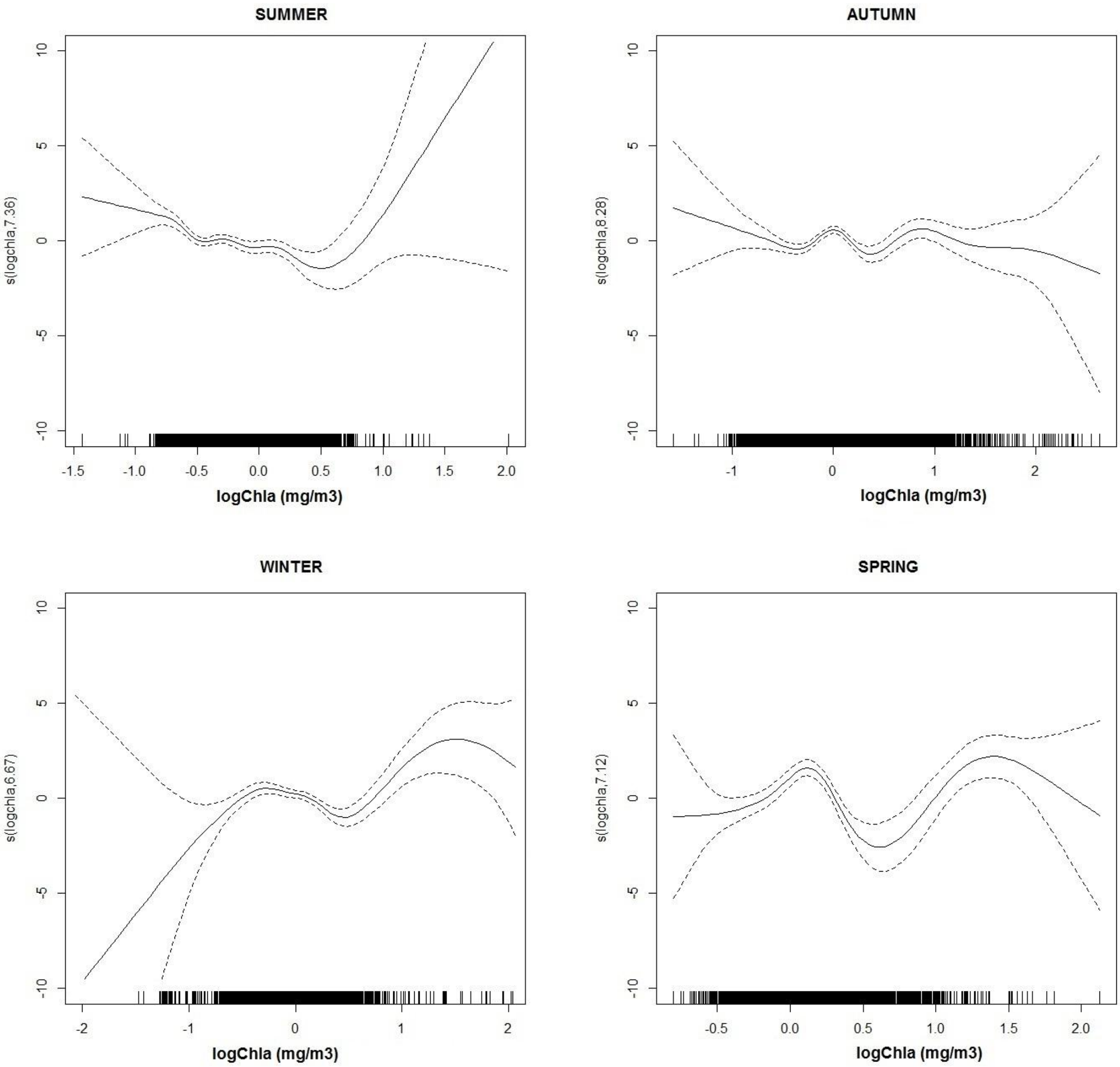

Figure 4. Genealized additive model smoothing curves of logChla (mg/m3) for the four seasonal models. Y-axis= fitted function with estimated degree of freedom. X-axis represents logChla range. Dashed lines represent 95% confidence. Values greater than zero on the y-axis indicate positive correlation, zero corresponds to no effect, and less than zero indicates negative correlation. Tick marks indicating the observations made for each value of the explanatory variable.

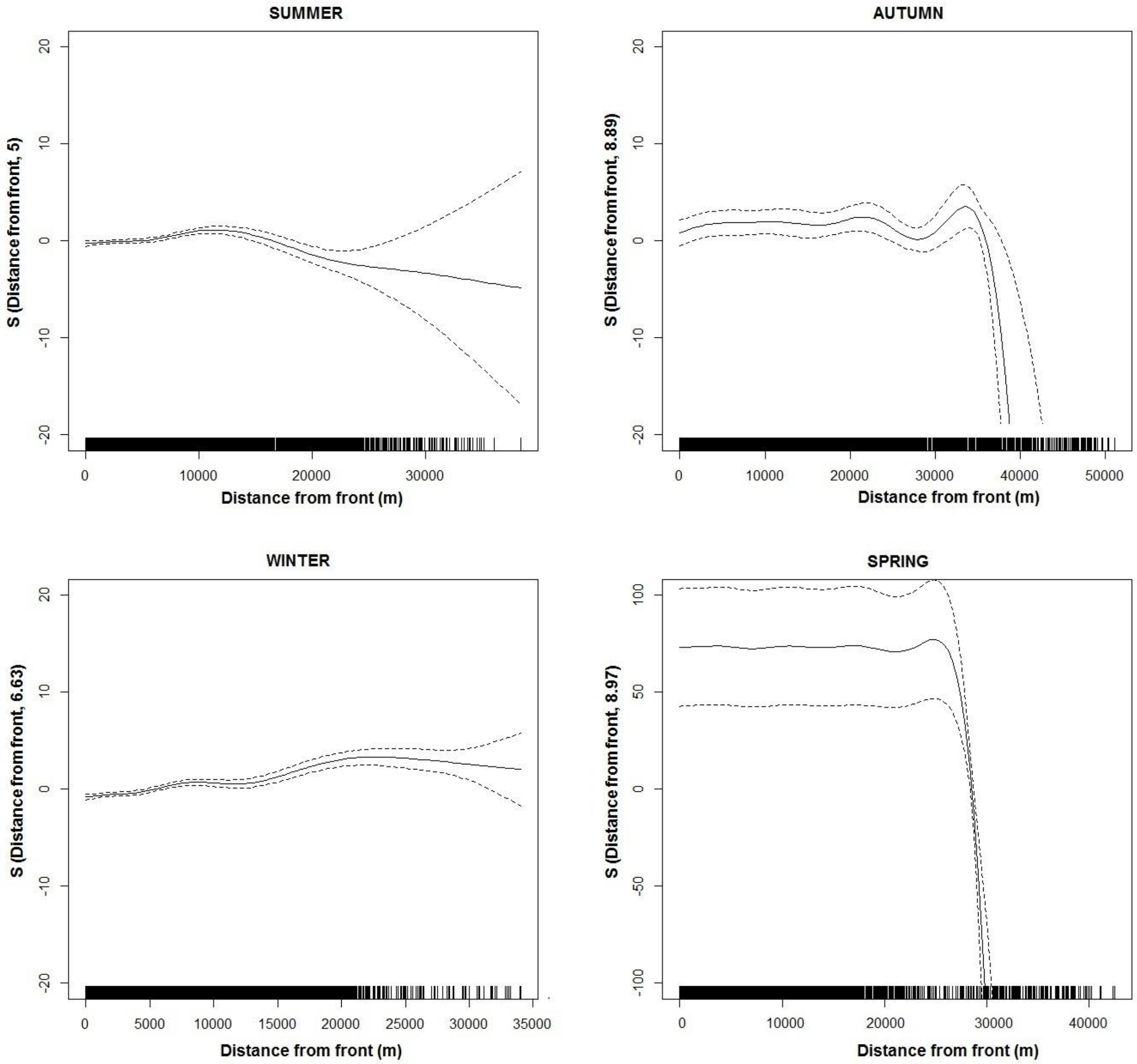

Figure 5. Genealized additive model smoothing curves of distance from front (m) for the four seasonal models. Y-axis= fitted function with estimated degree of freedom. X-axis represents the distance from SST front. Dashed lines represent 95% confidence. Values greater than zero on the y-axis indicate positive correlation, zero corresponds to no effect, and less than zero indicates negative correlation. Tick marks indicating the observations made for each value of the explanatory variable.

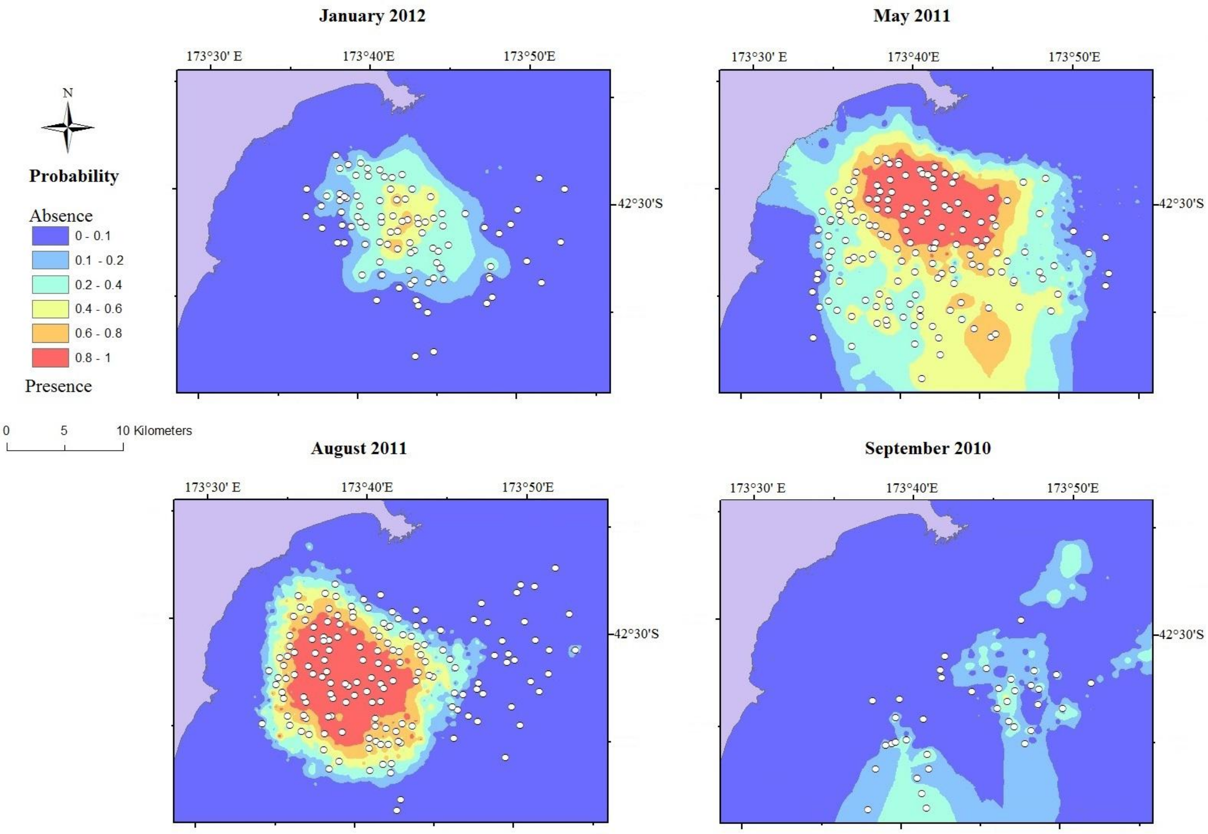

Figure 6. Monthly example of predicted probability of sperm whale presence produced by seasonal models. Actual sightings (white dots) are included for comparison. We interpolated predicted probability of sperm whale presence using an inverse distance weighted (IDW) technique.

Figure 6 shows how the models predicted the sperm whale presence within the canyon for an example in each season. We used the Marine Geospatial Ecology tool in ArcGIS to fit the seasonal generalized additive model (GAM). This ArcGIS tool created a map representing the presence of sperm whales predicted from a dataset of the predictor variables.

Models prediction corresponded to the sightings made during the same period of time so the models seemed to predict fairly well throughout the area. The prediction for autumn (September 2010 Fig. 6) showed the clear distribution difference between autumn and the others seasons, with whales found further offshore. The areas with the highest sightings of sperm whales were consistent with the models predictions.

6.5. Discussion

The present modeling of the distribution of sperm whales within the Kaikoura submarine canyon area showed marked and predictable changes in distributions between the seasons within a 900 km^2 area in relation to SST, Chl*a* and SST fronts.

In this study we combined techniques such as GIS and oceanographic variables extracted from satellite data at a multiple temporal and spatial scales collected from a shore-based station. As our shore-based survey was not constant through the seasons because of weather conditions, we investigated this inconsistency by using factors in our models such as year/month and scanning effort. We included the daily effort to account for the variation of time spent scanning the study area between the days. This study showed the possibility to use oceanographic variables collected from satellite imagery data in order to model cetacean distribution within a local area.

This study determined that the distribution of sperm whales off Kaikoura was strongly influenced by Chl*a*, SST and distance from SST fronts. The relevance of the oceanographic variables, in the description of the sperm whale habitat was closely linked to season. SST was a significant predictor for all the models, and it is also the best predictor for zooplankton and fish abundance (Rutherford *et al.* 1999, Worm *et al.* 2005). The seasonal relationship between sperm whale distribution and oceanographic features indicated a link with food availability. Studies have demonstrated that conditions present in frontal zones are favorable to the development of cephalopods populations with a decrease of squid linked with a decrease in SST fronts (Ichii *et al.* 2002). The sperm whales off Kaikoura preyed upon a variety of cephalopods, and these cephalopods species are probably following the same distribution as other cephalopod species around the world and aggregate near frontal zones and in areas of high productivity and low temperature (Rice, 1989, Moreno *et al.* 2009).

Our models showed that sperm whales preferred colder SST waters over the four seasons. Sperm whales appeared to aggregate in the section of the study area with the lowest SST. Our results are in accordance with previous studies showing a relationship between cold water and sperm whales foraging success (Whitehead *et al.* 1989, Smith and Whitehead 1993). Previous studies described that sperm whales defecate more in cooler SST areas probably related with a change in the prey distribution in response to water temperature influencing a lower foraging success at higher SST (Whitehead *et al.* 1989, Smith and Whitehead 1993, Whitehead 1996). Rutherford *et al.* 1999 found that temperatures at depth were highly correlated with SST and that SST was by far the best predictor for the diversity of zooplankton. This correlation also appeared for tuna and billfish (Rutherford *et al.* 1999, Worm *et al.* 2005).

Chl*a* concentration was a good predictor for sperm whale distribution off Kaikoura. The smooth functions curves were consistent through the four seasons with sperm whales mostly associated with areas of low Chl*a* concentrations. We observed some association with area of high Chl*a* concentration which needed to be analyzed carefully. The small sample size in the area of high Chl*a* concentration and the large confidence interval may influence these results. Our results correlated with Jaquet *et al.* (1996) results on sperm whale distribution in the tropical Pacific, they determined that Chl*a* concentration is a good indicator of sperm whale distribution with sperm whales found in waters of higher Chl*a*. In our final models, both the SST and Chl*a* were major variables to determine the whale's distribution. Previous studies have determined that the relationship with sperm whales and primary production only happened at spatial scales larger than 200km (Jaquet and Whitehead 1996, Jaquet *et al.* 1996). And that it is easier to understand the correlation between the concentration of Chl*a* and presence of baleen whales, because their main prey is euphausiid shrimp. Euphausiids are found at a low trophic level and their abundance is directly linked to primary productivity and

Chl*a* (Littaye *et al.* 2004). For sperm whales, which feed at a higher trophic level, on squid and fishes, some doubt remains about this correlation. Concerning our study, the relation with the average Chl*a* concentration can be consistent with the presence of a temporal lag between the peak of Chl*a* and the presence of sperm whales as explained in previous marine mammals studies (Littaye *et al.* 2004, Laran and Gannier 2008, Notarbartloo-Di-Sciara *et al.* 2008).

Previous studies determined that frontal zones enhanced phytoplankton, zooplankton and fish biomass (Sharples and Simpson 2001). Sperm whales may also be attracted to these SST fronts, favorable to the growth of cephalopods (e.g. Gaskin 1982, Bluhm *et al.* 2007, Doniol-Valcroze *et al.* 2007). Distance from SST fronts was a significant variable to describe sperm whale distribution through all our models. For baleen whales they hypothesized the possibility of a spatial and temporal lag between the fronts and the time for prey to aggregate. Concerning the detection of SST fronts, Miller (2011) determined that the lower limit of temperature difference to determine SST front can be analyzed ≤ 0.5°C if weaker fronts need to be established. In our study we used a difference of SST between cell ≥ 0. 5°C, which implied that within the Kaikoura submarine canyon it was possible to determine the presence of SST fronts. A previous study on sperm whales in the north-west Mediterranean Sea have used a difference up to 1.2°C between water cells (Gannier and Praca 2006), when another study on humpback whales used a difference ≥ 0.375°C (Dalla Rosa *et al.* 2012).

Our seasonal results of the sperm whale distribution can be linked with knowledge on the Kaikoura region and the several oceanographic events that influence it. In winter, sperm whales are found close to shore and Garner (1961) described the coastal mixing and river out flows producing upwelling of nutrient-rich subtropical water during the winter months. Garner (1961) also reported periodic influxes of cold subantarctic water in summer, detectable to the north but not to the south of the peninsula. This can be related with sperm whale found north offshore of the peninsula in summer months. An example of the highly productive area north of the Kaikoura peninsula was noticed during aerial observations with high presence of plankton and schools of fish in this area during summer (Stonehouse 1965).

Our study showed the importance of SST temperature and fronts on the sperm whales distribution within the Kaikoura submarine canyon. Future studies should try to estimate and build predictive models to determine if the change in water temperature caused by global warming will possibly influence the sperm whale distribution off Kaikoura. Recent review on the effect of climate change determined that the influence of the climate change on the oceans include reduced salinity related to ice melting, increased in water temperature, shifts in current systems such as upwelling (Robinson *et al.* 2005). By implication, it is predicted that species using cold waters will have their range reduced and their distribution shift towards the poles so these variations will impact the species migrations (e.g. Crick 1999, Pierce and Boyle 2003) and population distributions (e.g. MacLeod *et al.* 2005, Sparks *et al.* 2007). It is to be expected that predator distributions will be affected by prey, changes in prey distribution or abundance may precede shifts or declines in predator populations (Worm *et al.* 2005).

6.6. Conclusion

This paper improved our existing knowledge on the sperm whale-habitat relationship within the Kaikoura submarine canyon through shore-based sampling and satellite imageries. The biological and economical interest of the Kaikoura area should encourage future works studies to assess any change in whale distributions related to changes in environmental conditions. Also, it is not clear how important the submarine canyon is for the sperm whales populations. Future work should focus on determining where the resident sperm whales go when they are not within the submarine canyon and to detect any other feeding grounds around New Zealand. Determining the importance of this feeding ground is a major concern for the conservation of this species.

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7. Conclusion

7.1. Summary of findings

The aim of this research was to determine if the distribution of sperm whales within the Kaikoura submarine canyon is influenced by oceanographic variables. I used general additive models and determined that sperm whales distribution displayed a strong seasonal distribution within the Kaikoura submarine canyon in relation to oceanographic variables.

In chapter 2, I developed a protocol to improve the accuracy of theodolite measurements. I determined the theodolite accuracy by using data simultaneously recorded from a shore-based theodolite station and two boat-based GPS device. As expected, I observed that the accuracy fell rapidly with an increase in range of the object from the shore-based station. Results showed that the horizontal angle was accurately determined, but this was not the case for the vertical angle. To examine the distance error, I modeled the relationship between distance from the shore-based station and the difference between simultaneously recorded theodolite fixes and GPS positions. I examined the regression-based models for the distance errors and I selected the best fitted model (y ~ a*x^b**)** to correct theodolite fixes based on their distance from the theodolite station. This chapter revealed the necessity to calibrate theodolite measurements with an object of known position when tracking animals at sea. The major contribution of this research is that it presents a technique for enlarging the use of shore-based station for habitat and abundance studies, as far as the limit of the visual detection.

In chapter 3, I examined the daily abundance of sperm whales off Kaikoura by using distance sampling and mark-resight methods. In this chapter I explored an alternative method to boat-based abundance estimation to assess abundance from a shore-based station by using a modified technique usually selected from boat based platforms. For the first time the daily abundance of sperm whales off Kaikoura was determined using data collected from shore. The results showed a difference in sperm whale abundance compared to earlier work. This difference can be explained by a possible diminution of the use of this particular area by sperm whales. This change of habitat could be related with human activities, a redistribution of animals to offshore waters or to individuals moving to other areas in response to environmental variations influencing food availability. In conclusion, these methods could be integrated into management effort, offering a non-invasive survey to determine abundance of sperm whales off Kaikoura. Our method could be improved by using multiple shore-based stations with independent observers, offering the possibility to determine the number of sperm whale surfacing missed by the observers (Rugh *et al.* 1993, Hedley *et al.* 2008).

The work I accomplished in chapter 4, was to use a spatio-temporal model in order to extract sequential dives of a same whale within a single day. This chapter explained the mark-resight methods used in the chapter 3. Unlike many marine mammals, sperm whales have a very predictable behaviour when observed in a feeding ground. Knowing the specific behaviour of the sperm whale within the Kaikoura submarine canyon I tracked sequential dives of individual sperm whales on a daily basis. I based this approach on a good understanding of the animal behaviour within a particular area. Finally, I correlated the results of the model with data of sperm whale identification collected simultaneously from a boat-based station. The results showed that the model matched properly 88% of our sightings. This model can be adapted and used for marine mammal individual identification in areas where their behaviour is already well documented in order to follow individuals during their sequence of dives over a single day.

In chapter 5 I have investigated the relationship between the temporal and spatial distribution of sperm whales with the bathymetric features such as distance from shore, bathymetry and bathymetric slope. I used general additive models to determine which physiographic factors influence significantly the sperm whale distribution off Kaikoura. This has resulted in the identification of seasonal movement patterns with sperm whales using offshore and deeper water in spring and shallower water in winter. I determined that the distribution of sperm whales off Kaikoura was highly linked to the bathymetric features of the canyon. This seasonal shift in distribution is more than probably linked to a shift of their main prey. It is apparent that the bathymetric features are not the only factor affecting the distribution of sperm whales. Other parameters may influence the presence of sperm whales in particular parts of the canyon such as oceanographic variables. The assumptions of the impact of oceanographic variables on the sperm whales' distribution within the canyon are investigated in the chapter 6.

My study in chapter 6 represents the first time that sperm whale distribution off Kaikoura has been modeled in relation to oceanographic variables. It is well known that food availability is the main factor influencing the distribution of a species. Previous studies have established that cetaceans can be classified by habitats and have observed a change of habitat in relation to oceanographic variation which influences prey availability (Davis *et al.* 1998, Cañadas *et al*. 2002, Hamazaki 2002). GAMs models indicated that SST, Chl*a* and distance from SST front were all important parameters in predicting sperm whales distribution. A correlation was observed with sperm whale presence and areas of cold water, presence of SST fronts and low Chl*a* concentrations. The results showed that sperm whale distribution can be determined at a small spatial scale and they demonstrated the significance of small scale frontal processes. The present modeling of the distribution of sperm whales within the Kaikoura submarine canyon area showed marked and predictable changes in distributions between the seasons within a 900 km^2 area in relation to SST, Chl*a* and SST fronts. So, it appears that SST fronts may be responsible for the concentration and retention of sperm whales prey in the canyon, with an absence of whales in the canyon correlated with an absence of SST fronts. These models will be very useful for conservation management as they offer the possibility to predict the presence of sperm whales within the Kaikoura submarine canyon in relation to oceanographic variables. This is even more important for a sperm whale population which supports local tourism and has frequent interactions with tour vessels. This study also showed the value of open source satellite data and the possibility to use oceanographic variables to model cetacean distribution even on a small spatial scale and with data collected from a shore-based station.

7.2. Limitations and Future research

The main limitation for collecting data from a shore-based station is the distance limit at which individuals can be tracked. In this study I was limited to the distance at which I was able to sight sperm whales (25km). To reduce the impact of these limitations, future research needs to be conducted over extended study areas in order to examine the distribution and behaviour of sperm whales further offshore. Multi-platform data collection such as plane surveys, boat surveys and passive acoustic techniques (Leaper *et al.* 1992, Gillespie 1997, Gordon *et al.* 1998, Gannier *et al.* 2002, Praca *et al.* 2009), will increase the efficiency in finding and locating sperm whales at a larger spatial scale around the Kaikoura area. This will also allow us to determine if resident sperm whales leave the Kaikoura area or only move further offshore.

Another key limitation was the lack of measurement of prey availability within the study area. Measuring prey availability would improve our understanding of sperm whale distribution and habitat selection. Because of the temporal lag between a peak of chlorophyll concentration and the presence of sperm whales it will be more meaningful to relate the sperm whales distribution to their main prey. Jaquet and Gendron (2002) related sperm whale distribution with the abundance of squid. They did not find a relationship between distribution of squid and sperm whales but they found that sperm whales change their distribution in response to a decline in squid. Such study within the Kaikoura submarine canyon will help our understanding of sperm whales off Kaikoura and the possible impact of the shift of their main prey.

Additionally, the results from chapter 6 showed the importance of SST temperature and SST fronts on the sperm whales distribution within the Kaikoura submarine canyon. Changes in water temperature caused by global warming should be estimated in order to produce predictive models of possible changes in the distribution of the species (Worm *et al.* 2005). It is important to closely monitor this population to ensure that the occurrence of sperm whales so close to shore continues.

7.3. Conclusion

In conclusion, in this thesis I improved the technique used to determine positions of animals at sea. This method offers the possibility of tracking animals at larger distances from shore than previously done with great accuracy. I also used novel and innovative methods to determine abundance and individual identification from a shore-based station. This will offer new opportunities to use a shore-based station as a low-cost alternative to boat-based studies. Finally, I focused on improving the understanding of sperm whale distribution and habitat selection within the Kaikoura submarine canyon. My study is the first to collect continuous data on sperm whales from a shore-based station off Kaikoura and to model their distribution. This study also demonstrates that fine scale oceanographic processes can directly influence the distribution of foraging sperm whales. My findings on the association of sperm whales with areas of lower SST temperature should lead to better assessment of the effects of environmental variability and climate change on sperm whale distribution.

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8. Appendices

Chapter 2

SHORE-BASED MONITORING OF SPERM WHALES IN KAIKOURA CANYON: BEHAVIOUR, DISTRIBUTION AND INTERACTIONS WITH TOUR VESSELS

Ophélie Sagnol, Tim M. Markowitz and Wendy J. Markowitz

Whale watching has been described as a sustainable use of marine resources offering an economic alternative to whaling. However, in at least some cases research has found tour vessels to be a nuisance to whales and dolphins, with the potential to reduce the biological fitness of wild cetacean populations. Previous studies of sperm whales at Kaikoura have focused on boat-based research. The consistent occurrence of sperm whales near land combined with high vantage points on shore provides a rare opportunity to monitor these large-brained, deep-diving giants from a "perfect research blind," providing data on whale distribution and behaviour in both the presence and absence of vessels. Theodolite tracking has been used effectively in a number of studies to examine the effects of anthropogenic noise, habitat alteration and tourism on cetaceans. In this study, regular monitoring of sperm whales and whale watching vessels was undertaken using a surveyor's theodolite linked to a laptop computer running the tracking program Pythagoras. In parallel, we used a linked digital video camera-binocular system to confirm our observations. In order to assess the distribution and habitat use of sperm whales, location fixes (estimated longitude latitude positions based on horizontal and vertical angles) collected with the theodolite were imported into ArcGIS 10. Observations were made during 212 days between April 2010 and June 2011. A total of 2,717 surfacings were recorded using the theodolite and 1,204 surfacings using the digital video-binocular system. Both surface behaviour and distribution of whales varied seasonally. Blow interval and surface time peaked in summer, while swimming speed, distance from shore and water depth peaked in spring, when whale use of the Kaikoura Canyon area also appeared to decrease. Whales observed from shore were generally accompanied by tour vessels less than half the time. The greatest level of visitation occurred in the afternoon and during the summer months, when the number of whale surfacings accompanied by vessels slightly exceeded the number of whale surfacings unaccompanied by vessels. GIS analysis of whale and tour vessel distribution showed whale sightings were most tightly clustered in summer and autumn when the degree of overlap between areas where whales were accompanied and unaccompanied by boats peaked at 78-93%. There was a significant difference in ventilation rate (blow interval) for whales in the presence versus absence of whale watching vessels, but no difference in surface behaviour with number of vessels present. Swimming speed did not vary with vessel presence.

INTRODUCTION

BACKGROUND AND JUSTIFICATION

During the past few decades, sperm whales off Kaikoura have been the focus of both scientific investigation and the whale watching industry (Gordon *et al.* 1992, Childerhouse *et al.* 1995, Dawson *et al.* 1995, Jaquet *et al.* 2000, Richter *et al.* 2003). These studies have focused on boat-based research, although some shore-based monitoring of sperm whales has also been undertaken (Richter et al. 2006). In New Zealand, shore-based monitoring has been used more commonly in studies of tourism effects on dolphins, including Hector's dolphins at Porpoise Bay (Bejder et al. 1999) and Banks Pensinsula (Martinez et al. 2011), and dusky dolphins off the Kaikoura coast (Barr and Slooten 1997, Würsig et al. 2007, Markowitz et al. 2010).

Land-based monitoring of whales is uncommon because few populations of whales reliably reside or migrate close to shore (Forney 2009). However, shore station platforms have proven useful for examining effects of human activities on whales in the near shore environment in a number of settings. For example, shore-based monitoring has been used to examine the effects of oil exploration on grey whales in Russia (Gailey et al. 2007) and near shore construction projects on beluga whales in Alaska (Funk et al. 2005, Markowitz and McGuire 2007). Shore-based studies have previously been used to examine the effects of tourism on Southern right whales in Argentina (Lundquist et al. 2006) and grey whales in the calving lagoons of Baja, Mexico (Ollervides 1997). In New Zealand waters, shore-based monitoring of whales has included research on southern right whales in the Auckland Islands (Pateneude 2000) and humpback whales in Cook Strait (Gibbs and Childerhouse 2000; www.doc.govt.nz/about-doc/news/media-releases/cook-strait-whale-count-on-again/).

From a land-based research platform, the behaviour of cetaceans can be observed without disturbing them, effectively providing a perfect research blind (Würsig *et al.* 1991, Barr and Slooten 1999). In addition, it is less likely that whale watch tour operators will alter their behaviour because they know they are being observed than when they have scientific observers onboard (Chapter 3) or are in the presence of a research vessel (Chapter 4). The Kaikoura peninsula is an ideal place to install a land-based whale tracking station, with the existence of an elevated vantage point and individual whales close enough to shore to be reliably monitored. This provides a non-disturbing and inexpensive compliment to vessel research.

As part of a research effort focused mainly on boat-based data collection, Richter et al. (2003, 2006), examined blow rates of sperm whales at Kaikoura using high powered binoculars. In the current study, we build on this work by adding a digital video system linked to binoculars and increased theodolite tracking effort. Since the 1970s, surveyor's theodolites have been used in many studies to examine cetacean behaviour, movement patterns and habitat use, and also to assess the effects of human activities on marine mammals (Barr and Slooten 1999, Harzen 1998, Harzen 2002, Latusek 2002, Williams *et al.* 2002, Morete *et al.* 2003, Scheidat *et al.* 2004, Lundquist *et al.* 2006, Bailey and Thompson 2006, Schaffar and Garrigue 2008,). At Kaikoura, theodolite tracking has been used to monitor dusky dolphins and examine the effects of tourism on them for over 20 years (Cipriano 1992, Yin 1999, Barr and Slooten 1999, Würsig et al. 2007, Markowitz et al. 2009). Given the demonstrated utility of theodolite tracking in other studies of cetacean interactions with tourism, we decided to utilize this tool in a shore-based investigation of sperm whale-vessel interactions at Kaikoura.

RESEARCH OBJECTIVES

A shore-based monitoring programme was initiated to investigate the behaviour and distribution of sperm whales, current levels of interaction with tour vessels, and any measurable effects of tourism traffic on the whales. Specific objectives of this research were to:

1. ***Describe the behaviour and distribution of sperm whales in the Kaikoura submarine canyon area,***
2. ***Assess the level of interaction between sperm whales and tour vessels at Kaikoura, and***
3. ***Examine the effect of whale watching on the behaviour and distribution of the sperm whales.***

HYPOTHESES

In fulfilling these objectives, we tested the following hypotheses:

1. ***The distribution of sperm whales varies seasonally.***
2. ***Sperm whale behaviour is altered by the presence of whale watching vessels.***
3. ***Habitat use of sperm whales varies depending on the presence of whale watching vessels.***

WHALE INTERACTIONS WITH VESSELS

In order to address these objectives and hypotheses, we monitored sperm whales at Kaikoura in the presence and absence of vessels. While the boat-based research team made every effort to minimize their effect on the sperm whales (see Chapters 4-5), it is not possible to monitor sperm whales in the absence of vessels from a vessel. GPS data loggers (see Chapter 3) provided detailed GPS tracks of tour vessels and aircraft whether or not scientific observers were onboard; however, these data provided only information on the vessels, not on the interactions between the whales and vessels. Only the shore-based monitoring presented in this chapter provides information on sperm whale behaviour and distribution in the absence as well as in the presence of vessels and aircraft. By conducting the largest shore-based monitoring effort examining interactions between sperm whales and tour vessels at Kaikoura to date, we sought to fill an important gap in the available scientific information, comparing sperm whale behaviour in the presence and absence of vessels. To accomplish this goal, focal whale observations were classified as follows with respect to vessel interactions:

Whale only-	No vessel or aircraft near whale (<500m).
Whale watching tour vessel-	Presence of at least one whale watching tour boat (<300m).
Research vessel-	Presence of the research boat (<300m).
Aircraft-	Aircraft circling over whale (<300m).
Whale watching vessel and aircraft-	Presence of at least one whale watching boat and at least one aircraft (<300m).

METHODS

STUDY AREA

A shore station was established on a hill situated at the east end of the Kaikoura Peninsula (S 42°25’47.1’’ E 173°41’54.6’’) (Figure 2.1), providing a good vantage point overlooking a study area encompassing the Kaikoura Canyon, centre of the whale watching industry. The height of the station was surveyed using a surveyor’s theodolite (Sokkia Set 4000) and methods detailed by Würsig *et al.* (1991) at 99.88 m (±0.04m).

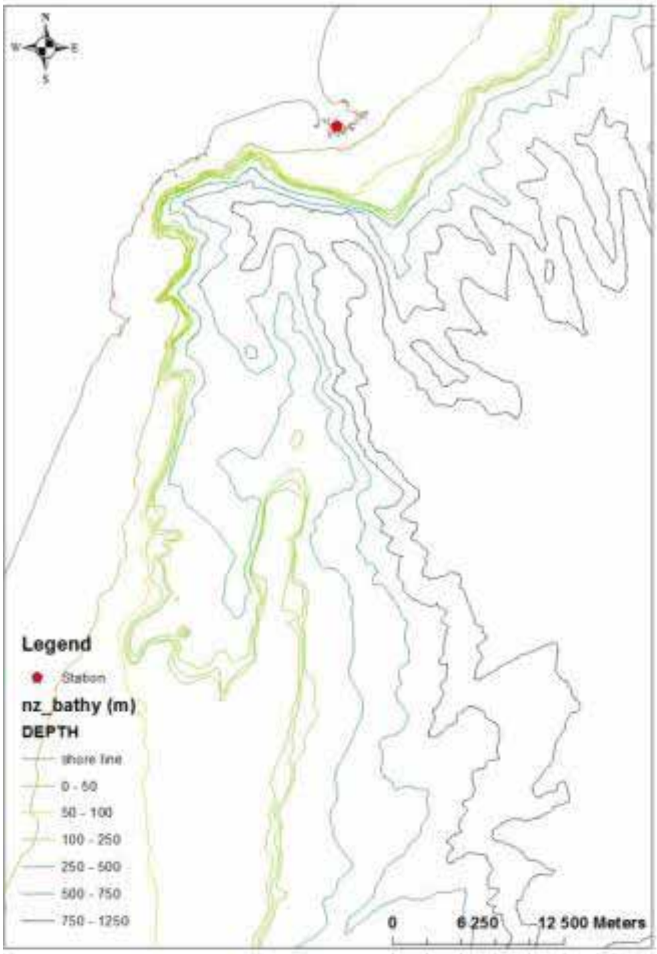


Figure 2.1. The Kaikoura Canyon study area is shown, including isobaths (water depth in meters) and location of the shore station (Red dot).

DATA COLLECTION

Positions and movements of sperm whales and tour vessels were measured using a theodolite Sokkia Set4000 and a system using binoculars and digital video (Figure 2.2).

Theodolite

A theodolite measures horizontal and vertical angles (Würsig *et al.* 1991, Gailey and Ortega-Ortiz 2002). The horizontal angle is zeroed relative to a reference point visible from the shore station. The theodolite was connected to a laptop running the tracking program Pythagoras (Gailey and Ortega-Ortiz 2002) set up with the theodolite eyepiece height, the station height and the GPS position of the station. The software transformed theodolite readings into latitude and longitude coordinates in real time with corrections built in accounting for curvature of the Earth and tide level (Gailey and Ortega-Ortiz 2002). Date and time stamped whale positions and behaviours, vessel tracks, environmental parameters, and other shore station data were logged into Pythagoras (Figure 2.3).

Figure 2.2. The research team tracks whales from the shore station. From left to right: theodolite operator, data logger (laptop), note taker and digital video binocular system operator.

During data collection, the study area was scanned constistently with the help of 20x80 binoculars and a 15-60x monocular spotting scope. Environmental conditions recorded included Beaufort sea state, swell height and direction, percent cloud cover, estimated wind speed and wind direction. From these data a visibility score was assessed of 0 to 4 (4 = perfect visibility). The location track for each whale began when the whale was spotted and finished with the fluke up dive of the focal whale. The same individual was tracked through a complete surfacing; from the first blow spotted until the fluke up. Theodolite fixes were taken on each blow and this also served as a record of blow time. Other behaviours observed during the surface period (Table 2.1) were recorded together with an estimated location by the theodolite.

Table 2.1. Behavioural events recorded during focal whale tracks (after Whitehead & Weilgart 1991).

Behavioural Event	Definition
Fluke up	Whale tail above the water surface; this usually initiates a long dive.
Shallow Dive	Sperm whale dives without showing fluke.
Lobtail	Whale slaps the tail at the surface of the water.
Spyhop	Whale head partially or completely above water surface.

Positions of whale watching boats, the research vessel or recreational boats approaching or around the whales were measured as often as possible to document vessel action, designated as: approaching, stationary and departing.

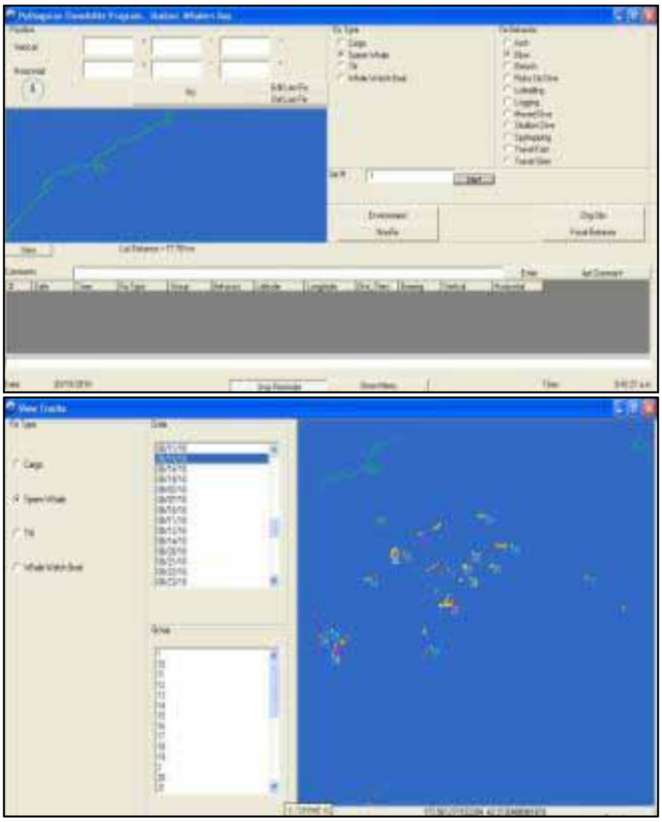


Figure 2.3. Screen captures show the data input (top) and track output (bottom) in Pythagoras tracking software. The violet point on the left represents the shore station and the lines represent all the whale tracks of the day (14 June 2010).

Digital Video-Binocular System

In parallel with the theodolite, a video-binocular range system (figure 2.4) was used to monitor and track the whales and vessels. Like the theodolite, the system provides the range and the position of the whale after analysis of the video using the software PAMGUARD. The video system provided a digital video record of whale behaviour and vessel activities that could be more readily reviewed and re-sampled post-hoc.

The video camera and binoculars were co-aligned so that the view the researcher sees in the binoculars is the same as what is recorded on the video camera. The aligned binoculars (20x80) and the video camera (Canon HV20) were fixed on top of a pole mounted on a seat so that the observer could use them comfortably. The video system requires both the whale and the horizon or a known shoreline to be in the same frame (Leaper and Gordon 2001). During whale tracking the whale was centred on the screen and a running verbal commentary was recorded to help with future analysis of respiration rate, time at surface, vessel interactions and behavioural sequences. Every time the system was moved to follow the whale movement the bearing was recorded using a handheld compass mounted on the video/binocular frame. Theodolite and video were usually used to follow the same whale.

Figure 2.4. Video system. Digital video binocular system is used to monitor and track whales and vessels.

RESEARCH EFFORT

Sperm whales and vessels were tracked on 212 days from April 2010 through June 2011, encompassing a total of 1162 hours of effort. Scanning effort by season is described in table 2.2.

Seasonal differences in research effort were a result of weather conditions at both the data collection platform (shore station) and on the water. The number of days of effort was reduced in winter months due to deteriorated weather conditions. During spring 2010, sperm whales were absent from the study area from mid-October to the beginning of November.

To describe changes in whale distribution and behaviour throughout the year, a seasonal scale was used. Seasons were defined as follows:

Autumn March, April and May
Winter June, July and August
Spring September, October and November
Summer December, January and February.

Table 2.2. Total shore station monitoring effort.

Season	Effort (h:m:s)	# Days
Autumn 2010	244:57:11	36
Winter 2010	124:52:42	26
Spring 2010	175:05:48	42
Summer 2010-11	283:05:44	49
Autumn 2011	240:50:24	41
Winter 2011	93:50:00	18
Total	**1162:41:49**	**212**

Theodolite tracking effort

Sperm whales were successfully tracked with the theodolite for a total of 226 hours corresponding to 2717 surfacing events (surfacing = more than one theodolite location recorded for the same whale). Effort by tracking and number of tracks by season are described in table 2.3. The increased number of tracks during summer 2010-11 and autumn 2011 is explained by the presence of more sperm whales in the study area.

Table 2.3 Theodolite tracking of sperm whales.

Season	Whale Theodolite Track Duration (h:m:s)	Number of Surfacings
Autumn 2010	46:54:40	472
Winter 2010	17:36:20	241
Spring 2010	14:24:24	177
Summer 2010-11	57:18:04	607
Autumn 2011	59:08:37	797
Winter 2011	31:23:40	423
Total	**226:45:45**	**2,717**

Video system effort

Sperm whales were successfully tracked with the video system for a total of 117 hours corresponding to 1204 surfacing events. Effort by tracking and number of tracks by season are described in table 2.4. Use of the video system decreased as the project progressed because the theodolite was found to be the more effective system.

Table 2.4. Digital video records of sperm whales.

Season	Digital Video Recording Duration (h:m:s)	Number of Surfacings
Autumn 2010	70:38:04	677
Winter 2010	31:05:33	365
Spring 2010	10:26:10	120
Summer 2010-11	2:58:56	18
Autumn 2011	2:37:51	24
Total	**117:46:34**	**1,204**

DATA ANALYSIS

Surface Behavior

For analysis of surface behavior, we included only encounters during which the fluke up was spotted. Brief surfacings (<5 blow intervals) or surfacing with double or missing blows (determined by blow intervals <5sec or >50 sec) were excluded from analysis. This totalled 1088 surfacings recorded with the theodolite (Autumn 2010=226, Winter 2010=104, Spring 2010=42, Summer 2010-11=192, Autumn 2011=341 and Winter 2011=183) and 515 with the video system (Autumn 2010=364, Winter 2010=83, Spring 2010=64 Summer 2010-11=4) used for analysis. Surface duration recorded for whales are based on duration from the first blow detected. This is not necessarily representative of the entire time whales spent at the surface (see results). Rather, it is an indication of the time the observer spent following a whale. For more accurate estimates of surface time, see Chapter 4. Leg speed (the distance between locations divided by time between locations), was calculated by the tracking software Pythagoras. A maximum swim speed filter of 30km/hr was applied to the data. Video system data presented here were collected in parallel with the video record. A second observer recorded observations made by the video system in conjunction with the recording.

GIS Analysis

Data sorting, statistical analyses and figure production were performed in Microsoft Excel 2007, Microsoft Xlstat Pro 7.5, Microsoft Access 2003 and ArcGIS 10.

In ArcGIS 10, all map features (coastline map, bathymetric chart and data layers) were initially imported using the coordinate system WGS 84. To increase accuracy, the data frame was then transformed to NZ UTM 59S. All the data imported in ArcGIS 10 with the coordinate system WGS 84 were then exported using the same coordinate system as the data frame.

Sperm whale and vessel positions (longitude and latitude) were overlaid onto a coastline base map and a bathymetric chart supplied courtesy of the National Institute of Water and Atmospheric Research, New Zealand (NIWA) using ArcGIS 10. The bathymetric chart used was graduated by an increment of 10m at shallow depths (<200m) followed by an increment of 50m at depths >200m. In order to limit replication during analysis only one position per surfacing (Longitude-Latitude) for each sperm whale was plotted. Data layer shape files (points) were then joined by spatial proximity to the bathymetric shape file, such that each point was assigned a depth equal to the nearest isobath. As a result, a single depth estimated by the nearest isobath was assigned to each sperm whale surfacing.

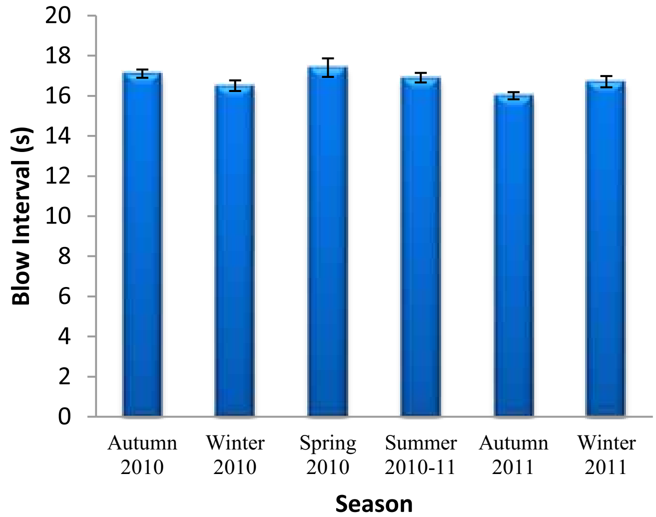
The study area was delimited using a buffer polygon of 20 km around the shore based station. To limit the effect of distance on the theodolite accuracy only data within 20km have been considered in the analysis that follows.

To examine the distance of sperm whales from the coastline, spatial proximity analysis was performed in ArcGIS 10, determining the distance from each feature in the sperm whale shape file from the coastline shape file To measure the geographic distribution of sperm whales and whale watching boats, standard deviation ellipse analysis was performed in ArcGIS 10, summarizing the spatial characteristics as the dispersion (area km²) and the mean centre (Longitude Latitude) of the geographic feature.

RESULTS

SEASONAL CHANGES IN BEHAVIOUR

Figures 2.5-2.7 compare the surface behaviour of sperm whales within the submarine canyon by season. For each surfacing (theodolite n=1088 and Video system n=515) mean blow interval (time difference between two blows in seconds) was calculated. Mean blow interval of sperm whales varied significantly between seasons based on theodolite location recordings (ANOVA n=1088, F=4.145, p=0.001) as well as digital video records (ANOVA, n=515, F=4.412, p=0.004), although the seasonal pattern was most apparent in the video records (Figure 2.5). Post-hoc pairwise comparisons (Tukey HSD) showed significant differences between summer and autumn 2010-2011 (P = 0.035) and between autumn 2010 and autumn 2011 (P =0.002) for theodolite data; and differences between summer and both autumn (P=0.01) and winter (P=0.02) for digital video records.



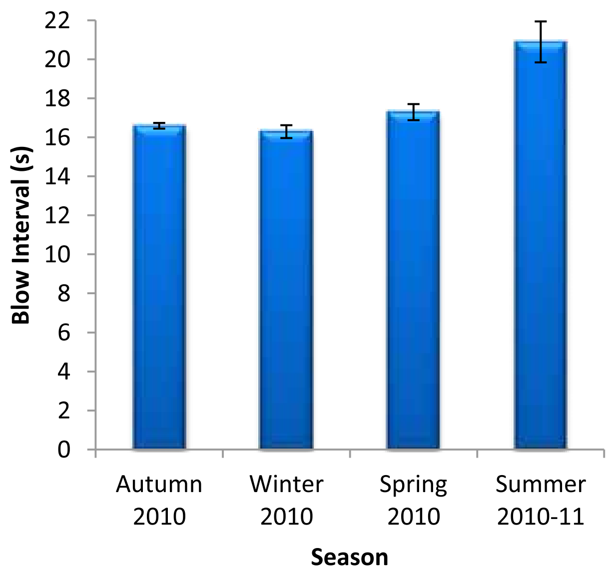
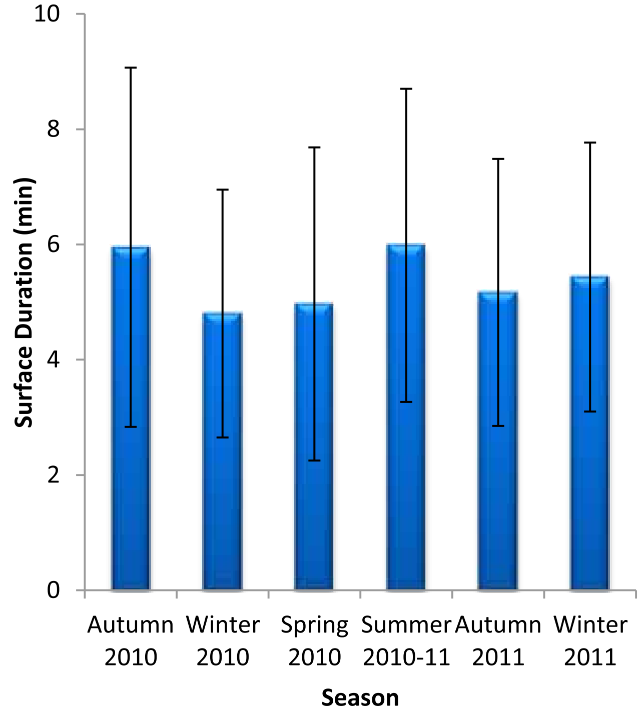


Figure 2.5. Blow interval (seconds) of sperm whales tracked from shore is compared by season using two research methods (theodolite- top, digital video-bottom). Bars represent mean values with standard errors.

Estimated surface time (time the whale was tracked at the surface from first observation to fluke up) was compared by season using the two shore-based methods. Surface time varied significantly between season based on both theodolite locations (ANOVA n=1088, F=5,870, p=<0.0001) and digital video records (ANOVA, n=515, F=3.930, p=0.009). Post-hoc pairwise comparisons (Tukey HSD) showed significant differences in surface time between autumn and winter 2010 (p=0.002), autumn 2010 and autumn 2011 (p=0.004), summer 2010-2011 and winter 2010 (p=0.002) , and summer 2010-11 and autumn 2011 (p=0.006).



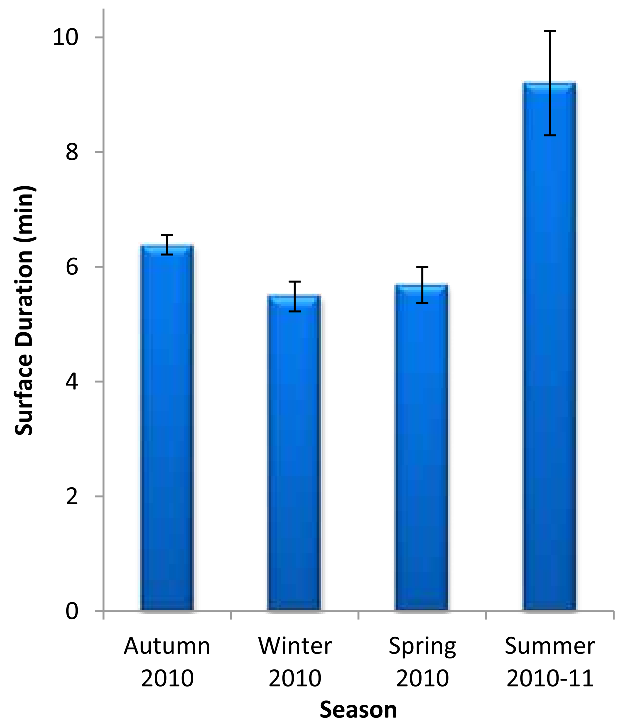


Figure 2.6. Mean surfacing duration (minutes) of sperm whales tracked from shore are compared by data collection method (theodolite- top, digital video-bottom). Bars represent mean values with standard errors.

Estimated Swimming Speed of Whales

The estimated swimming speed of sperm whales at the surface varied significantly between seasons (ANOVA, n=1036, F=6.351, p=<0.0001), peaking in the spring (Figure 2.7), the same season when the whales were most scarce (Table 2.5) and found furthest from shore (Figure 2.8) in the deepest water (Figure 2.9). Mean leg speed (distance between successive locations /time between locations) of whales was significantly faster in spring than in autumn (Tukey p=0,010), winter (Tukey p=0.0002), and summer (Tukey p=0018 and Tukey p=0.009).

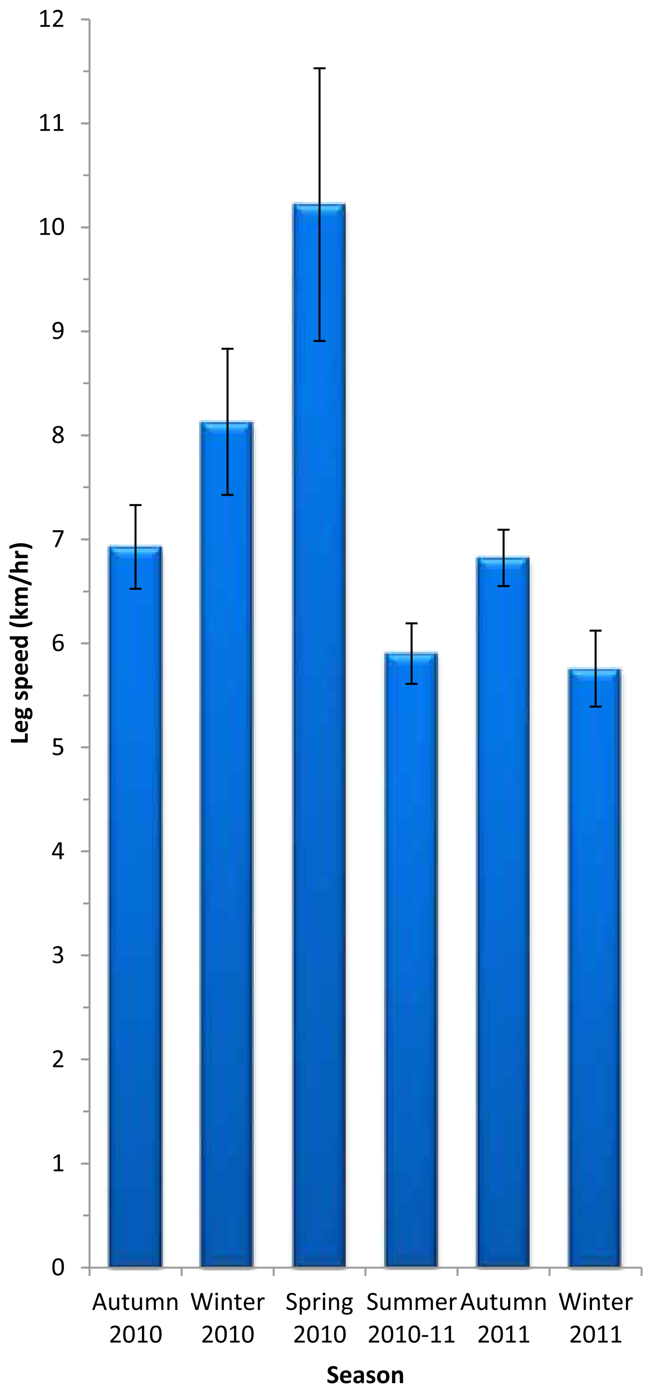


Figure 2.7. Leg speed (km/h) of sperm whales tracked from shore with a surveyor's theodolite is compared by season. Bars represent standard errors. Bars represent mean values with standard errors.

HABITAT USE AND DISTRIBUTION

Distance from Shore

Distance of sperm whales from shore and mean water depth at which sperm whales were sighted varied seasonally, peaking in spring and summer (Figures 2.8, 2.9). Distance of sperm whale sightings from shore varied significantly between seasons (ANOVA F=58.198, p<0.0001), with the whales located significantly further offshore in spring and summer than in other seasons (Tukey HSD p<0.0001). Distance from shore peaked in the spring (Figure 2.14), with the whales leaving the study area altogether for a couple of weeks during spring months (figure 2.8).

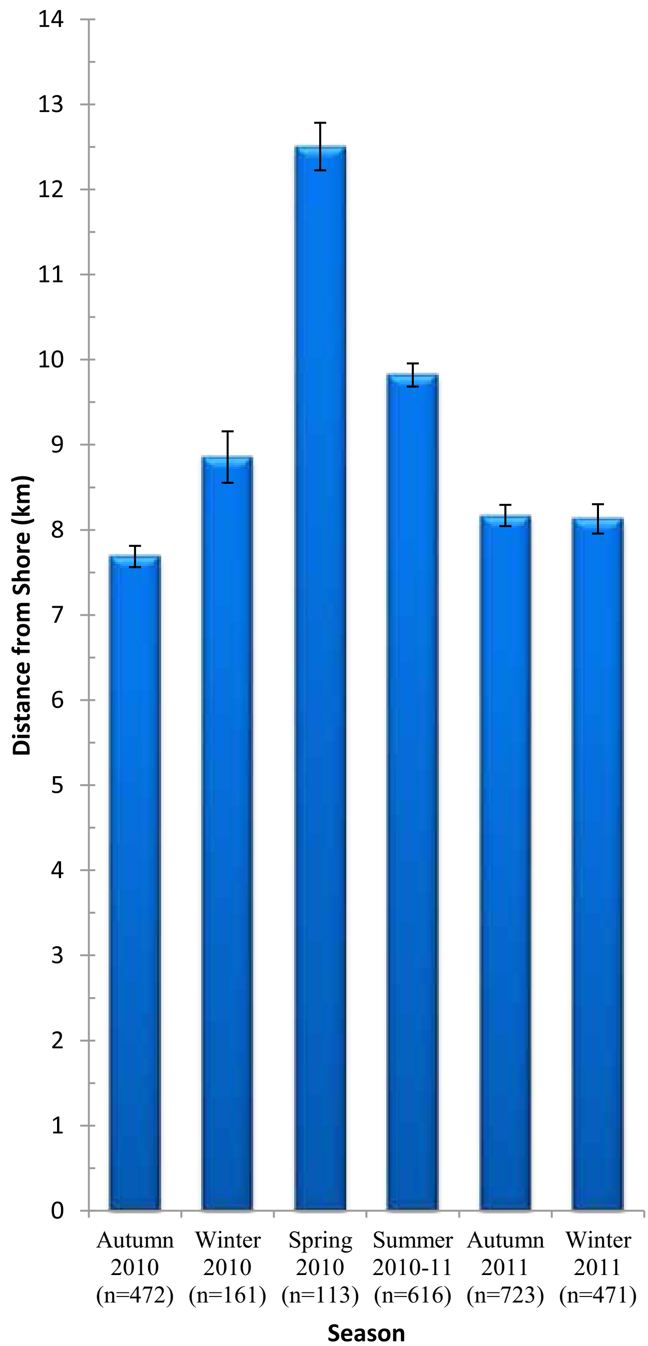


Figure 2.8. Distance from shore (km), estimated by longitude and latitude position of sperm whales from shore using a surveyor's theodolite. Bar represent standard errors.

Water Depth

Estimated mean water depths at which whales were located (figure 2.9) varied significantly between seasons (ANOVA, n=2556, F=42.301 p<0.0001). Post-hoc pair wise comparisons revealed similar findings to those for distance from shore, with sperm whales tracked at significantly greater water depths in spring and summer than in other seasons (Tukey HSD, p<0.0001). For autumn and winter months, there was no significant inter-annual variation in the mean water depths at which sperm whales were located between years (ANOVA, F=0.003, ns and F=0.068, ns).

Overall, sperm whales were most often found in water depths ranging from 1050-1250 m (table 2.5). Only 6.8% of total sightings of sperm whales occurred at depths <500m (Table 2.5). No whales were found in waters less than 500m deep in the spring (Figure 2.10).

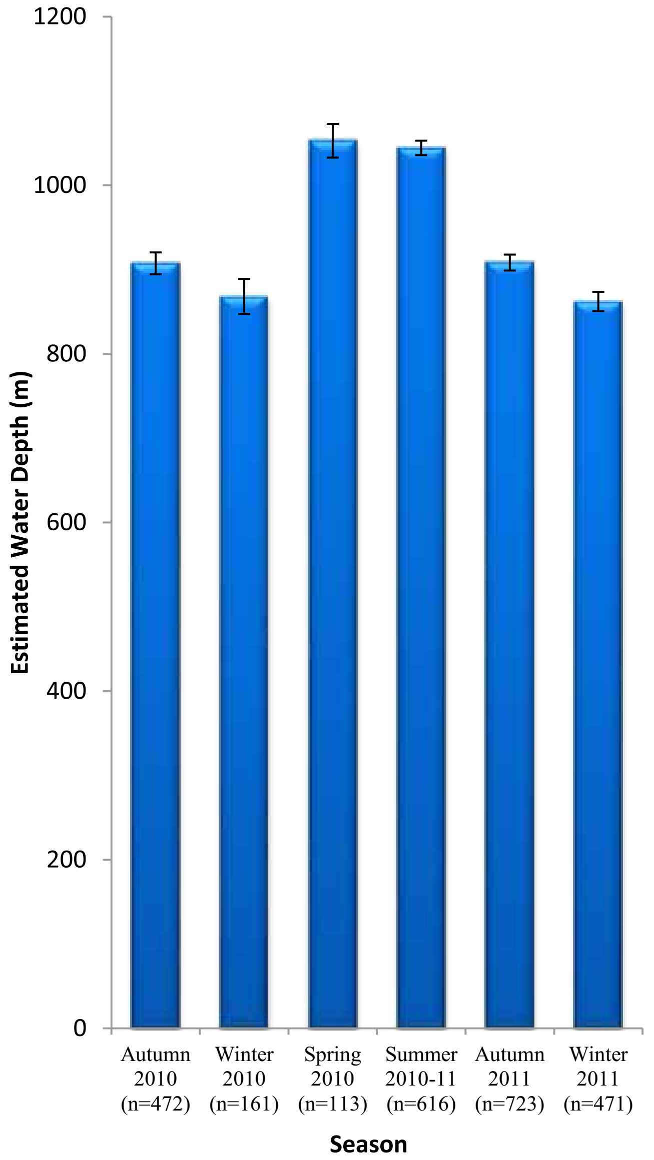


Figure 2.9. Water depth, estimated by longitude-latitude position of sperm whales tracked with a surveyor's theodolite, is compared by season. Bars represent mean water depths with standard errors.

Table 2.5. Number (top) and percent (below) of whale sightings at various water depths (m) are compared by season.

Season	<300	300-500	550-800	850-1000	1050-1250	>1250	Total
Autumn 2010	22	24	112	128	171	15	472
	5%	5%	24%	27%	36%	3%	
Winter 2010	3	16	45	47	45	5	161
	2%	10%	28%	29%	28%	3%	
Spring 2010	0	0	20	30	43	20	113
	0%	0%	18%	27%	38%	18%	
Summer 2010-11	1	11	91	146	302	65	616
	0%	2%	15%	24%	49%	11%	
Autumn 2011	13	39	208	205	222	36	723
	2%	5%	29%	28%	31%	5%	
Winter 2011	7	38	163	136	116	11	471
	1%	8%	35%	29%	25%	2%	
Total	**46**	**128**	**639**	**692**	**899**	**152**	**2556**
	2%	**5%**	**25%**	**27%**	**35%**	**6%**	

Colour bars indicate relative number of sightings by depth from high (red) to low (green).

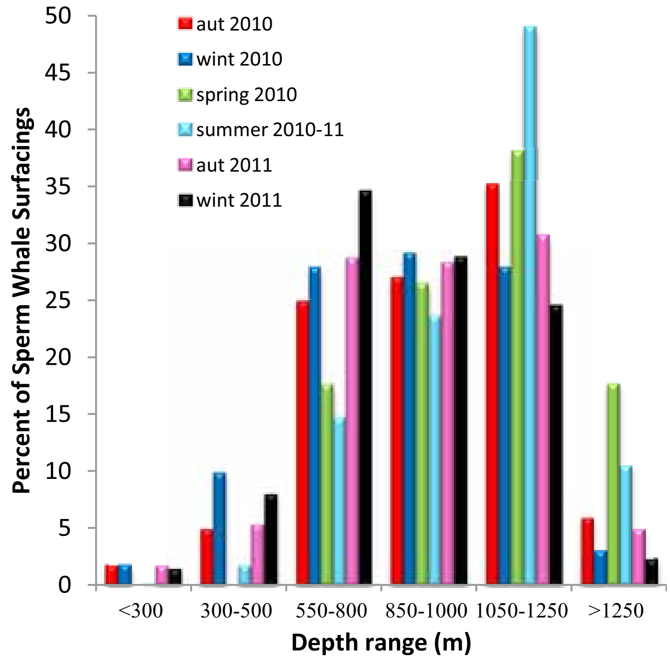


Figure 2.10. Percent of sperm whale surfacings in different water depth bins is compared by season (water depths estimated by longitude-latitude position from theodolite fixes).

Overall Distribution

The distribution of sperm whales estimated from shore-based theodolite tracking showed seasonal variation (figure 2.11). Examination of standard deviation ellipses indicated that the distribution of sperm whales was most scattered in winter 2011, and tightest in autumn 2010 and summer 2011 (Table 2.6). Whales ranged not only further offshore but were also tracked further to the north on average during the spring (Figure 2.12).

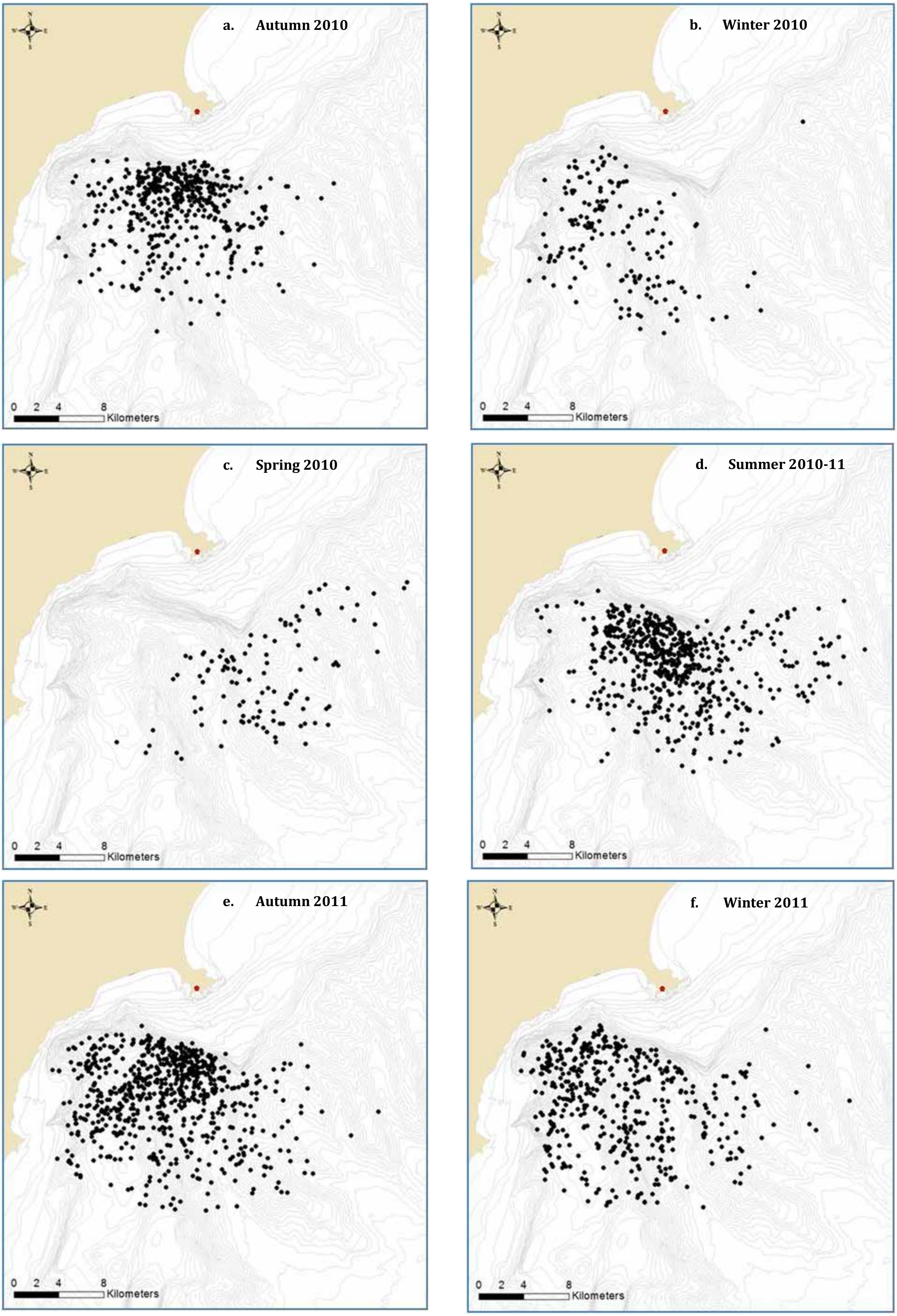


Figure 2.11. Sperm whale locations are compared by season. (Red dot= shore station, black dot= sperm whale location from theodolite record).

Table 2.6. Area of standard deviation ellipses and mean centre location for sperm whale locations are compared by seasons.

Season	Area (km^2)	Longitude	Latitude
Autumn 2010	73.3	173.6790	42.5077
Winter 2010	102.3	173.6477	42.5312
Spring 2010	107.8	173.7746	42.5282
Summer 2010-11	93.6	173.7132	42.5200
Autumn 2011	105.2	173.6698	42.5180
Winter 2011	125.8	173.6579	42.5213

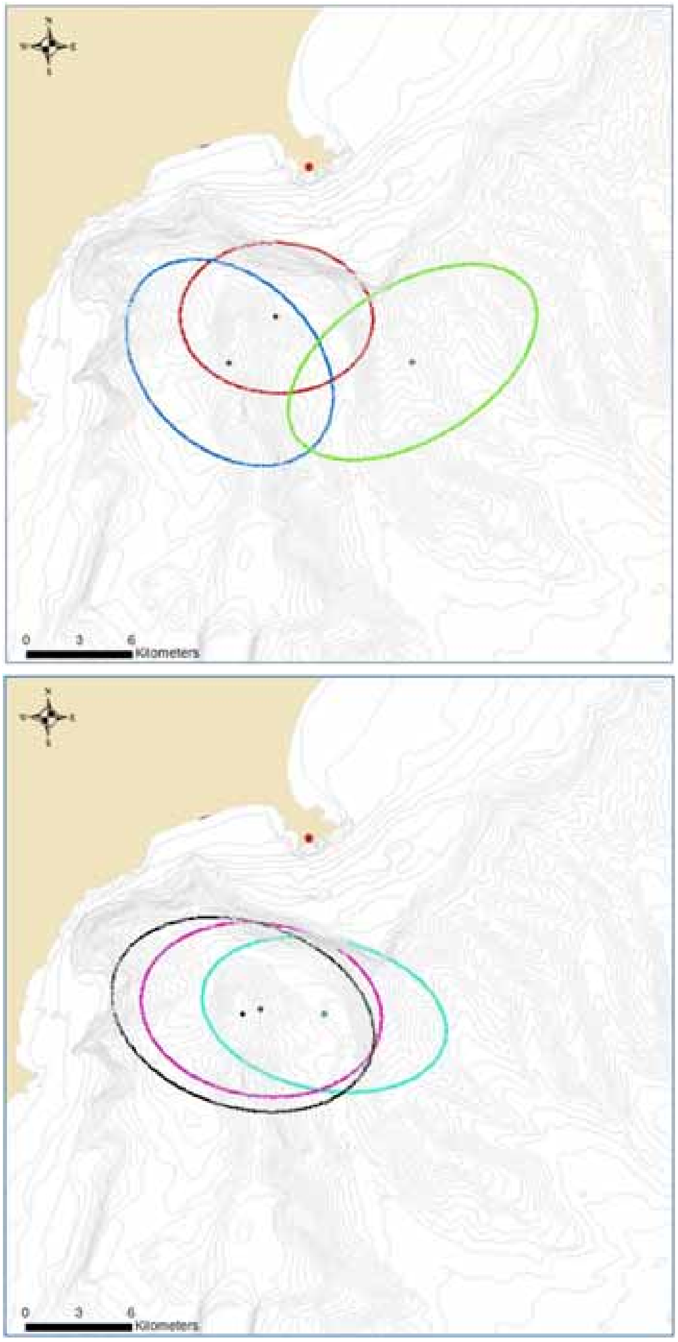


Figure 2.12. Area of standard deviation ellipses and mean centre location for sperm whales locations are compared by season. On top red : autumn 2010, blue : winter 2010 and green : spring 2010. On the bottom: blue summer 2010-11, pink: autumn 2011 and black winter 2011.

WHALE INTERACTIONS WITH VESSELS

Interactions by Time of Day

In order to assess level of interaction between sperm whales and tour activities, we examined the proportion of surfacings during which whales were accompanied by various boats and aircraft by time of day and season. Overall, whales were accompanied by vessels during less than half of all surfacings (Figure 2.13), and were least likely to be visited by either boats or aircraft during the morning hours (before 12:00 pm).

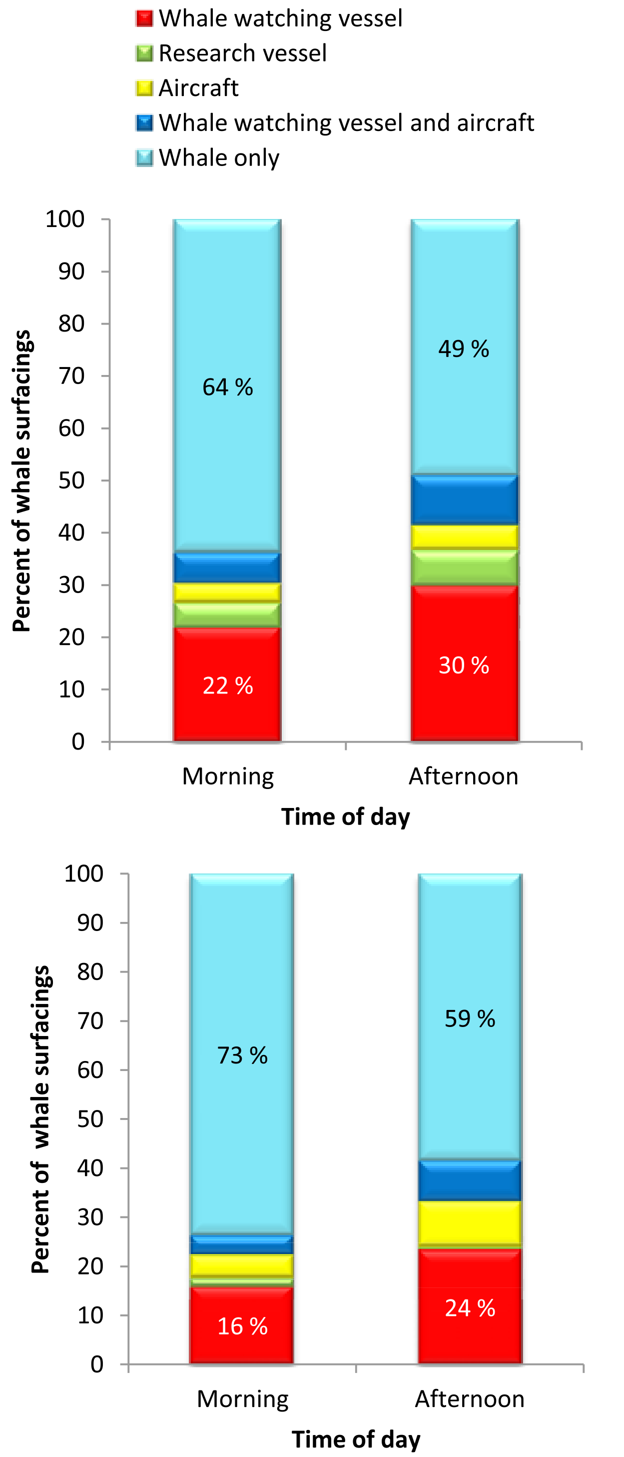


Figure 2.13. Percent of type of encounter is compared by time of the day monitored by theodolite (top) and digital video record (bottom). Data labels show percentages for the two largest categories, whales alone (black text) and whales accompanied by whale watching tour boats (white text).

Interactions by Season

A summary of interactions of whales with vessels and aircraft by season is provided in figure 2.14. A total of 703 surfacings of whales associated with whale watching vessels was recorded. For both methods, the dataset included considerably more instances of whales surfacing without vessels or aircraft than with vessels or aircraft A decrease in vessels and aircraft trips during autumn and winter meant that a smaller proportion of observed surfacings had whale watching platforms present. In summer, the proportion of surfacing with whale watch vessels present was highest, probably due to an increase in whale watching trips during the peak tourism season (Figure 2.14). Most interactions occurred with whale watch tour boats, particularly during the summer and autumn (Figure 2.15).

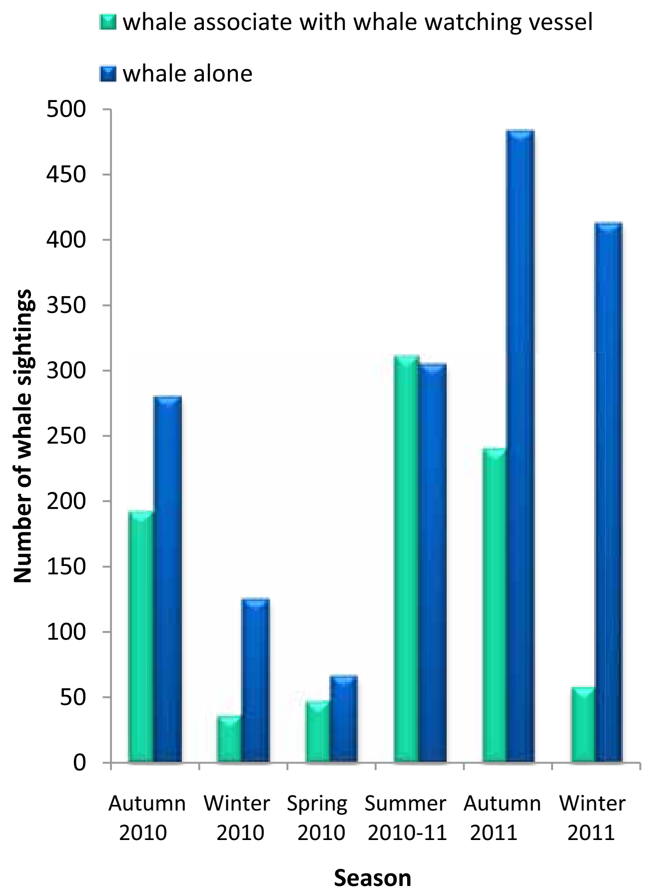


Figure 2.14. Number of sightings of whales alone versus whales accompanied by one or more vessels is compared by season.

Figure 2.16 compares the distribution of whale watching tour vessels with the distribution of whales by season. The distribution of sightings of whales alone and whales associated with whale watching vessel is compared in figure 2.17. Whale distribution and interaction with tourism activity varied seasonally. Whether in shore or offshore, most whale sightings and whale watch tour interactions occurred over the relatively deep water of Kaikoura Canyon. Thus the distance from shore of whales alone and whales accompanied by vessels showed greater seasonal variability than the water depth (Figures 2.20 and 2.21).

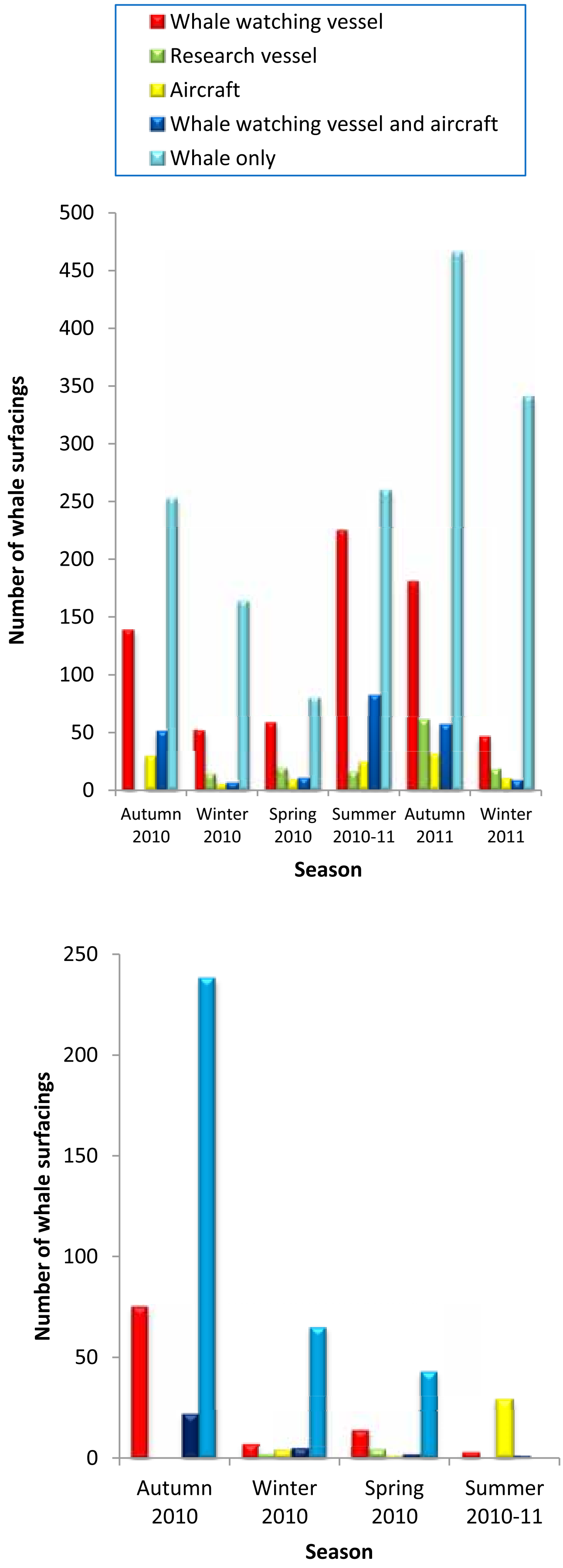


Figure 2.15. Seasonal type of encounter for theodolite locations (top) and video system track (bottom).

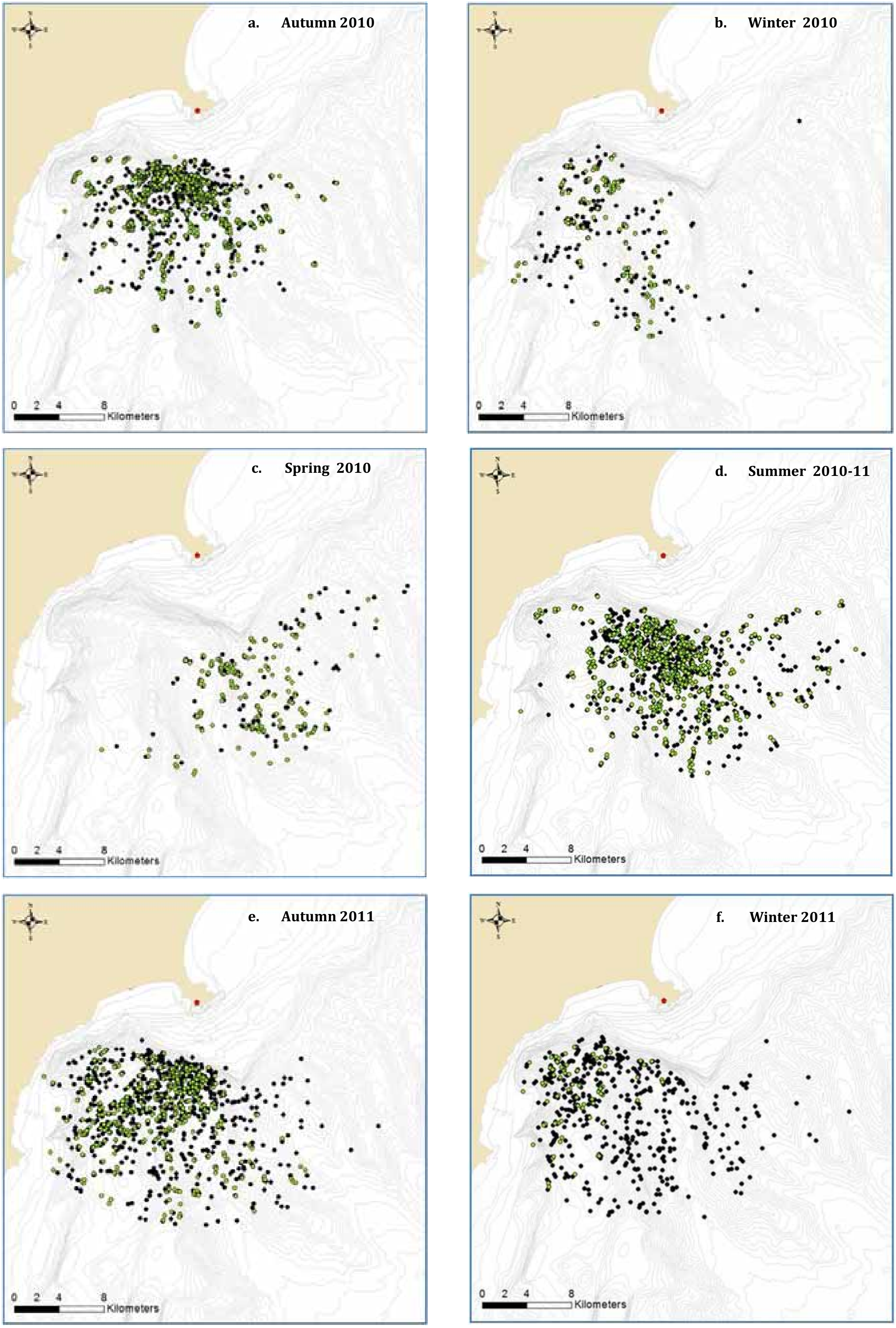


Figure 2.16. Sperm whale locations and whale watching vessel locations are compared by season. (Red dot= shore based station, black dot= sperm whale, green dot= whale watching vessel).

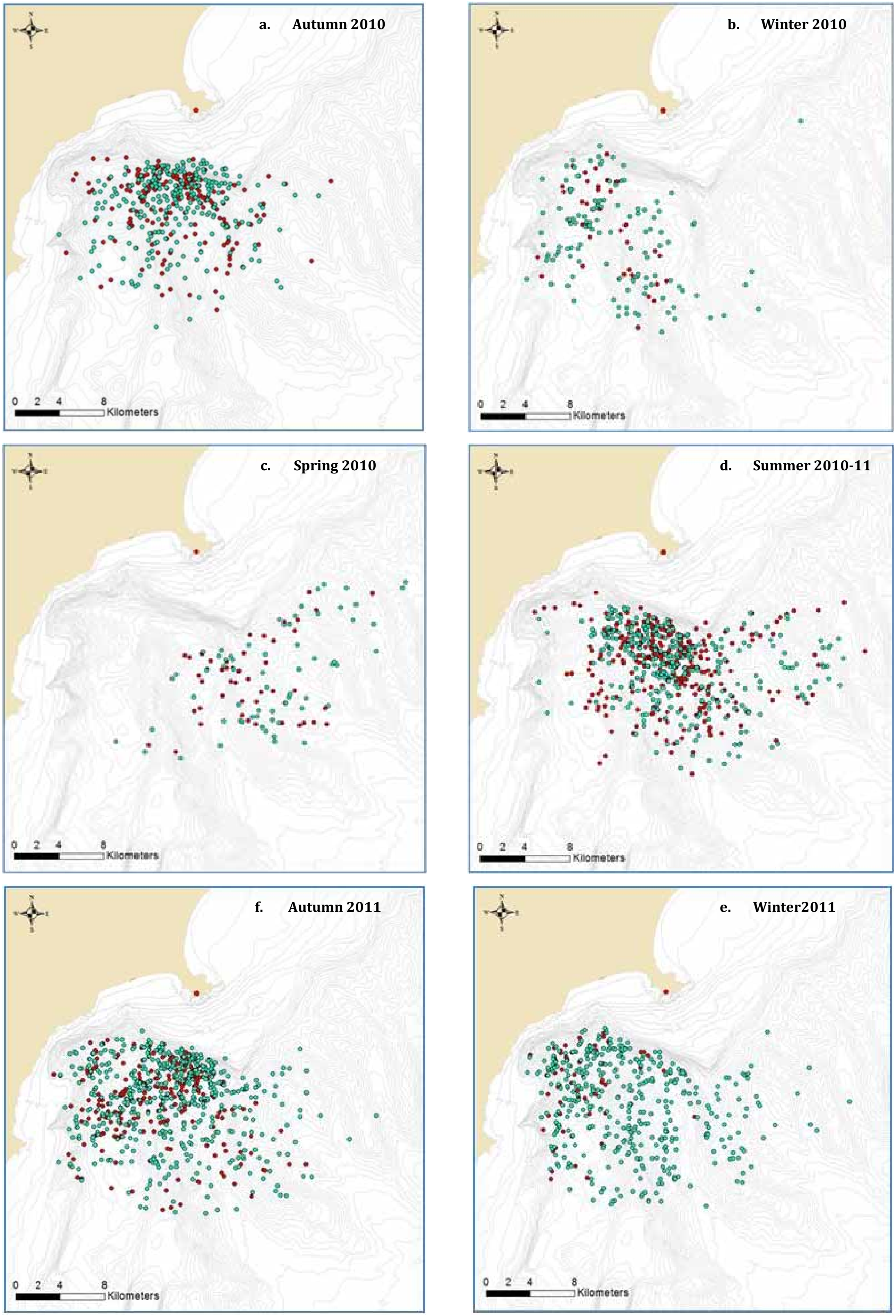


Figure 2.17. Locations of sperm whales alone and sperm whales associated with whale watching vessels are compared by season. (Red dot= whale associated with whale watching vessel, blue dot= sperm whale alone).

Comparison of standard deviation ellipses (Tables 2.7 and 2.8, Figures 2.18 and 2.19) revealed that the area where whale watching tours operated is significantly different from the area of the sperm whale distribution (ANOVA n=12, F=9.135, p=0.013). The mean central location did not vary significantly between whales accompanied by vessels and those not accompanied by vessels.

Table 2.7. Area and mean centre (Longitude-Latitude) of standard deviation ellipses for whale watching locations are compared by seasons.

Season	Area (km^2)	Longitude (°E)	Latitude (°S)
Autumn 2010	64.4	173.6753	42.5037
Winter 2010	83.3	173.6388	42.5225
Spring 2010	78.3	173.7568	42.5364
Summer 2011	82.5	173.7041	42.5183
Autumn 2011	87.8	173.6583	42.5179
Winter 2011	49.6	173.6588	42.5190

Whale watching vessels ranged as far in search of whales in winter as in other seasons (Table 2.7), but interaction with vessels took place over a smaller proportion of the sperm whale distribution during winter than in other seasons (58% and 48%, Table 2.8). In summer and autumn interactions occurred over the greatest proportion of the whales' range (78-93%, Table 2.8).

Table 2.8. Area (km^2) calculated for standard deviation ellipse is compared by season for sperm whales accompanied with and without whale watching boat.

season	Area (km^2) with boats	Area (km^2) without boats	%
Autumn 2010	69.6	74.5	93
Winter 2010	64.5	110.8	58
Spring 2010	85.0	118.5	72
Summer 2011	85.1	101.0	84
Autumn 2011	87.7	113.0	78
Winter 2011	61.1	127.0	48

Standard deviation ellipses for whale watch vessel locations monitored from shore indicate that whale watching tours were conducted furthest offshore in spring (Figure 2.18 top, green) and summer (Figure 2.18 bottom, blue). Whale watch tours found closer to shore in autumn and winter followed the contours of the Kaikoura Canyon, generally staying in the deepest water (Figure 2.18).

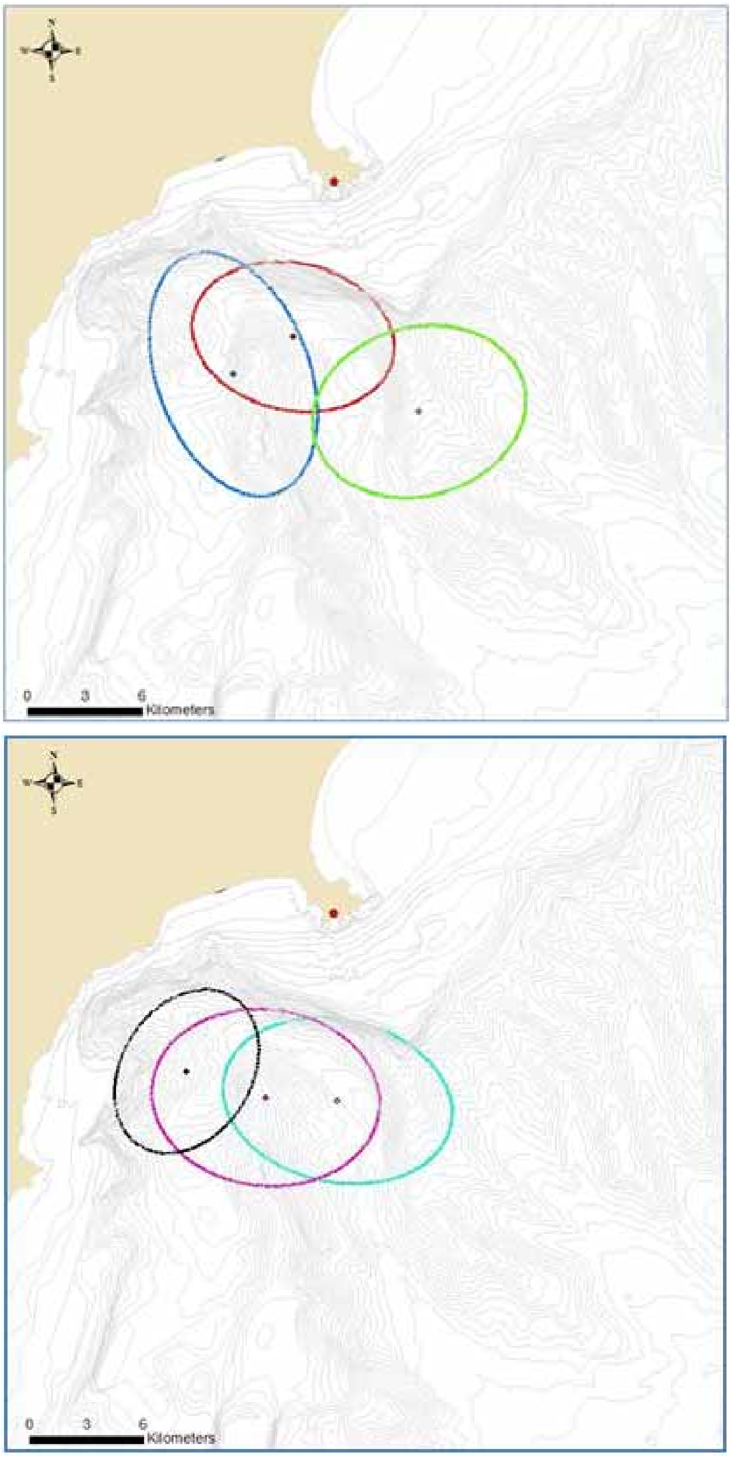


Figure 2.18. Area and mean centre (Longitude-Latitude) of standard deviation ellipses for whale watching vessel locations are compared by seasons. On top red : autumn 2010, blue : winter 2010 and green : spring 2010. On the bottom: blue summer 2010-11, pink: autumn 2011 and black winter 2011.

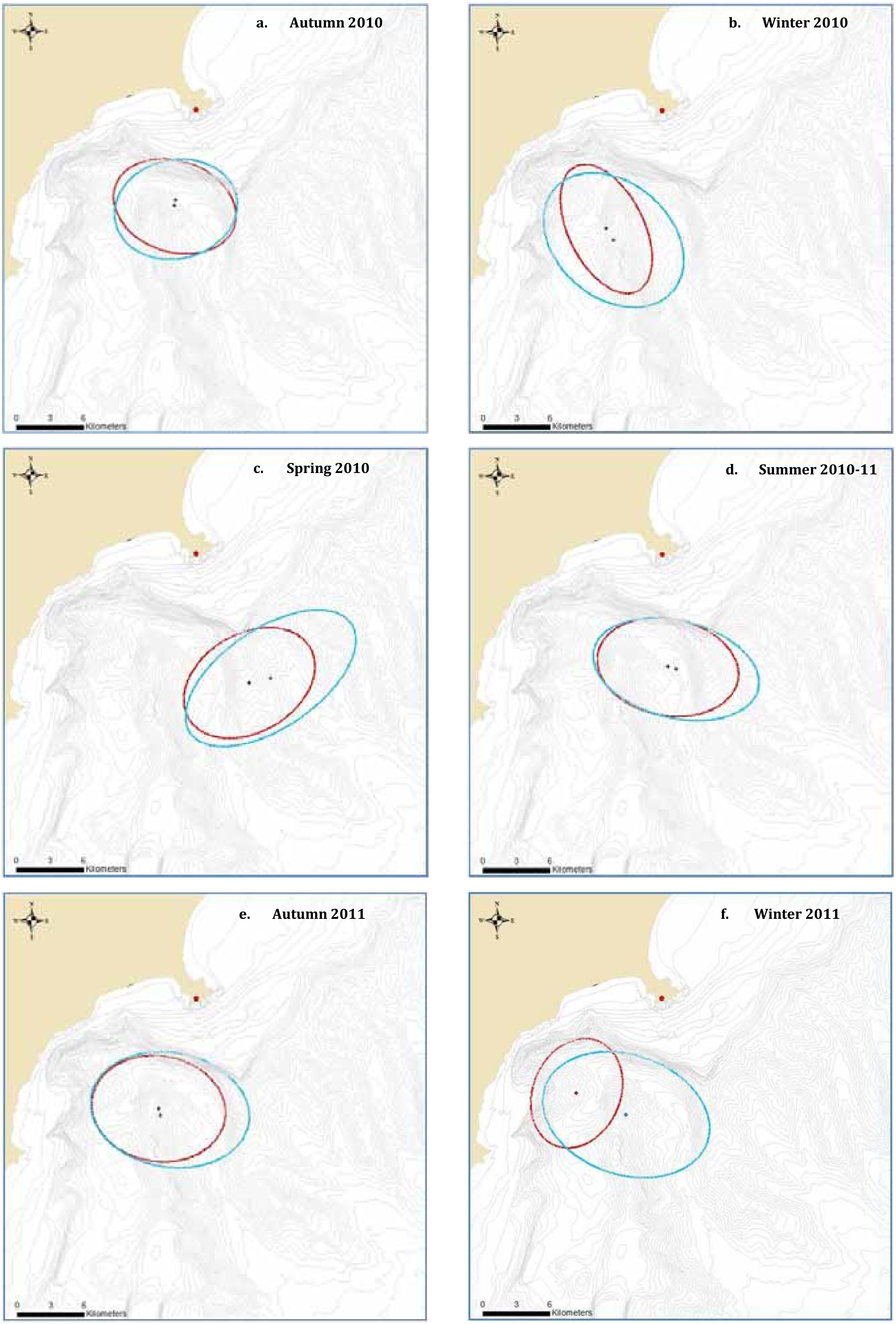


Figure 2.19. Area and mean centre (Longitude-Latitude) of standard deviation ellipses for sperm whales alone (blue) and sperm whales associated with whale watching vessels (red) are compared by season.

During summer 2010-11 and winter 2011, distance from shore of sperm whales alone and sperm whales associated with whale watching vessels (Figure 2.20) was significantly different (ANOVA, n=616, F=5.236,p=0.022 and ANOVA n=471, F=42.119, p<0.0001).

The water depths at which sperm whales were fixed alone and associated with whale watching vessels (Figure 2.21) varied significantly in autumn 2010 (ANOVA, n=472, F=12.502, p=0.0004) and in winter 2011 (ANOVA, n=471, F=6.951, p=0.009).

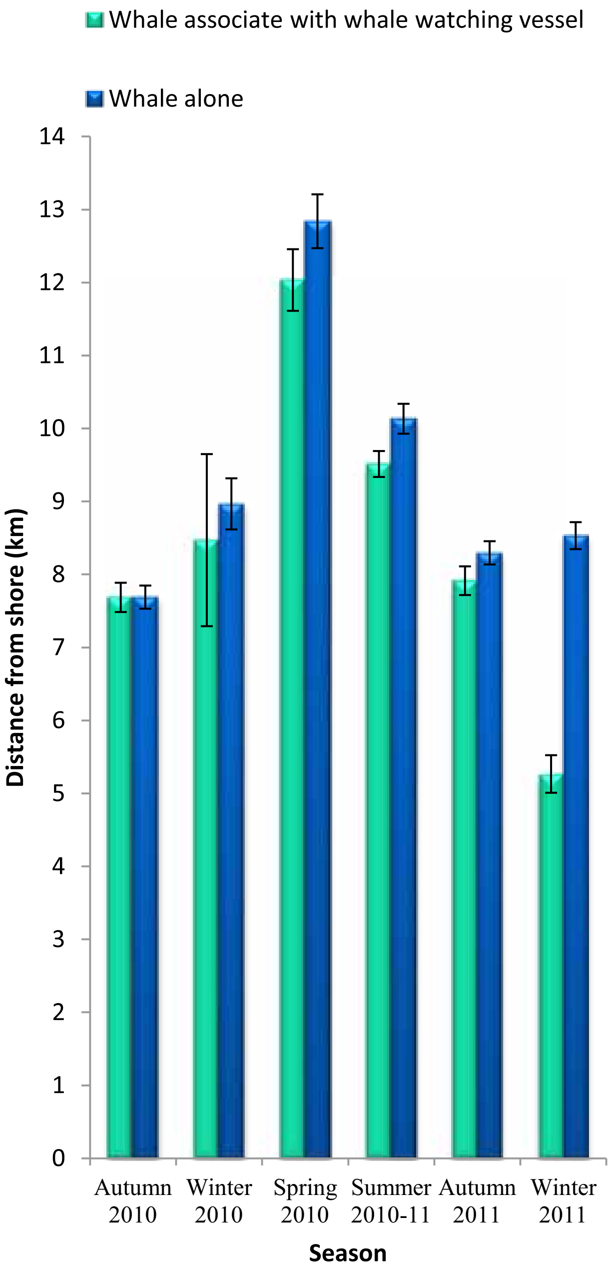


Figure 2.20. Distance from shore (km) of sperm whales alone is compared to the distance from shore of sperm whales associated with a whale watching vessel. Distance from shore was estimated by drawing the shortest straight line between the shoreline and the whale theodolite locations assigned to the on nearest isobaths on a bathymetric chart. Bars represent means values with standard errors.

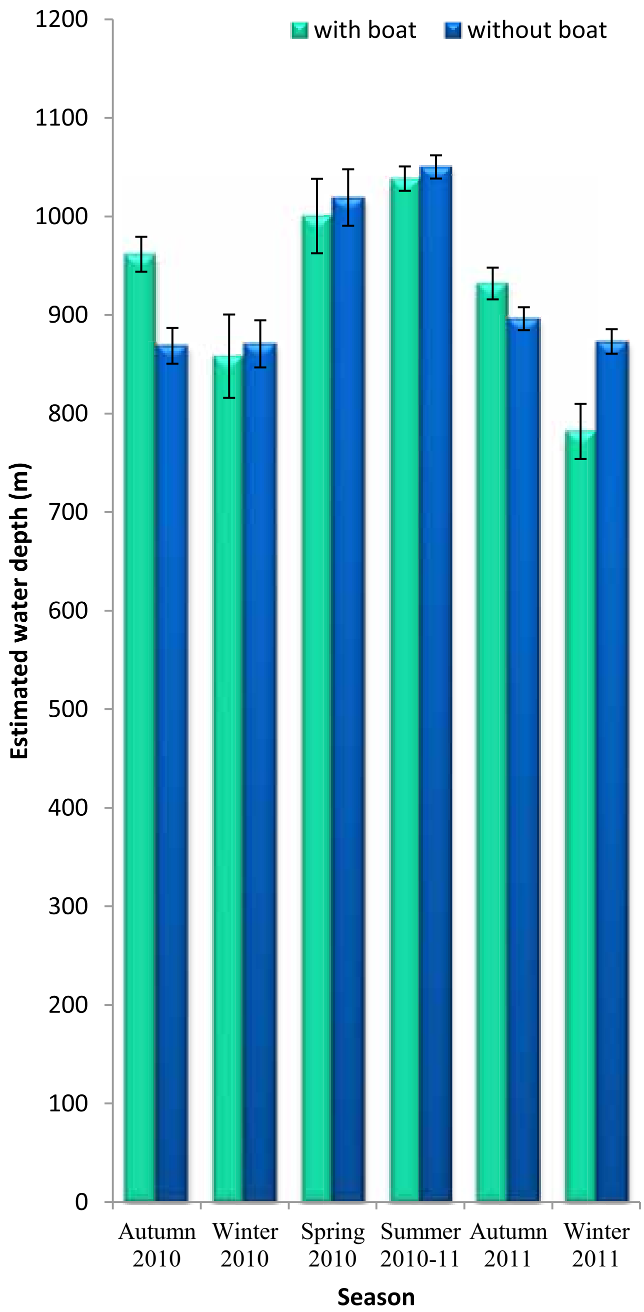


Figure 2.21. Estimated water depth (m) of sperm whales alone is compared to the estimated water depth of sperm whales associated with a whale watching vessel. Depth was estimated by theodolite locations assigned to the on nearest isobaths on a bathymetric chart. Bars represent means values with standard errors.

EFFECTS OF VESSELS ON WHALE BEHAVIOUR

Surface behaviour of sperm whales was compared by type of vessel encounter. Ventilation rate (blow interval) varied significantly with type of encounter (Figure 2.22, ANOVA, n=1088, F=6.614, p<0.0001). Whales associated with whale watching vessels and with whale watching vessels and aircraft had significantly longer mean blow intervals than whales alone (Tukey p=0.027; Tukey p=0.001) or whales associated with the research vessel (Tukey p=0.020; Tukey p=0.001). There was no significant difference in leg speed with type of encounter (ANOVA, n=1036, F=2.100, ns).

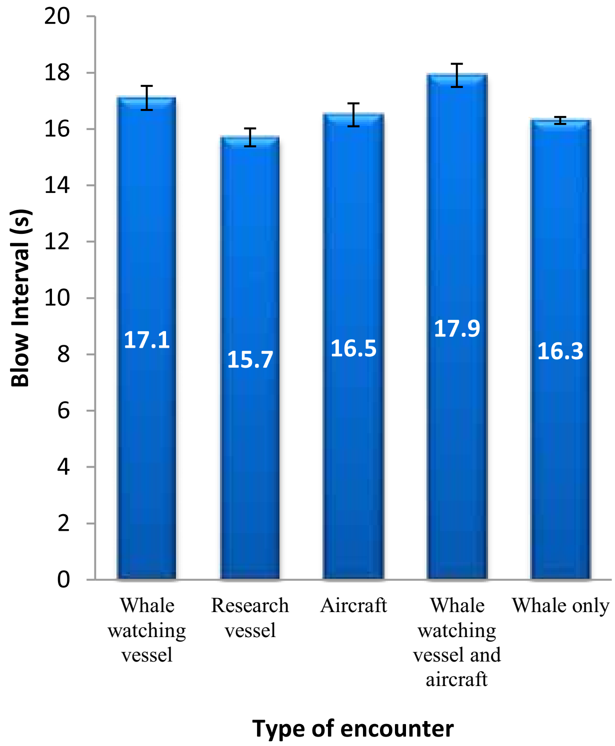


Figure 2.22. Mean blow interval (s) of sperm whales tracked from shore are compared by data collection method. Bar represent standard errors.

Interactions by Season

Whales not associated with vessels and aircraft had significantly different mean blow intervals by season (ANOVA n=626, F=3.176, p=0.008, figure 2.12). Effectively, ventilation patterns of whales associated with whale watching vessels (ANOVA n=275, F=1.620, ns), with research vessel (ANOVA n=62, F=1.781, ns), with aircraft (ANOVA n=44, F=1.496, ns) and with whale watching vessel and aircraft (ANOVA n=81, f=1.065, ns), showed no statistical difference between seasons. This result suggests the effect of interactions with vessels and aircraft on blow interval supersedes any effect of season on this behavioural parameter. The impact of season on mean blow interval for whales alone was no longer apparent in the presence of vessels and aircraft. This significant difference appeared to occur only for ventilation patterns in autumn (2010, 2011, Tukey, p=0.043). Data collected with the video system confirmed that ventilation patterns of whales associated with whale watching vessels (ANOVA n=99, ns), the research vessel (ANOVA n=6, F=6,438, ns), aircraft (ANOVA n=34, F=0,964, ns), whale watching vessels and aircraft (ANOVA n=30, F=1,135, ns) showed no statistical difference between seasons.

Interactions by time of day

Time of the day (figure 2.13) does not appear to be a factor influencing the mean blow interval of sperm whales in the Kaikoura Canyon. If we look closely at all types of encounters, whales associated with whale watching vessels (ANOVA n=275 F=0.039, ns), the research vessel (ANOVA n=62 F=1.112, ns), Aircraft (ANOVA n=44 F=0.012, ns), whale watching vessels and aircraft (ANOVA n=81 F=0.041, ns) and whales only (ANOVA n=626 F=0.209, ns) showed no statistical difference with time of day.

Results of mean blow interval were similar for data collected using the video system. Whales associated with whale watching vessels (ANOVA n=99 F=0.298, ns), the research vessel (ANOVA n=6 F=0.858, ns), aircraft (ANOVA n=34 F=0.744, ns) whale watching vessels and aircraft (ANOVA n=30 F=3.804, ns) and whales only (ANOVA n=346 F=0.005, ns) showed no statistical difference with time of day.

As was found with ventilation patterns, time of day is not a factor influencing mean leg speed of sperm whales. No statistical differences were found for whales associated with whale watching vessels (ANOVA n=262 F=0.268, ns), with the research vessel (ANOVA n=60 F=0.0003, ns), with aircraft (ANOVA n=44 F=3.054, ns), with whale watching vessels and aircraft (ANOVA n=76 F=0.04, ns), and whales only (ANOVA n=594 F=0.185, ns).

Number of whale watching vessels

The surface behaviour of sperm whales did not vary significantly with the number of whale watching vessels present ANOVA n=275 F=1.188, ns). During the majority of surfacings in which whales interacted with whale watching vessels, whales were associated with only one boat (n=192). Whales were associated with two boats during 72 surfacings and with three whale watching boats during only 11 surfacings. Whales were visited by the greatest number of vessels in summer, followed by autumn (Figure 2.23).

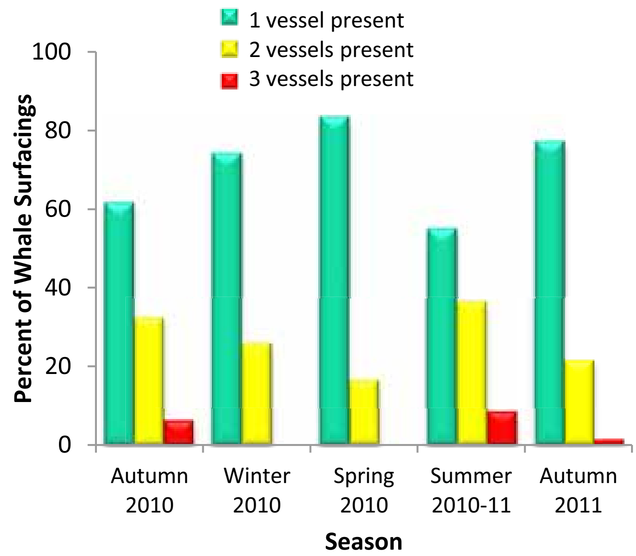


Figure 2.23. The number of whale watching vessels accompanying whales is compared by season. Bars indicate the percent of surfacing whales accompanied by one, two, and three vessels.

DISCUSSION

This chapter presents information on the behaviour and distribution of sperm whales within the Kaikoura submarine canyon. The behaviour and distribution of sperm whales associated with whale watching vessels, aircraft and the research vessel, was compared with whales not interacting with vessels.

In general, the factor most influencing sperm whale behaviour and distribution appears to be season. Similar results were reported by Richter *et al.* (2003). Seasonal changes were detected in blow interval (longest in spring and summer, shortest in winter), time whale was tracked at surface (an indication of surface time, highest in summer), and mean leg speed (highest in spring).

Habitat use also varied seasonally, with whales found further offshore in spring and summer than in autumn and winter. Vessel positions recorded with the theodolite from the shore station showed a narrower distribution than those based on GPS data loggers (Chapter 3). This is likely because shore-based monitoring focused on vessels in the vicinity of whales (not all vessel tracks), and was limited by distance from shore (due to reduced visibility of vessels further from the station).

Changes in water depth by season were not as great as changes in distance from shore because whales moving inshore stayed inside the canyon where the water was deepest. Whales were found at the deepest mean water depths (over 1km) in spring and summer. In general, whales were most prevalent in the 850-150m depth range. Only rarely did they occur in water <500m deep.

The seasonal distribution reported by Jaquet *et al.* (2000) is comparable to the results in this chapter, with sperm whales found closer to shore in winter months. The absence of sperm whales within the canyon during October was also previously noted by Jaquet *et al.* (2000). Overall, the mean water depth at which sperm whales were sighted in this study agrees with the findings reported by Jaquet *et al.* (2000) ,between 500 to 1500m, although fewer whales were sighted at depths exceeding 1250m.

Interactions with vessels occurred during less than half of all monitored surface intervals. Interactions were most common in the afternoon and in the summer months.

Although the distribution of whale sightings varied between instances when whales were observed at the surface alone and instances when they were accompanied by tour vessels, these findings do not appear to indicate habitat displacement. Whale interactions with tour vessels generally occurred in a narrower range, closer to shore than the range of whale sightings in the absence of vessels (Figures 2.19 and 2.20). While we cannot rule out the possibility that some whales moved offshore to avoid vessel interactions, the most parsimonious explanation for these findings is that the differences were due to tour vessels approaching and interacting more often with those whales closest to port.

We found a difference in ventilation patterns for whales alone versus whales accompanied by whale watching vessels. The finding that blow interval varied between surfacings where whales were accompanied by vessels and those where they were not may indicate an effect of whale watch tourism with the potential to influence sperm whale foraging efficiency and energy budgets. The mean blow interval documented in this study from the theodolite station (16.6 sec) was similar to that reported by Richter *et al.* (2003, 16.7 sec). Moreover, our studies of whale distribution showed that the whales were found in deeper water around the peak summer tour season. While it is not possible to measure sperm whale energy use (nor indeed food consumption), it seems likely that the whales are particularly energetically challenged in the spring and summer when they are found in the deepest water. If tour vessels are reducing the oxygen intake of the whales, this could be a cause for concern. The effect of vessels on ventilation rate appeared to supersede the effect of season on the same variable, as seasonal differences disappeared in the presence of tour vessels.

The research vessel had no measurable effect on the whales' surface behavior, including their breathing rate. While it is almost certain the whales are aware of the presence of the research vessel, this finding suggests that the research vessel provides a reasonable independent platform from which to monitor whale interactions with tour vessels unobtrusively (Chapter 4). Aircraft by themselves also had no effect, and the combined effect of aircraft and whale watch vessels on ventilation rate was no greater than that of the whale watch vessels by themselves. This suggests that aerial tours may have less of an effect on the behavior of sperm whales than boat tours, a finding similar to that in a recent study of dusky dolphin interactions with boats and planes off Kaikoura (Markowitz et al. 2009).

One shortcoming of this research was that individual whales could not be identified and tracked over time through their dive cycles. Chapters 4 and 5 of this report describe photo-identification and acoustic tracking research conducted from a vessel which was able to collect these data. A strength of shore based observation is that it provides ability to collect true no vessel control data to compare with those from whales with vessels present. This strength, combined with a broader vantage from which to observe whale interactions with tour vessels across the Kaikoura Canyon area may explain why we were able to detect some differences in the behaviour and distribution of whales interacting with tour vessels that were not detectable from either the research vessel or the tour vessel (most notably ventilation rate).

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Chapter 3

REMOTE TRACKING AND ONBOARD MONITORING OF WHALE WATCHING ACTIVITY AT KAIKOURA, NEW ZEALAND

Ophélie Sagnol and Tim M. Markowitz

This chapter examines whale watching tourism at Kaikoura using the tour vessels and aircraft themselves as research platforms. Although this approach does not provide an independent vantage from which to monitor sperm whale interactions with tours, it does provide an opportunity to gather detailed information on the tours themselves. The objectives of this chapter were to document levels of whale watching tourism activity, areas in which whale watching vessels operate, and interaction of vessels with sperm whales. To address these research objectives, we utilized two methods: remote tracking by GPS data logger systems and direct monitoring by scientific observers onboard tour vessels and aircraft. The research effort onboard whale watching boats occurred year round during 94 trips, peaking in Autumn. The distance between whale watch tour vessels and whales during an encounter averaged 75 ± 1.8m (mean ± se). Sperm whales changed heading >10° during 75% of interactions with whale watch vessels. Neither heading changes nor blow intervals varied significantly with distance of whales from the whale watch vessels. To obtain general data on vessels, GPS data loggers were deployed onboard whale watching vessels and aeroplanes from Spring 2009 through Winter 2011. Additional data for aerial tours were downloaded from online GPS track logs. GPS tracks showed less activity in winter than other seasons, with summer and autumn the busiest seasons. Tours ranged furthest offshore and alongshore in spring, when the sperm whales were relatively scarce. Tours occurred across the narrowest ranges in winter.

INTRODUCTION

This portion of our study evaluated tourism off Kaikoura, New Zealand from whale watch tour vessels. This platform provides for detailed study of a "focal tour" examination of tour vessel movements, speeds, and interactions with animals. To obtain as much information as possible on vessel activity given the large number of boat and aerial tours, we utilized remote tracking in the form of onboard GPS data loggers. In addition, we deployed scientific observers onboard tours to document vessel-whale interactions in more detail. Because they are performed from the tour vessel, observations of whale behaviour from this platform cannot provide the same quality of information as data collected from an independent platform (e.g., research vessel, shore station). However, to gather data on what the vessel is doing (e.g., areas visited, distance from whales during an encounter, speed of movement), the ideal place to be is onboard. Remote tracking was used so that we could continue to have onboard monitoring, even when scientific observers could not be present.

Whale watching began in Kaikoura in the late 1980s and has grown considerably since that time, as the number of passengers and vessel sizes increased (Te Korowai 2008). Whale watching platforms operated by local companies include aircraft (both fixed wing planes and helicopters, Figure 3.1) and Whale Watch Kaikoura tour vessels (five 17-18m catamarans with jet engines, Figure 3.2). Tours operate year round, so long as weather permits and whales are in the area.

Figure 3.1. Aircraft monitored in this study included helicopters and fixed wing aeroplanes. Helicopters (left) were fitted with GPS data loggers to track their movements. Fixed wing planes (right) were either fitted with GPS data loggers (Kaikoura Aeroclub) or used their own GPS logging system which could be downloaded by researchers (Wings Over Whales). Onboard observers also collected data on some fixed wing flights.

Boat tours typically last 2-2.5 hours, while aerial tours are typically about 30 minutes. Both aerial and boat tours typically take visitors to see a number of other attractions in addition to whales (e.g., scenery, dolphins, fur seals, birds). Thus, while whales are the focus of the tour, the actual time spent with whales is a relatively small fraction of the total tour. Whale watch skippers often stop to listen with a directional hydrophone to locate whales during dives, especially on tours early in the day.

The use of a tour vessel as a research platform from which to measure the effects of the same tour vessel inherently introduces confounding factors in studies of cetacean responses to tourism (Bejder and Samuels 2003). Nevertheless, such a platform has been used with some success by researchers examining dolphin responses to tourism (e.g., Constantine 2001, Dans et al. 2008). An advantage of the use of tour vessels is that it allows systematic sampling of details related to vessel operation and tour activity (Bejder and Samuels 2003, Markowitz et al. 2009).

RESEARCH OBJECTIVES

The objectives of this research were to:

1. Document whale watching tour activity from both aircraft and boats, comparing it by platform and season;
2. Examine interactions of whale watching tours and sperm whales from the vantage point of the tour vessels, measuring vessel distance and speed concurrently with whale behavior; and
3. Note any apparent changes in whale behavior in the course of encounters with tour vessels.

a. Aoraki

b. Paikea

c. Tohora

d. Te-Ao-Marama

e. Wawahai

Figure 3.2 Five vessels used by Whale Watch Kaikoura over the course of the two year investigation. Vessel movements were monitored by GPS data loggers and vessel activities were monitored by onboard observers.

METHODS

MONITORING BY GPS DATA LOGGERS

GPS loggers (Figure 3.3) were deployed in four whale watch tour boats and four aircraft (three loggers in helicopters, one logger in an aeroplane operated by Kaikoura Aeroclub). GPS data from another aerial tour, Wings over Whales, were downloaded directly from their web-based tracking system. GPS loggers were powered directly by the electrical system onboard whale watching vessels. Logger's onboard aircraft ran on an independent battery power supply that needed to be changed once per week.

Figure 3.3. GPS data loggers such as this one were used to monitor movements of tour vessels over a two year period.

The GPS loggers collected GPS positions (GMT time, Longitude and Latitude) every 15 seconds. The data from the GPS loggers were downloaded from all platforms every two months. Tracking data downloaded from the GPS loggers were extracted using Data log Data Downloader and stored in a folder named by the platforms name. The next step was to convert the data, previously in an .nmea format into a .csv format using JDatalog in order to be able to import this data into a Microsoft Access database.

GPS locations, flight speeds, and altitudes from Wings Over Whales flights were logged every minute and downloaded from the tracplus website for analysis (http://www.tracplus.com/). Data from takeoff and landing (determined by examining daily logs for flight speed and altitude) were excluded from analyses.

To examine the position (Longitude and Latitude) of the whale watching vessels, GPS positions imported into Microsoft Access were extracted by platform (whale watching boats and aircraft) and by seasons, then exported into ArcGIS 10. As detailed in Chapter 2, GPS positions were imported using the WGS 84 coordinate system onto a coastline base map and a bathymetric chart supplied by the National Institute of Water and Atmospheric Research (NIWA). For more accurate estimates, the data frame was changed to NZ UTM 59S, and a buffer of 1000m around the coastline base was created, removing vessel positions not related to whale watching.

To examine variability in the areas where whale watching companies operated, standard deviation ellipses were examined in ArcGIS 10. The best fit area (km²) and the central point (Longitude and Latitude) were then determined in ArcGIS. The area data did not follow a normal distribution, so they were transformed using y=ln(y). Central location followed a normal distribution so no transformation was necessary.

MONITORING BY ONBOARD OBSERVERS

Whenever possible, scientific observers were sent onboard whale watching vessels (Figure 3.4).

Figure 3.4. A whale watching vessel follows a sperm whale.

Vessel data collected on these trips included vessel approach time and bearing, range of the whale from the boat using a Bushnell laser range finder, and the presence plus position of other vessels (within 300m) relative to the whale. Whale data collected on these trips included heading (estimated by compass), blow rate, behaviour (e.g., breaching, tail slapping), and fluke photographs for identification of individual whales (see Chapter 4). To examine changes in the heading of the whale we subtracted the last heading record of an encounter from the first heading of the encounter.

Observations were made onboard whale watching vessels on 94 trips. During two trips no whales were found by the whale watching crew. The number of whale watching trips varied seasonally due to research team logistics and availability of space on whale watch vessel tours (Figure 3.5).

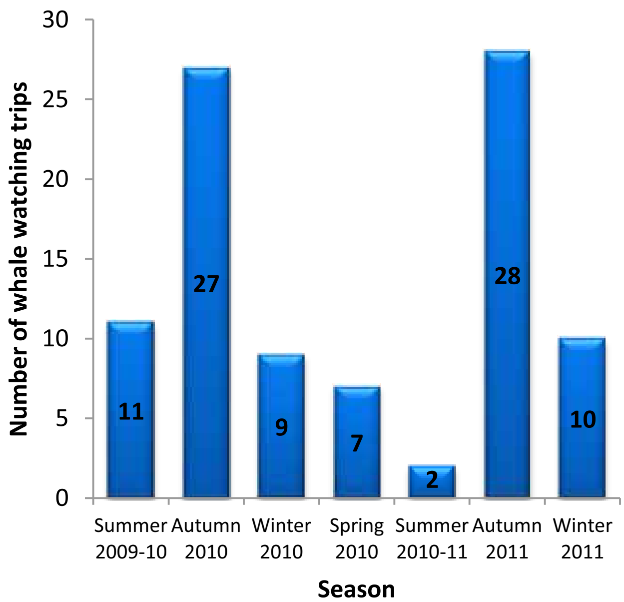


Figure 3.5. The number of whale watching trips monitored by onboard observers is compared by season.

Aerial whale watch tours (Wings Over Whales) were monitored by onboard observers on eight occasions. Data collected included altitude, length of time circling, presence of other vessels and any noteworthy behaviours of sperm whales.

RESULTS

COMPARING TOUR VESSELS AND AIRCRAFT

Seasonal variation of whale watching activity was evident from GPS data logger tracks of all vessels and aircraft. Based on standard deviation ellipses (Figure 3.6), the different tour companies utilized similar areas (ANOVA, n=23, F=0.860, ns). However, seasonal and interannual variation in the area in which the companies operated was significant (ANOVA, n=23, F=13.519, p<0.0001, Table 3.1).

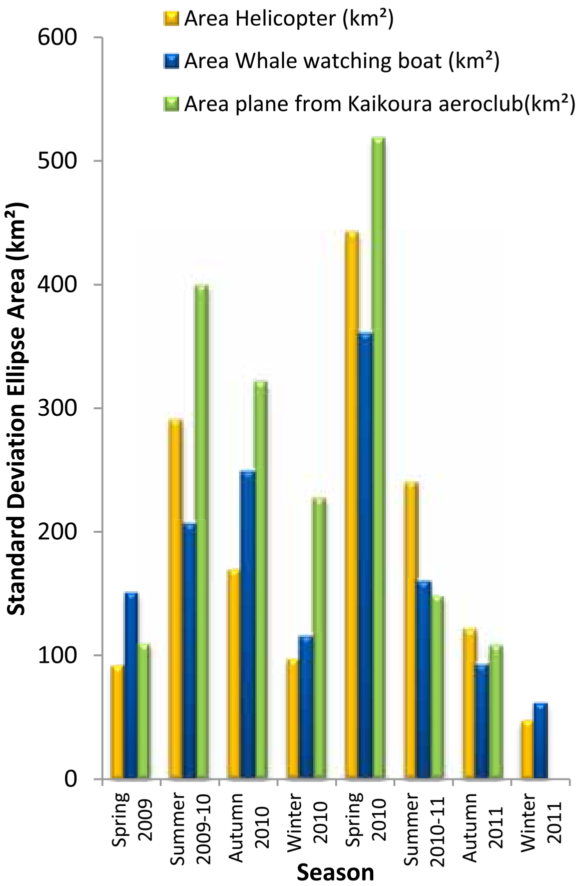


Figure 3.6. Areas of standard deviation ellipses based on GPS tracks are compared by whale watching platforms and season.

Table 3.1 Tukey HSD pairwise post-hoc comparisons of seasonal variation in area utilised by tour companies.

Season	Year	Comparisons			
Spring	2010	A			
Summer	2009-2010	A	B		
Autumn	2010	A	B	C	
Summer	2010-2011		B	C	
Winter	2010		B	C	
Spring	2009			C	D
Autumn	2011			C	D
Winter	2011				D

The central location in which whale watching companies operated (table 3.2) did not significantly vary between platforms (Longitude ANOVA, n=23, F= 0.196, ns; Latitude ANOVA, n=23, F=0.874, ns). But central location varied significantly between seasons (Longitude ANOVA, n=23, F= 15.756, p<0.0001; Latitude ANOVA, n=23, F=8.698, p=0.0002).

Table 3.2. Central location (Longitude and Latitude) are compared by platforms and seasons. Tabular values presented are minutes of longitude and latitude (All central locations were found within the same degrees, 173° East Longitude and 42° South Latitude). There were no GPS data logger tracks for the aeroclub plane during winter 2011

Season		Spring 2009	Summer 2009-10	Autumn 2010	Winter 2010	Spring 2010	Summer 2010-11	Autumn 2011	Winter 2011
Boats	173°E Long	41.9’	41.0’	39.7’	38.5’	44.4’	41.5’	37.6’	36.0’
	42°S Lat	30.4’	30.9’	30.9’	30.7’	31.7’	30.8’	30.6’	30.3’
Planes	173°E Long	41.9’	41.6’	39.9’	39.4’	43.7’	39.5’	39.9’	
	42°S Lat	30.4’	31.8’	31.4’	31.7’	32.7’	30.7’	30.2’	
Helicopters	173°E Long	41.3’	43.2’	40.1’	37.1’	45.2’	42.8’	39.9’	36.8’
	42°S Lat	30.4’	31.7’	30.5’	30.8’	32.5’	30.7’	30.6’	30.2’

WHALEWATCH BOATS

Information Extracted from GPS Data Logger Tracks

For whale watch boats, GPS data logger tracks showed clearly that summer and autumn were the busiest seasons, with less activity in winter (Figures 3.7 and 3.8). Examination of standard deviation ellipses showed whale watch tour boats generally ranged furthest offshore and alongshore in search of whales during the spring and tracks were limited to the smallest near shore area in winter (Figure 3.9).

The mean speed calculated from GPS data logger tracks for all whale watch boats was 23.8 ± 0.07 km/h (12.8 ± 0.04 knots). This includes movement of vessels in transit (top speeds exceeding 40 km/h) as well as approaching and following whales and dolphins (speeds of 0-15 km/h).

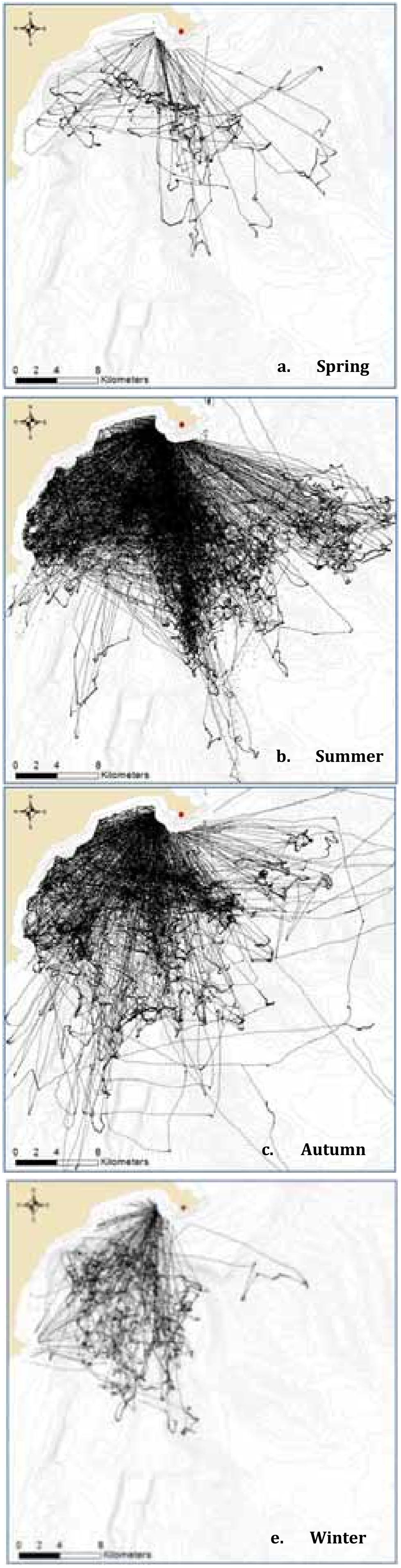


Figure 3.7. GPS positions extracted from GPS loggers onboard Whale watch boats are compared by seasons (2009-10).

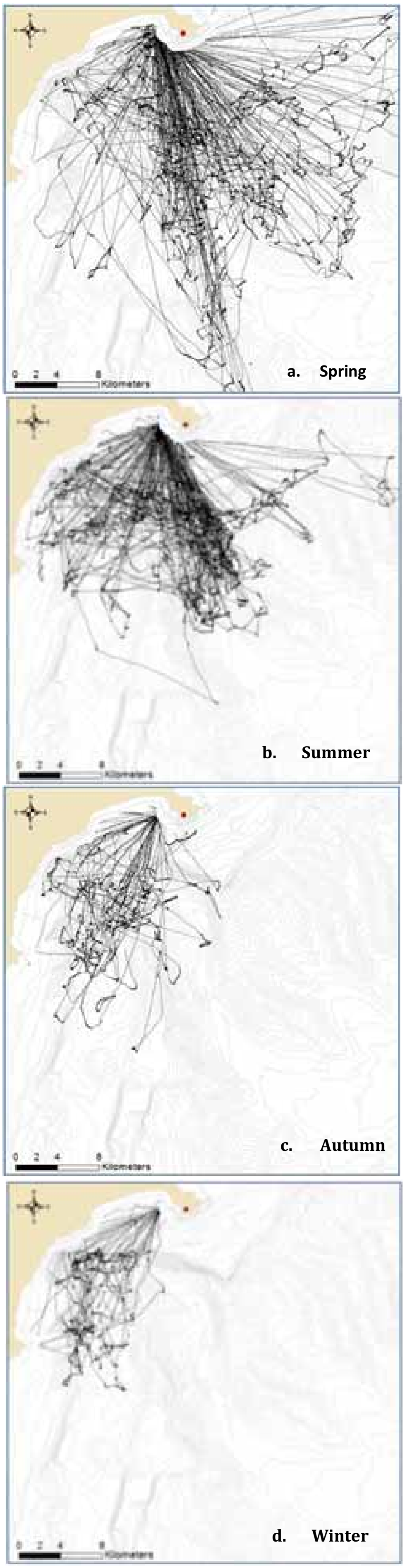
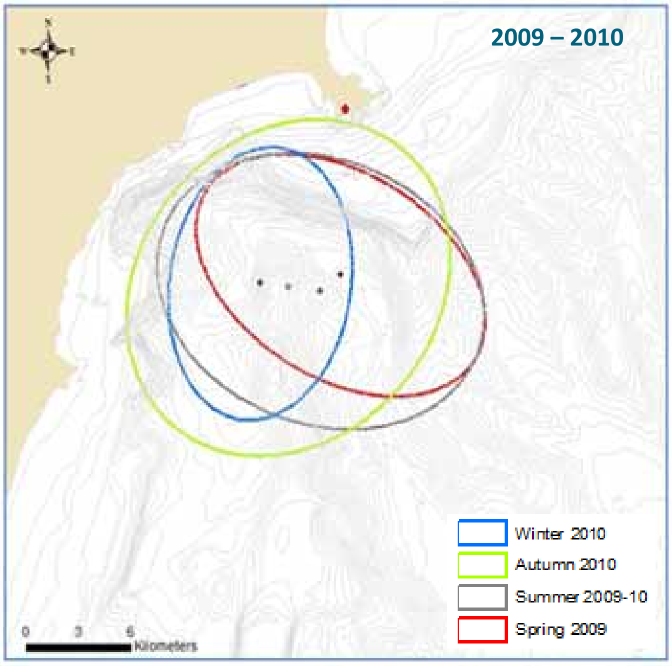


Figure 3.8. GPS positions extracted from GPS loggers onboard Whale watch boats are compared by seasons (2010-11).



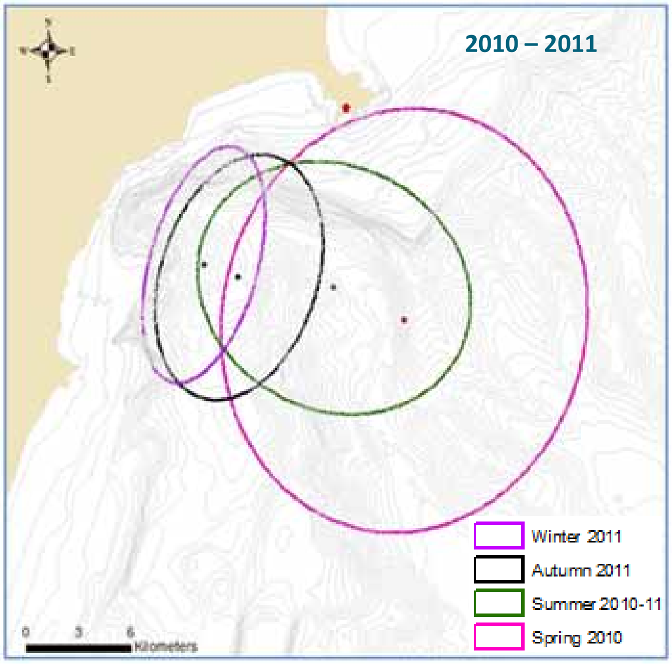


Figure 3.9. Area and mean centre (Longitude-Latitude) of standard deviation ellipses for GPS positions extracted from GPS data loggers onboard whale watching vessels is compared by season for the two year study (Top: 2009-2010, Bottom: 2010-2011).

Onboard Monitoring from Whale Watch Boats

A total of 187 whale encounters were recorded during 94 whale watching trips. The number of encounters observed (Figure 3.10) followed a similar pattern to the number of trips (Figure 3.5).

The distance of the whale watching vessel from the whale was estimated 127 times using a laser range finder. The distance between the vessel and the whale during an encounter averaged 75 ± 1.8m (mean ± standard error). A whale watching boat approached within 50m of a whale on only one occasion (32m). Most interactions occurred at distances of 50-90m (Figure 3.11).

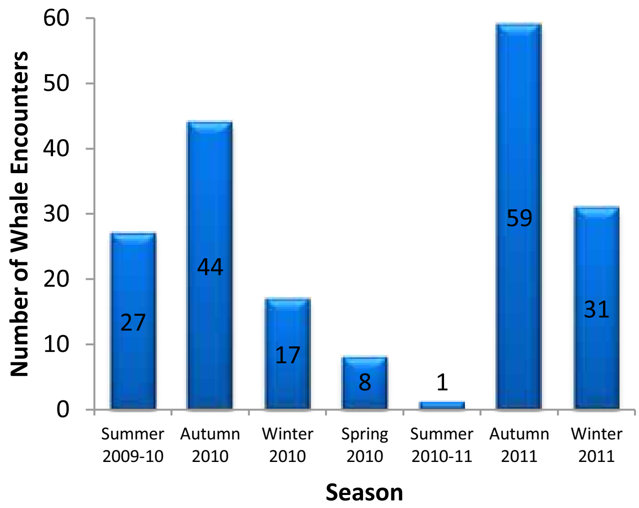


Figure 3.10. Number of sperm whale encounters monitored by scientific observers onboard whale watch tour boats by season.

To examine sperm whale behaviour, we focused our analyses on encounters ending with a fluke up dive. Whales submerged without fluking up on 11 occasions (5.9%). For those encounters where whale heading could be reliably and consistently determined (n = 95 encounters), whales changed heading >10° from the beginning to the end of the encounter 75% of the time (71 encounters). Distance of whale watching vessels from the whales did not appear to influence changes in whale heading. There was no significant difference in the distance of whales from vessels that changed heading versus those that did not (Kruskal Wallis,n=25, χ^2=3.841, ns, Figure 3.12).

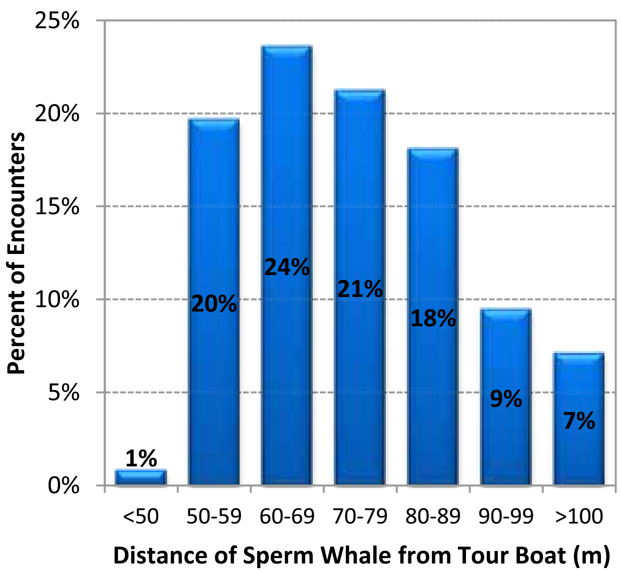


Figure 3.11. This frequency distribution shows the percent of sperm whale interactions with tour vessels that occurred at distances of <50, 50-59, 60-69, 70-79, 80-89, 90-99, and >100 m measured from the tour vessel with a laser range finder (n =127).

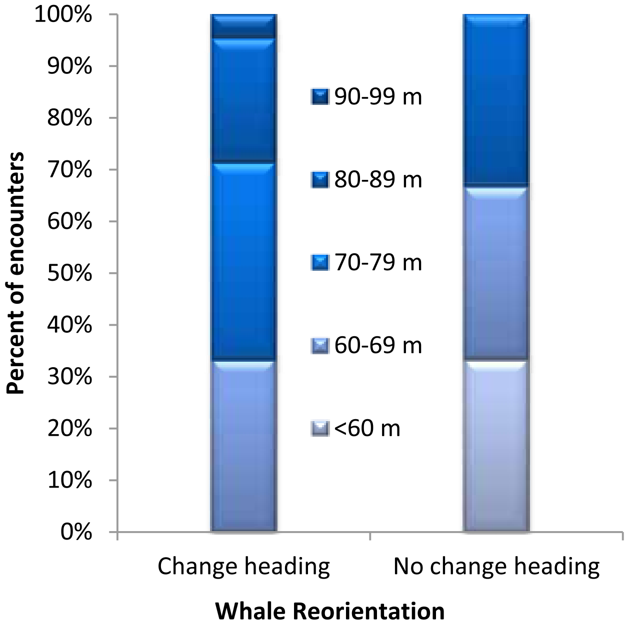
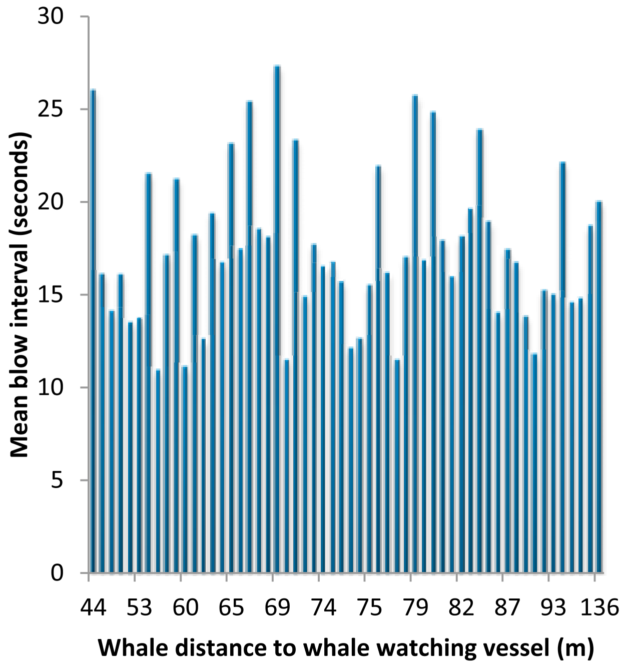


Figure 3.12. Distances between the whale watch tour boat and sperm whales (m) are compared for whales that changed heading during encounters (> 10°) versus those that did not.



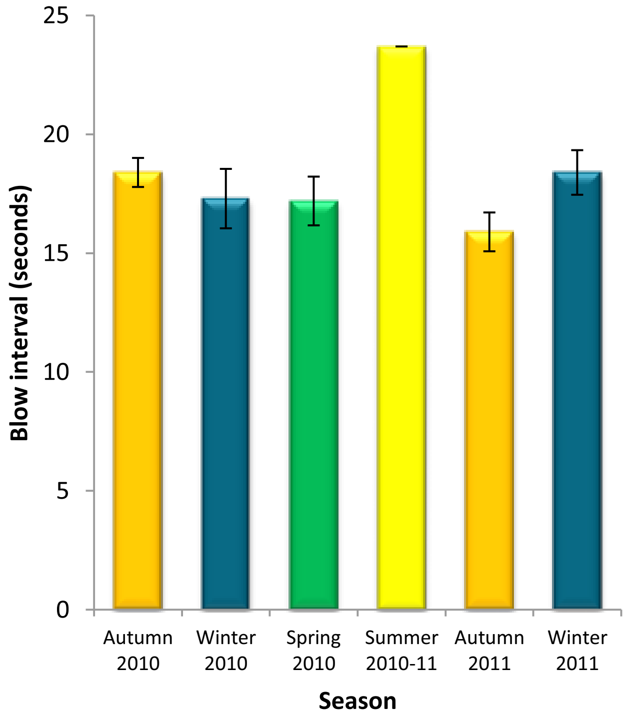


Figure 3.13. Blow intervals of sperm whales attended by whale watch vessels are compared by distance from the vessel (top) and by season (bottom). Bars represent means with standard errors.

Neither the length of encounters between whale watch vessels and whales at the surface (ANOVA, n=187, F=1.185, ns) nor the number of whale blows per encounter (ANOVA, n=131, F=1.451, ns) varied significantly between seasons. The time the whale watch vessels attended a whale at the surface prior to a fluke up dive ranged from 4.2 to 7.9 minutes (median = 6.8 minutes). The number of blows per encounter ranged from 9 to 27 as the first blows were never sighted. These are not true estimates of whale time or number of breaths at the surface because whale watch tour vessels generally approach whales after they have already surfaced (i.e., after the first blow of the surface interval). The first blow following surfacing was never spotted during all 94 trips. Thus, the values reported here document time the whales were accompanied at the surface by the vessel, a fraction of their total time at the surface. Based on the focal follow data from the independent research vessel, surface time averaged 10 minutes in the presence of whale watch vessels (see Chapter 4). Combining these two analyses, it appears that whale watch vessels which approached a whale generally attended that whale for more than half the time it was at the surface (68% on average).

In order to calculate the blow interval (a measure of ventilation rate during the encounter), only whale encounters without missing or double blows (described as interval blow <5sec and >50sec) were used. A total of 92 encounters were analysed and compared by seasons (Figure 3.13). Mean blow interval was normalized using ln(y). Blow interval of sperm whales collected onboard the whale watching vessel did not vary significantly with the distance of the whale from the boat (ANOVA, n=56, F=1.962, ns), but did vary significantly between seasons (ANOVA, n=92, F=2.716, p=0.025).

AERIAL WHALE WATCHING TOURS

Helicopter Tours

Seasonal variability in aerial tour activity was evident in GPS data logger tracks from the helicopters (Figures 3.14 and 3.15). Generally, helicopter tour activity was least in winter months and peaked in summer and autumn (with some interannual variability (Figures 3.14 and 3.15).

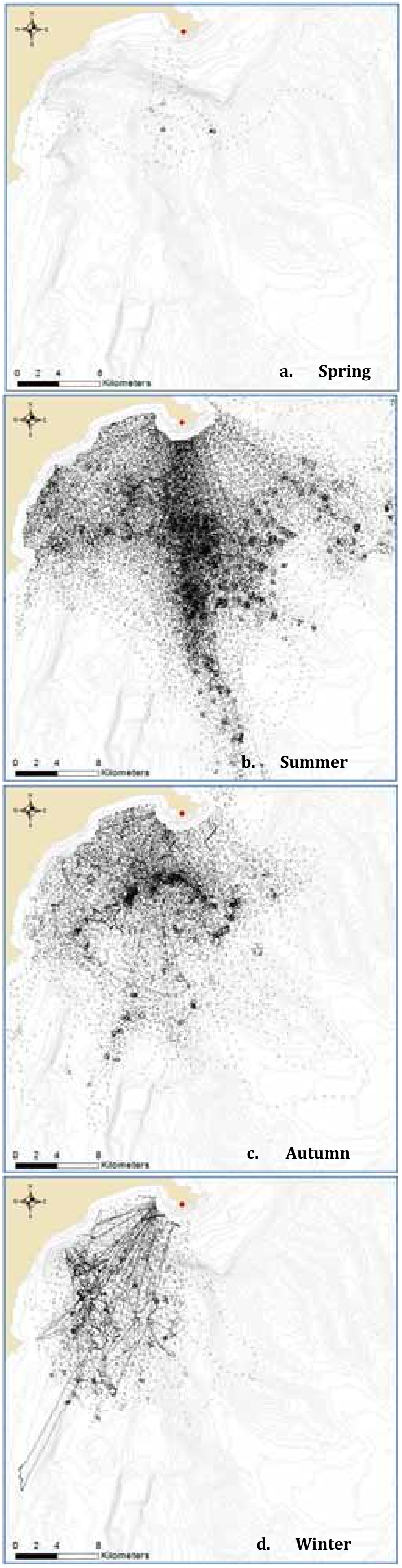


Figure 3.14. GPS positions extracted from GPS loggers onboard helicopters during 2009-10 are compared by season.

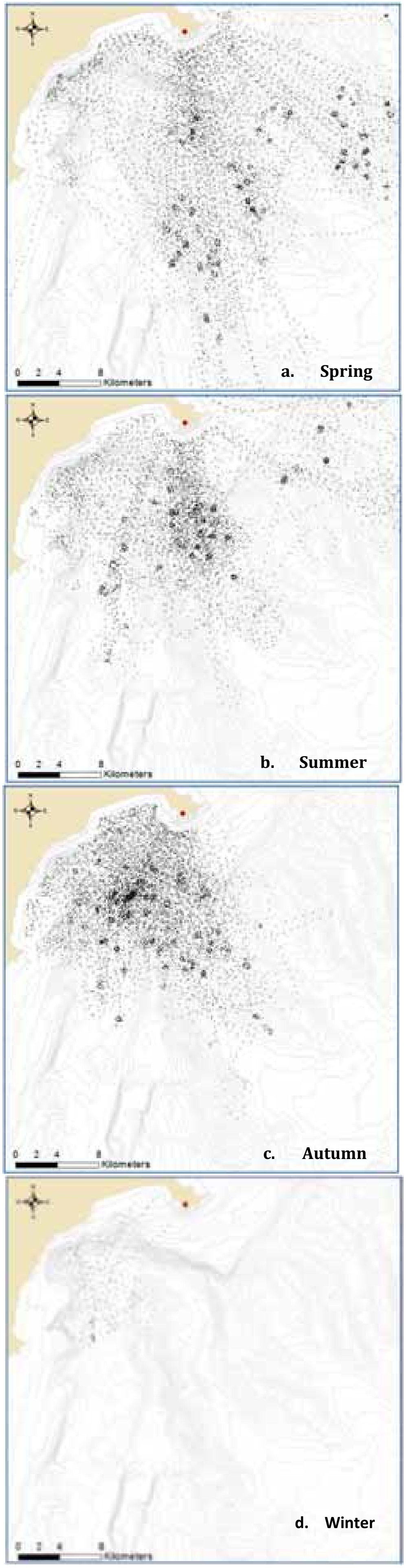


Figure 3.15. GPS positions extracted from GPS loggers onboard helicopters during 2010-11 are compared by season.

Analysis of standard deviation ellipses for helicopter tours showed tours ranging further offshore and alongshore in spring and summer, and across a narrower range closer to shore in autumn and winter (Figure 3.16). Some interannual variability was evident, with tours taking place across the widest range in summer during 2009-2010, and in spring during 2010-2011. In both years, helicopter tours were conducted over the narrowest range in winter, with intermediate ranges in autumn (Figure 3.16).

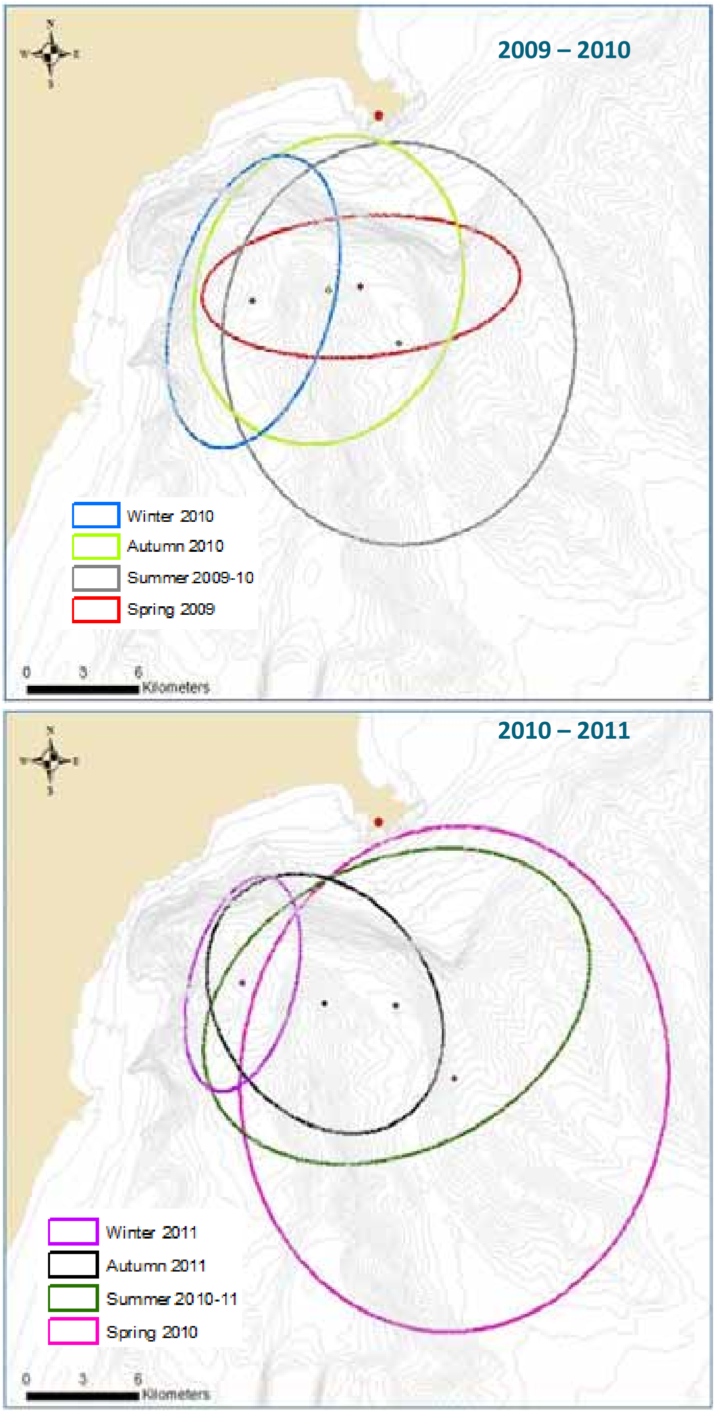


Figure 3.16. Area and mean centre (Longitude-Latitude) of standard deviation ellipses for GPS positions extracted from GPS loggers onboard helicopters is compared by season for 2009-2010 (top) and 2010-2011 (bottom).

Aeroplane Tours

The most consistent aeroplane tours were run by Wings Over Whales. According to GPS track logs archived and downloaded online, Wings Over Whales operated flights in the Kaikoura area on 83% of days. Amount of aerial tour activity varied seasonally (Figure 3.17), with the highest number of days and hours operating in late spring and summer (November through February) and the lowest amount of tour activity in late autumn and winter (May through August). Seasonal variability in areas visited by fixed wing aircraft tours was evident in GPS data tracks from both tour companies (Figures 3.19 — 3.22).

Wings Over Whales tours were flown at an average (mean ± standard error) flight speed of 189 ± 4.2 km/h (102 ± 2.2 knots) and altitude of 234 ± 4.0 m (766 ± 13.1 ft). Records taken by observers onboard Wings Over Whales flights based on the plane's altimeter while circling over the whale showed a similar average altitude of 221 ± 23.4 m (726 ± 76.8 ft), with a range of 143 to 305 m (Figure 3.18 left). There was no significant difference between average flight altitude and altitude while circling whales (Mann-Whitney, U= 62380, ns), although this may be due to limited power (n=8 flights with onboard observers). Mean altitude of Wings Over Whale flights did show some seasonal variation ($F=60.299$, $df=3$, $P < 0.001$), with planes flying lowest on average during the peak summer tourism season (Tukey, $P < 0.05$, Figure 3.18 right).

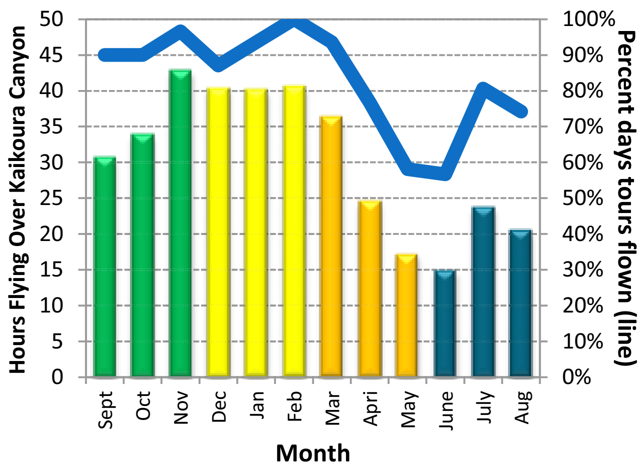


Figure 3.17. Amount of aerial tour activity is compared by month for fixed wing aircraft tours run by the Wings Over Whales company based on data downloaded from online flight logs.

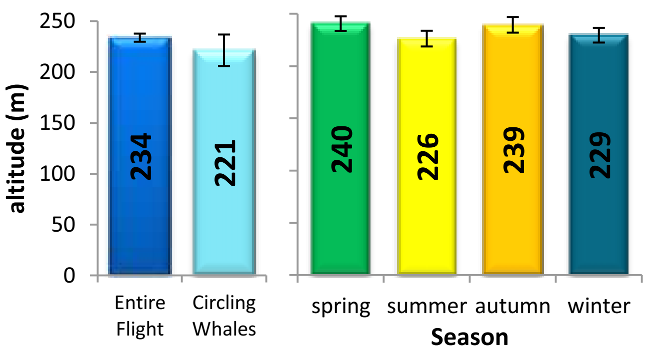


Figure 3.18. Altitudes of whale watch tour planes (Wings Over Whales) are compared: for the entire flight versus the time circling whales (left) and by season (right). Bars represent means with standard errors.

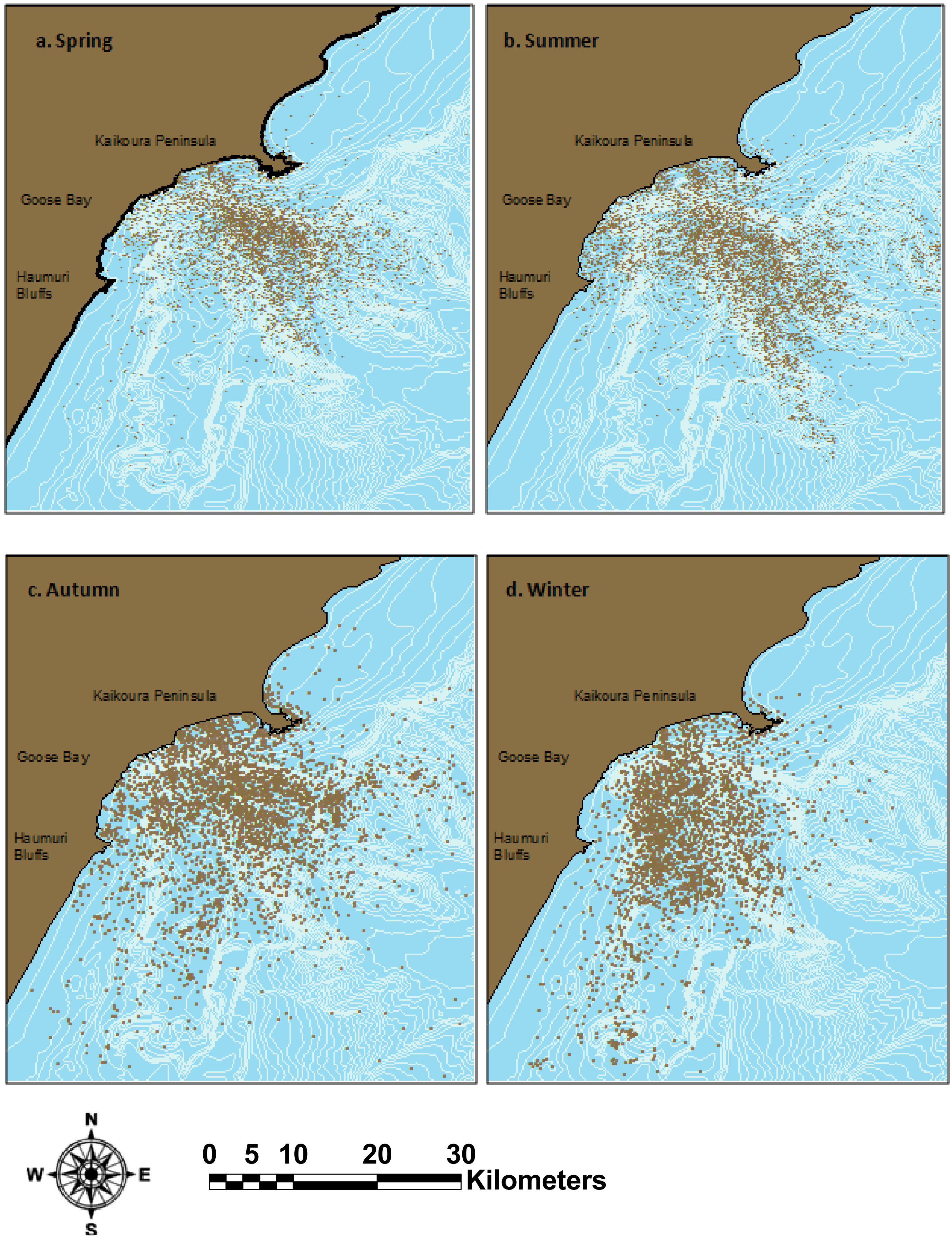


Figure 3.19. GPS positions downloaded from daily online flight logs for Wings Over Whales aerial tours are compared by season. Positions were logged at one-minute intervals (data downloaded from www.tracplus.com, courtesy of John MacPhail).

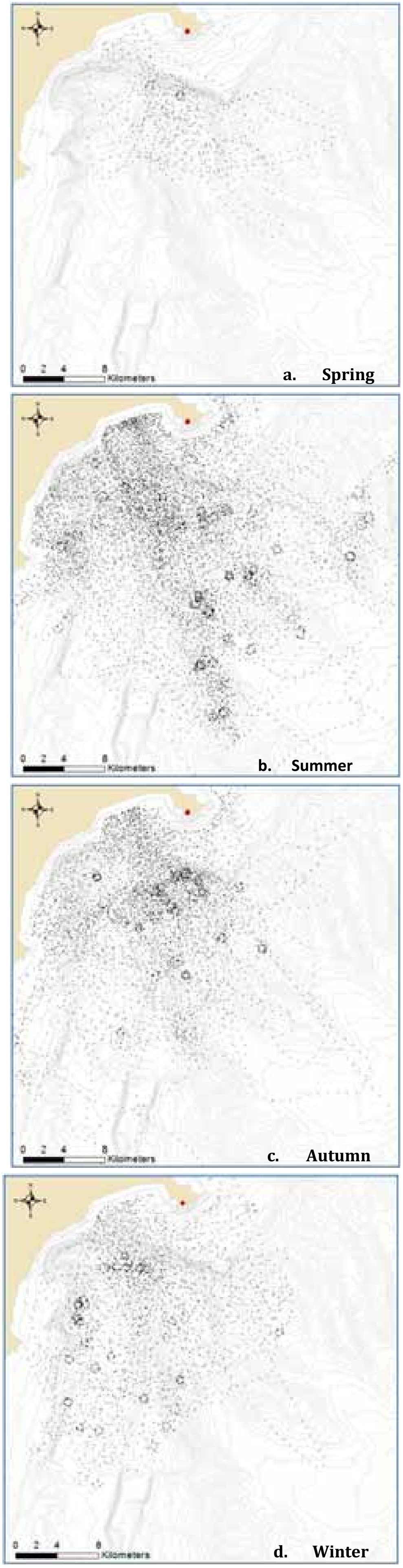


Figure 3.20. GPS positions extracted from GPS loggers onboard plane from Kaikoura aeroclub are compared by season (2009-10).

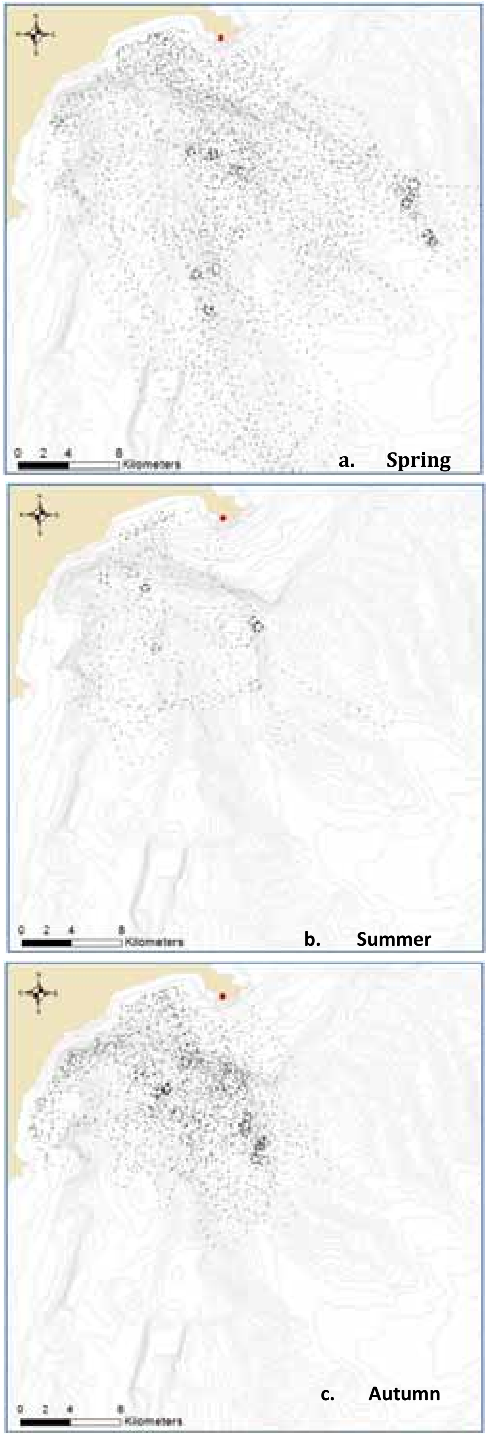


Figure 3.21. GPS positions extracted from GPS loggers onboard Kaikoura aeroclub plane are compared by season (2010-11).

The view from the air (Figure 3.22) provided observers with a good vantage for observing behaviors often missed from boat-based observations, including defecation which was noted on two occasions. However, space and logistical limitations resulted in a small sample size for onboard observations during aerial tours.

Figure 3.22. Picture of a sperm whale from a Wings Over Whales plane during a tour.

DISCUSSION

Onboard Monitoring from Whale Watch Boats and Aircraft

This chapter presents data collected onboard whale watching vessels and aircraft in order to examine the interaction of vessels with sperm whales. Season was the factor which most influenced the ventilation pattern of sperm whales. Similar results were reported in chapter 2.

Distance from the tour vessel to the whale was recorded 127 times by onboard observers with a laser range finder, averaging 75m. Our findings confirm that the whale watching vessels are generally following the regulations (99.2% of the time), staying >50m away from the whale in all but one instance (32m).

We observed an apparent effect of vessels on the directional heading of the whales. On all the encounters with whale watching vessels, whales changed heading 75 % of the time. Similar results regarding heading change recorded from a research vessel were reported by Richter *et al.* (2003) and in Chapter 4 of this report.

Observers on aircraft documented an average altitude of 221m when planes were circling over sperm whales at the surface, with a range of 143m to 305m. One limitation of this research was the small sample of data collected from aeroplanes. For this reason, we lacked power for statistical comparison of mean flight altitude with altitude while circling over whales.

Information Extracted from GPS Data Loggers and Online GPS Tracking Logs

The data extracted from the GPS data loggers provided information on whale watch tour operating areas and seasonal effort for both vessel and aircraft tours.

As expected, seasonal variation of whale watching activity was documented. Summer and autumn were the busiest seasons, with an increase in whale watching activity. Different companies used similar areas. Regular communication between vessel and aircraft tours facilitates information sharing regarding whale position and dive times. This coordination serves to increase the sighting success for the companies. It also likely increases the number of visits to those particular whales first spotted by the companies.

The seasonal and interannual variation in the area in which the companies operated was significant; this is correlated with findings in chapter 2 showing seasonal variability in the distribution of sperm whales.

The information from GPS data loggers provides a valuable measure of whale watching activity throughout the year. However, due to logistical challenges, there were some missing records. While data loggers onboard whale watch vessels had an onboard power supply, GPS data loggers onboard helicopters and the plane from Kaikoura Aeroclub ran on battery power packs that lasted a maximum of one week. Consequently, some periods with tour activity may have been missed. GPS data loggers onboard whale watching boats were at times unplugged, so data were lost. GPS tracks from Wings Over Whales tours downloaded from their online records provided fairly consistent coverage, allowing us to estimate the proportion of days and number of hours these aerial tours operated by time of year. These records showed flights most days of the year, but also a clear seasonal effect with twice the flight hours in summer as in winter.

Although remote tracking for both vessels and aircraft provided a good general gauge for inferring the level and extent of tour activity, the data gathered do not provide direct information on sperm whale interactions with tours. Some more detailed information on whale-tour interactions was collected by observers onboard whale watching tours, providing higher quality information about vessel and aircraft activity during encounters with sperm whales. The best vantage for gathering data on the behaviour of whales during these interactions as well as in the absence of tours was generally from either the shore station for a broad view (Chapter 2), or from the independent research vessel platform for a narrower, focal whale view (Chapter 4).

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