Biological Conservation 202 (2016) 127–137

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

Use of local ecological knowledge to investigate endangered baleen whale recovery in the Falkland Islands

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ARTICLE INFO

Article history:
Received 12 May 2016
Received in revised form 9 August 2016
Accepted 16 August 2016
Available online 6 September 2016

Keywords:
Commercial whaling
Population recovery
Historical ecology
Local ecological knowledge
Balaenoptera borealis
Balaenoptera physalus

ABSTRACT

Baleen whale populations have increased around the world after the end of commercial whaling in the 1980s. Anecdotes from local inhabitants of the Falkland Islands tell of an increase in whale sightings after an almost complete absence. However, no long-term monitoring exists to assess such recovery. With increasing maritime activities around the Islands, local managers need to understand the status and distribution of baleen whales to avoid impeding the potential recovery process. In the complete absence of scientific data, harvesting local ecological knowledge (LEK) from residents could provide means to assess whether whale numbers are increasing. We collected historical knowledge and mapped historical observations through structured interviews with 58 inhabitants and filtered observations for the highest reliability. We also collated existing historical catch and sighting data to compare species composition in inshore and offshore waters. A total of 3842 observations were compiled from the 1940s to 2015. This collation of information provided first-time evidence on the return of the whales in the Falkland Islands' waters. There was a clear increase in numbers of whales sighted, from no observations in the 1970s to 350 observations between 2010 and 2015 for similar effort, mostly of endangered sei whales (*Balaenoptera borealis*) and fin whales (*Balaenoptera physalus*). We mapped contemporary whale sighting hotspots to inform current marine spatial planning efforts. The use of LEK is highlighted here as a useful way to gain a better understanding of changes in the status of threatened species when no scientific monitoring has been conducted.

1. Introduction

Since the end of the commercial whaling era in the 1980s and added protection through international legislations, there has been evidence of whale populations increasing worldwide (Carroll et al., 2014; Magera et al., 2013; Paterson et al., 1994; Scott et al., 2005; Stevick et al., 2003). The protection of humpback whales (*Megaptera novaeangliae*) in the 1950s and 1960s, for example, has caused this population to increase from a few thousand individuals, to over 60,000 individuals, shifting from an Endangered IUCN conservation status in the 1980s to Least Concern by 2008 (Hoffmann et al., 2011; Reilly et al., 2008). Fin whales (*Balaenoptera physalus*), as another example, had decreased in number by over 70% during the commercial whaling era, and since their protection in the 1980s, has increased in abundance in both hemispheres (Edwards et al., 2015). Further, the southern right whale (*Eubalaena australis*) has, after over 40 years, returned to its former New Zealand mainland calving grounds (Carroll et al., 2014). Knowledge on these and other recovering whale populations is important, as they can contribute to the essential understanding of a species' global distribution and status (Edwards et al., 2015).

The Falkland Islands and its surrounding waters (Fig. 1) are hosts to at least three endangered baleen whale species (suborder Mysticeti): the blue whale (*Balaenoptera musculus*), fin whale and sei whale (*Balaenoptera borealis*; Otley, 2012). Other baleen whales that have been reported in these waters are the minke whale (*Balaenoptera* spp.), the southern right whale and the humpback whale (Otley, 2012). Similar to other islands in the South Atlantic, the Falkland Islands' waters were historically used by the commercial whaling industry (Jones, 1969). Sperm whales (*Physeter macrocephalus*) and southern right whales were initially targeted in these waters, as they were easier to capture (Salvesen, 1914; Smith et al., 2012). As these species' numbers eventually dwindled and technology advanced, the target shifted to blue, fin, and sei whales in the late 1860s (Salvesen, 1914). By the early 1900s, the stock of whales in these waters further diminished to unprofitable numbers, evidenced by the limited success of the New Island whaling station (Fig. 1; Bonner, 2007; Salvesen, 1914), which had a low seasonal yield compared to other southern whaling industries (e.g. the South Shetland Islands and South Georgia), and was closed within six years of its establishment (Vamplew, 1975).

In recent years, anecdotes heard from long-term local aircraft pilots have indicated that more and more baleen whales have been spotted in

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http://dx.doi.org/10.1016/j.biocon.2016.08.017
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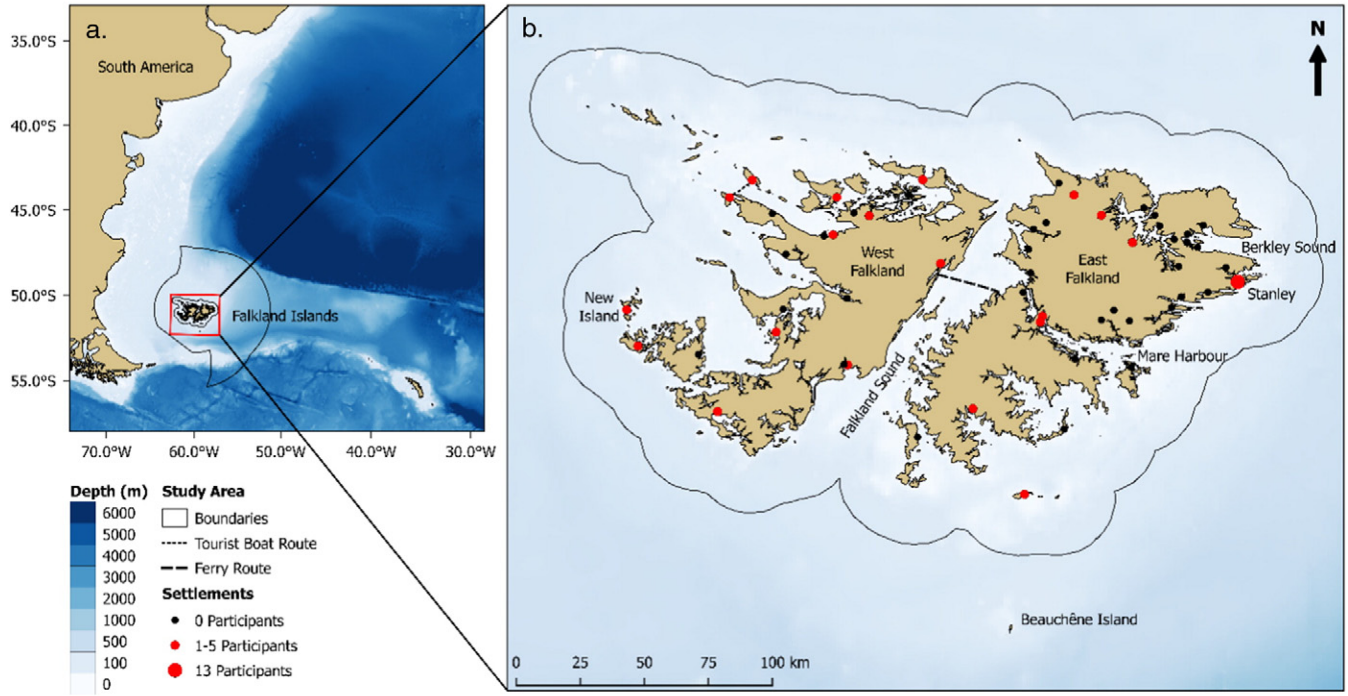

Fig. 1. Maps of the Falkland Islands and its position on the Patagonian shelf. Boundaries show the offshore study area (a) and inshore study area (b). The ship routes indicated are the ferry between East and West Falkland, and the tourist boat between Carcass Island and West Point Island.

the Falkland Islands' waters. It is possible that whale numbers are in the midst of recovery. However, little is known about the historical and contemporary composition and status of baleen whales in these waters (Otley, 2008). Apart from what can be gathered from whaling data (e.g. Adie and Basberg, 2009), stranding data (e.g. Otley, 2012) and two sparsely-conducted empirical surveys (e.g. Thomsen, 2014; White et al., 2002), there have not been many scientific studies on baleen whales in the Falklands Islands' waters. Understanding the historical change in whale numbers in the Falkland Islands can provide information to assess potential recovery and for management purposes. The Falkland Islands Government aims to maintain the protection of resident and migrating cetaceans in its waters, and recognises that a deficiency of information causes a high risk to biodiversity, especially with potential threats from increasing marine use through shipping, tourism, oil exploration and commercial fisheries (Otley, 2008). Ship strikes, for example, could be a concern for these recovering species (Berman-Kowalewski et al., 2010; Williams and O'Hara, 2010), making information on whale distribution and abundance an important component for marine spatial planning (Petruny et al., 2014). However, with no long-term cetacean monitoring in place, there is a lack in seasonal and decadal information on whale presence. Information on historical trends is therefore lost, and systematic surveys cannot be done in retrospect. This lack can, nevertheless, be substituted by an alternative source of information: local ecological knowledge (LEK).

LEK can be defined as ecological knowledge gained through experience or observations (Olsson and Folke, 2001). The person providing this knowledge is not necessarily an 'expert' in the ecological subject, but predefined factors (e.g. occupation or amount of exposure to the surrounding environment where the observation takes place) can contribute towards the credibility and reliability of such knowledge for its use in scientific fields. LEK has been beneficial to researchers, managers and policymakers in understanding complex systems and historical change when research over large or remote areas or over long periods of time have not or cannot be conducted (Brook and McLachlan, 2008; Drew, 2005). It can provide information on species occurrences for future management and research. It has been used in marine management contexts to define marine protected areas (e.g. Mellado et al., 2014), and as a supplement in fisheries management (Pauly, 1995; Sáenz–Arroyo et al., 2005). It can also be used to infer species distributions (e.g. Frey et al., 2013), habitat suitability (e.g. Polfus et al., 2014), and historical population trends (e.g. McPherson and Myers, 2009). The Falkland Islands' small human population, with inhabitants scattered across the Islands in remote settlements and closely linked to their natural environment through their farming culture, allows for a wide distribution of year-round inshore observers in this remote area, and thus can be a valuable source of knowledge. Obtaining knowledge on baleen whale presence and historical change from this population could serve as an essential starting point for future research and management objectives in the Falkland Islands.

With at least three endangered baleen whale species occurring in the Falkland Islands' waters, it is important to assess the present status of these whales and compare it with their historical status to determine if they are in the midst of recovery. Here, we gather all possible evidence on whale presence in the Falkland Islands' waters by collating and analysing observations collected as LEK and supplementing them with the limited existing empirical sighting data, including historical commercial whaling catch data for comparison in species composition. We present here the first study on historical change in whale observations and nearshore distribution around the Falkland Islands to assess potential recovery and identify sighting hotspots to inform marine spatial planning and future research. This may also provide insights on the potential recovery of endangered baleen whales in the South Atlantic.

2. Materials and methods

2.1. Study area

The Falkland Islands is located in the South Atlantic at the southern end of the Patagonian Shelf, east of the South American continent (Fig. 1a). Its Exclusive Economic Zone (EEZ) covers an area between 51° and 53°S and 57° and 62°W. The islands have 3125 inhabitants (Falkland Islands Government Policy Unit, 2013), living in settlements throughout the archipelago. The largest settlement (2/3 of the population) is the only town, Stanley. There are two ports (Stanley and Mare

Harbour) and another natural harbour extensively used by ships during the fishing season: Berkley Sound. A ferry runs between the two main islands once or twice a day in the austral summer (a few times a week in winter), and a tourist boat runs between Carcass Island and West Point Island on most days over the austral summer. The territorial sea (22 km from land) of the Falkland Islands (excluding Beauchêne Island) is hereafter referred to as the 'inshore study area' for analyses (Fig. 1b). The inshore study area covers 30,509 km^2 and includes maximum water depths of 150 m. The 'offshore study area' is the rest of the Falkland Islands' EEZ, outside of the territorial sea (Fig. 1a). This offshore study area covers 423,387 km^2 and includes water depths of up to 4856 m.

2.2. Collection of local ecological knowledge via structured interviews

Historical LEK was gathered using structured interviews with selected Falkland Islands residents. Ninety-four households, located in settlements throughout East and West Falkland and the surrounding islands, were contacted by phone to solicit participation. These households covered 34 out of 46 mainland settlements, and 8 out of 12 total outer island settlements.

Prior to participation, all interviewees were first introduced to the study and its objectives and were provided with an information sheet. They were then asked to read and sign a consent form for the interview and use of the information provided for the study. All interviews were conducted individually and face-to-face in the Falkland Islands.

Participants were asked a series of questions to confirm the amount of time they spent living in the Falkland Islands, their confidence in baleen whale identification, and their perception on trends in sightings over time. To gauge their confidence in whale identification, they were assigned a score between 1 (low) and 5 (high) for their ability to identify cetaceans at the family level (e.g. *Balaenopteridae* versus *Delphinidae*) and more specifically to identify baleen whales at the species level (e.g. sei versus fin whale). As an open-ended question, participants were asked if they could recall a period of time when they had not seen any baleen whales.

Participants were prompted to draw on an *A*1-sized laminated map the locations of their whale sightings over different decades, from the earliest they could remember to 2015. The interview map displayed the Falkland Islands and the boundary of the inshore study area, with a 1 km^2 grid throughout the area as a reference for scale and later use for digitising the maps. Using a dry-erase marker, participants drew polygons over the grid to indicate areas of sightings and were encouraged to give as many details about each sighting as they could recall. For each polygon, the following attributes were recorded whenever possible: (1) the species seen; (2) the approximate year(s); (3) the approximate month(s); (4) the minimum and maximum number of whales seen; (5) the observation platform; (6) an estimate of how often they visited that location during the decade; and (7) the frequency of sightings they had in relation to those visits. The latter two criteria were generalised into five descriptive levels of frequency, based on verbal cues provided by the participants (Table 1). To ensure consistency in mapping and interpretation of the sighting descriptions (i.e. verbal cues), all interviews were conducted by the same interviewer and the interviewer accompanied the participants at all times as the maps were drawn. A photograph was taken of the map before erasing the drawings. The participants then drew sightings for the subsequent decade.

At the end of each interview, participants were asked to suggest other local residents as additional sources of whale sightings so that more potential experts could be identified. Based on the description of the reference (i.e. experience, knowledge, or profession) and/or the number of participants who recommended them, these referred people were later contacted and invited for an interview.

2.3. Defining LEK expertise through reliability ranking

In LEK schemes, it is important to establish a standard criterion under which experts are identified within the community, so that the most reliable knowledge is elicited (Davis and Wagner, 2003). Our experts were defined as the initially-chosen participants, representing individuals who had lived in the Falkland Islands over a long period of time, and/or individuals who are naturalists or work near, on, or over the sea. The subsequently interviewed participants named through referrals also reinforced the robustness of knowledge obtained. For the LEK dataset, the level of expertise itself was not assessed per participant, but rather for each observation they provided. We assessed each observation by assigning a reliability rank from A to G, based on criteria described in Table 2, and adopted from Frey (2006) and Frey et al. (2013). By working alongside each participant as the maps were drawn, and recording verbal cues such as 'assuming' that an observation was of a particular species, or being 'sure' of the species seen, an observation was ranked lower or higher in reliability, respectively. The highest ranked observation (rank A) was one where a participant had also provided a photograph of a sighting for that location; the lowest ranked observation was one where an erroneous description of the species was given (rank G), or the location where the whales were seen was coarsely or arbitrarily drawn (rank F), indicative of the participant's lack in understanding of what is being asked of them (Table 2). Assigning a reliability rank to each observation thus allowed for data filtering, so that the most reliable and robust observations were kept for analyses and mapping.

2.4. Collation of existing data: whaling archives, at-sea surveys, citizen science

As a supplement to LEK, we gathered existing baleen whale sighting data for the study area from a wide range of sources, including public and private databases, citizen science, local government records, and grey and published literature. The sources comprised of historical commercial whaling catch positions, line-transect and radial point-count survey data, and opportunistic sightings. We separated these data into three categories: whaling, survey, and opportunistic data.

Whaling data were made available by the International Whaling Commission (IWC) from their Individual Catch Summary Databases (version 5.6; Allison, 2014). These included 25 whaling expeditions

Table 1
Categories of visit and sighting frequencies, based on verbal cues from interview participants. A value of effort is also assigned to the visit categories for evaluation of observation hotspots.

Frequency of…	Effort Value	Category	Description	Verbal cues
Visits (per decade)	1	Once	One instance or a specific event per decade.	One time; once
	2	Few	2–5 visits per decade.	A few times over the past … years
	3	Occasional	One or a few visits per year.	From time to time; a couple or several times a year
	4	Often	Visiting over long periods (<6 months) per year.	Every [season]
	5	Frequent	Residing or passing through the location >6 months per year.	Frequently; always; most of the year; a lot
Sightings (across visits)		Once	One sighting in a given decade, or for a specific visit.	One time; once
		Seldom	Rare sightings (e.g. 2–3 sightings across visits).	Hardly ever; a few times
		Occasional	Seen for <1/2 the visit frequency.	Several times
		Often	Sighting for >1/2 the visit frequency.	Frequently; most days
		Always	Sighting at almost each visit.	Every time; guaranteed to see them

Table 2
Reliability ranks applied to observations from the empirical and local ecological knowledge (LEK) datasets, as adopted from Frey (2006) and Frey et al. (2013).

Rank	Characteristic	LEK data application	Empirical data application
A	Verified occurrence.	Expert evaluation of physical evidence (i.e. photos).	Same as LEK data application.
B	Highly probable occurrence.	Real-time notes and positions taken and presented at the time of the interview.	Expert, real-time recorded observation, but no preserved physical evidence provided.
C	Probable occurrence.	Observations where the interviewee is confident in identification at the species and/or family level (identification score of 3–5).	Reported observation that is likely to be accurate; statement of lower confidence in identification; citizen science data with high confidence in identification.
D	Possible occurrence.	Species identification is based on an assumption or inference, but not the interviewee's actual knowledge; the interviewee has low confidence in identification at the species or family level (identification score of 1–2).	Observation with unknown confidence in species identification; citizen science record with 'probable' confidence in identification.
E	Questionable occurrence.	Potentially inaccurate observation due to an observer's lack of knowledge, or no supporting details; citizen science record with 'possible' confidence in identification.	Same as LEK data application.
F	Highly questionable occurrence.	Highly inaccurate position; polygons were too coarse or 'arbitrarily' drawn by the interviewee; the interviewee shows an inability to understand the map scaling.	High potential of inaccuracy; citizen science record with no reported confidence in identification.
G	Erroneous occurrence.	Misidentified species.	Same as LEK data application

with catches within the Falkland Islands' waters between 1905 and 1973. The precision of the recorded positions ranged from approximately 1.6 to 110.0 km, or had no accuracy given (Allison, 2014). Concurrent with development in technology, the positions were more precise over time (i.e. after the 1960s).

We obtained survey data from the IWC through their Database Estimation Software System (DESS; International Whaling Commission, 2011). These are sightings from the International Decade of Cetacean Research/Southern Ocean Whale and Ecosystem Research (IDCR/SOWER) cruises from the years 1978 to 2003. The precision of these records ranged from approximately 0.8 to 1.6 km (International Whaling Commission, 2011). Additional survey data were obtained from the Japanese Scouting Vessel (JSV) database for the period 1965–1986 (Miyashita et al., 1995). Other survey data were obtained from the Joint Nature Conservation Committee (JNCC), which recorded marine mammal sightings during a seabird line-transect survey throughout the Falkland Islands' EEZ from 1998 to 2001 (White et al., 2002). Unpublished records from a later JNCC line-transect survey from 2003 to 2004 that included some areas of the Falkland Islands' EEZ were also made available from the Government of South Georgia and the South Sandwich Islands (GSGSSI). Both JNCC surveys used the Seabirds At Sea Team (SAST) standardised methodology (Tasker et al., 1984). The locations of the sightings were recorded with an approximate precision of 0.3 km. Sightings from an inshore line-transect survey conducted for 10 days in 2014 were obtained from Falklands Conservation, with positions recorded at a precision of approximately 0.3 km (Thomsen, 2014). At-sea sightings from a 0.3 km radial point-count survey from an oil exploration platform in 2012 were also available (Munro, 2013).

We acquired opportunistic sightings from citizen science records. Sightings from land or small recreational boats from the local Cetacean Watch Group project were made available by the local NGO, Falklands Conservation, where sightings were recorded by the public on a standard form. The local air transport service (Falkland Islands Government Air Service; FIGAS) had sightings recorded by pilots. The citizen science records covered the years 1991 to 2006, with a wide range of accuracies, from specific GPS coordinates to references to 30 km government management grids. Further opportunistic sightings were extracted from documents from the Falkland Islands Museum and National Trust Archives, online databases (OBIS-SEAMAP; Halpin et al., 2009), government fishery observer reports (Falkland Islands Fisheries Department), and published literature (Iñíguez et al., 2010). OBIS-SEAMAP contained sightings from the UK Royal Navy (Maughan, 2003), which were taken between 1997 and 2001 and were precise to the nearest 0.2 km. The Falkland Islands Fisheries Department provided 540 fishery observer reports for the years 2001 to 2015, from which baleen whale sightings were extracted. The precision of these sightings ranged from 0.2 to 30 km (GPS coordinates or government management grids, respectively).

These existing datasets (henceforth called 'empirical' data) were collated and the following attributes were extracted for each sighting: (1) species name; (2) date; (3) minimum and maximum number of individuals seen; (4) observation platform; (5) location. We then assessed each observation and assigned reliability ranks to them (Table 2), which allowed for homogenisation to map this dataset with the LEK dataset.

2.5. Defining and mapping observations in the inshore study area

We mapped all inshore study area observations in QGIS version 2.10.1 (QGIS Development Team, 2009). For the LEK dataset, an occurrence was not necessarily discrete, and could comprise multiple sightings at a given location for a specific decade (i.e. multiple instances within a decade, delineated by sighting and visit frequency). In contrast, for the empirical dataset, an observation was defined as a specific capture, survey or opportunistic occurrence event or sighting (i.e. one instance; Table 1).

A polygon vector grid of 1 km^2 resolution was applied to the inshore study area. Empirical observations in the form of point locations were buffered according to the occurrence resolution and spatially joined to the inshore vector grids to convert these observations into a gridded format. Empirical observations with only descriptive locations (e.g. shoreline or harbour names, or local fishery zones) were digitised based on the descriptions where possible. Observations that lacked location information or were too coarse (resolution >30 km) were not mapped and were excluded from this part of the analysis. The LEK observations were mapped by digitising the photos of the maps over the 1 km^2 grid by selecting cells that intersected with the polygons drawn by the participants.

Each observation was assigned a unique identification number during digitising, and all available attributes for the observation were added. All gridded observations were then combined to form a vector catalogue of baleen whale observations for the inshore study area.

2.6. Analysis of observations

We analysed the observations to assess historical changes across decades and between the whaling (up to the 1980s) and post-whaling (after 1990) eras to determine seasonal change and species composition and to map observation hotspots for the post-whaling era. As the empirical data gathered were spatio-temporally limited and inconsistent, often covering different areas for short periods of time, and originating from different methodologies, identifying historical changes of presence and abundance was not possible. Decadal change was thus determined using LEK only, as it offered a more consistent dataset over several decades. For all other analyses (i.e. seasonal change, whaling and post-whaling era species composition, and mapping), however, both datasets could be used.

Table 3
List of the types of data and accepted sources and their years of coverage. A count of inshore and offshore observations is provided for each source. This count includes all reliability ranks.

Category	Source	Years	Count	
			Offshore	Inshore
Whaling	Databases			
	IWC Individual and Summary Catch Databases	1905–1979	2497	241
Survey	Databases			
	IWC IDCR/SOWER Database (DESS)	1978–2003	7	0
	JSV Database	1965–1986	19	0
	Government of S. Georgia and the S. Sandwich Islands	2003–2004	16	1
	Grey (Unpublished) Literature			
	Munro, 2013	2012	30	0
	Thomsen, 2014	2014	0	57
	White et al., 2002	1998–2001	132	29
Opportunistic	Citizen Science Records			
	Falklands Conservation	1999–2006	5	83
	Falkland Islands Government Air Service	1994–2003	15	20
	Falkland Islands Museum and National Trust Archives	1991–1996	1	1
	Databases			
	OBIS-SEAMAP	1997–2001	3	1
	Government Records			
	Falkland Islands Fishery Observer Reports	2001–2015	43	1
	Grey (Unpublished) Literature			
	Munro, 2013	2012	5	0
	Thomsen, 2014	2014	0	1
	Published Literature			
	Iñíguez et al., 2010	2005–2007	1	2
Local ecological knowledge	Interviews	1940–2015	0	631

All analyses were conducted in QGIS with the MMQGIS and GroupStats extensions. Historical change in the number of observations in the inshore study area was calculated by taking the sum of all LEK observations per decade, stratified by the frequency of sightings described in Table 1.

We then assessed seasonal trends in whale observations across all years by adding the number of observations per month for each species, and then all species combined. Only reliability ranks A to C were used, as they represented the most reliable observations (Frey, 2006; Frey et al., 2013).

We also compared whaling and post-whaling era species composition for the inshore and offshore study areas. The average inshore and offshore count of each species, taken from the minimum and maximum counts, was calculated for both the empirical and LEK observations. Only observations of reliability ranks A to C were used, but empirical sources assigned a lower rank due to precision issues (i.e. coarse grain > 30 km) were also included in this calculation.

Finally, the observations were filtered to keep only the post-whaling observations and were used to identify hotspots of whale sightings in the inshore study area. All observations ranked D to G were removed from the dataset. The density of observations per 1 km^2 grid cell for all species was calculated. A relative assessment of observation effort was produced by assigning a value from 1 to 5 to the frequency of visits obtained from the interviews (Table 1) and a value of 1 to the frequency of visits for the empirical data (i.e. it was assumed that these locations were visited only once for each survey and opportunistic sighting, as they were all single events). The average visit frequency value across observations within each 1 km^2 grid was mapped. Finally, we compared this averaged observation effort with the density of observations to identify locations with the highest relative effort (average values ≥ 4), and with the highest observation densities; these are the hotspots of whale observations with the highest confidence.

3. Results

3.1. Quality and structure of the data

A total of 3842 observations were collected (Table 3), of which 72.2% and 27.8% were located offshore and inshore, respectively. The offshore observations mainly comprised of whaling and survey data (90.0% and 7.4%, respectively). The whaling data also made up a large part of the inshore observations (22.6%), but the majority of the inshore observations was from LEK (59.1%). Table 3 describes in detail the number of observations originating from the different data sources.

The 631 LEK observations were obtained from 58 participants, of which 40 (68.9%) were from the initial contact list of households, and 18 (31.1%) were from referrals. The initial 40 participants represented a 42.6% rate in participation, and the referrals represented a 72.0% rate. Over 22% (n = 13) of the participants resided in Stanley, while the remainder resided in 19 of the surrounding mainland and island settlements, with 1 to 4 participants from each settlement (Fig. 1); one participant resided on the local ferry. Only 3 participants (5.2%) were under age 30, with 31.3% of participants aged 30 to 50, 29.3% aged 50 to 64, and 24.2% older than 65. A majority of participants had spent their entire lives in the Falkland Islands, with over 46.6% having spent over 50 years on the Islands. Few participants (12.1%) had spent <10 years on the Islands. Most participants were familiar with marine mammals and could identify cetaceans by family (87.9%), but fewer were able to identify baleen whales to species (55.2%).

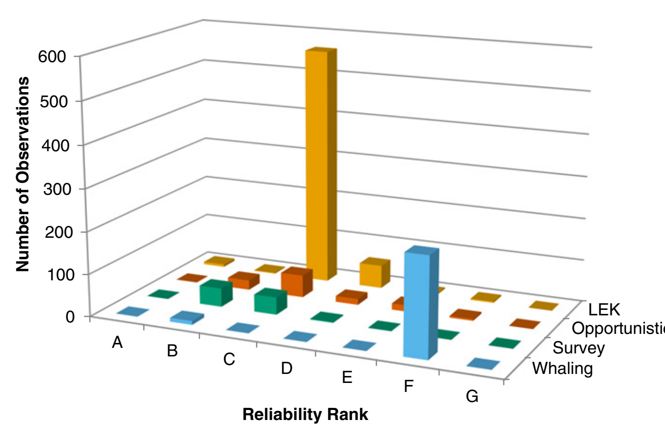

Fig. 2. Count of reliability ranks for inshore whale observations for each data type. Observations of ranks A to C represent the most reliable records used for analysis of species composition and observation hotspots.

In regards to reliability, most inshore observations were ranked C (61.4%) across all data types, while 30.7% of observations were unreliable (ranks D to F; Fig. 2). The most reliable observations (ranks A to C) covered the 1940s to 2015, and thus these were the years analysed.

3.2. Historical change in whale sightings in the inshore study area

A clear temporal pattern in whale observation numbers was observed from 1940 to 2015 (Fig. 3). Observation numbers since the 1940s were low, and decreased to none over the 1970s, and only three observations in the 1980s. The number of observations then increased by 5-fold in the 1990s, and by 11-fold in the 2000s. There was another notable increase between the 2000s and 2010s. However, as this later decade contained only 5 years (this study was conducted in 2015), it is likely that the increase will be much higher in that decade. There was also a change in the frequency of sightings in relation to the number of visits to an area, from only 7 observations classified as 'often' and 'always' in the 1990s, to 107 in the 2000s and 160 in the first 5 years of the 2010s.

Over 70% of interview participants could recall a time when whales were not seen in the Falkland Islands' waters, while 22.4% could not, and 6.9% were unsure. Further, 60.3% of participants stated that they noticed an increase in whale presence; 22.4% were unsure.

During the whaling era, the sum of whale observations within each 1 km^2 grid cell for most whales was low in most regions of the study area, with a maximum value of 4, and the cells with observations covered only 6.5% of the inshore study area (Fig. 4). The highest number of observations in the post-whaling era increased by up to 5-fold, and the grid cells containing whale observations covered a total of 44.9% of the inshore study area. Sei and fin whales showed the highest increase in observations and spread in the spatial distribution of observations.

3.3. Species composition

All data types indicated that the most abundant species in the Falkland Islands' inshore waters is the sei whale, constituting >60% of the species composition during the whaling era and 49.8% to 62.7% in the post-whaling era, based on LEK and empirical data, respectively (Table 4). Offshore, the most abundant species over both eras was the fin whale. However, the amount of fin whales observed in post-whaling years is still 36.9% less than what was seen in the whaling years. This is also the same case for the inshore composition of humpback whales when compared with the New Island data. During the whaling era, only 0.1% of observations were minke whales. Since the end of the whaling era, they have represented an increased percentage of observations at 24% (Table 4). Blue and southern right whales were the least

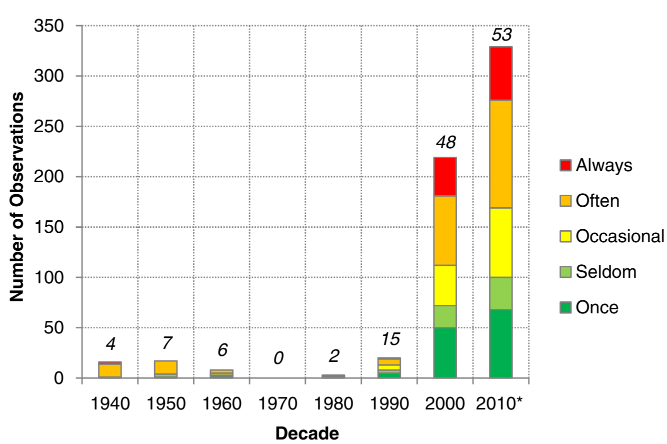

Fig. 3. Decadal trends in number of baleen whale observations, based on Local Ecological Knowledge (LEK), stratified by the frequency of sightings within the decade of each observation. Note that 2010 (*) only reports observations for 5 years (2010–2015), and therefore observation numbers may be much higher on a decadal scale. The italicised number (*n*), located above each bar, is the count of interview participants who provided observations for that decade.

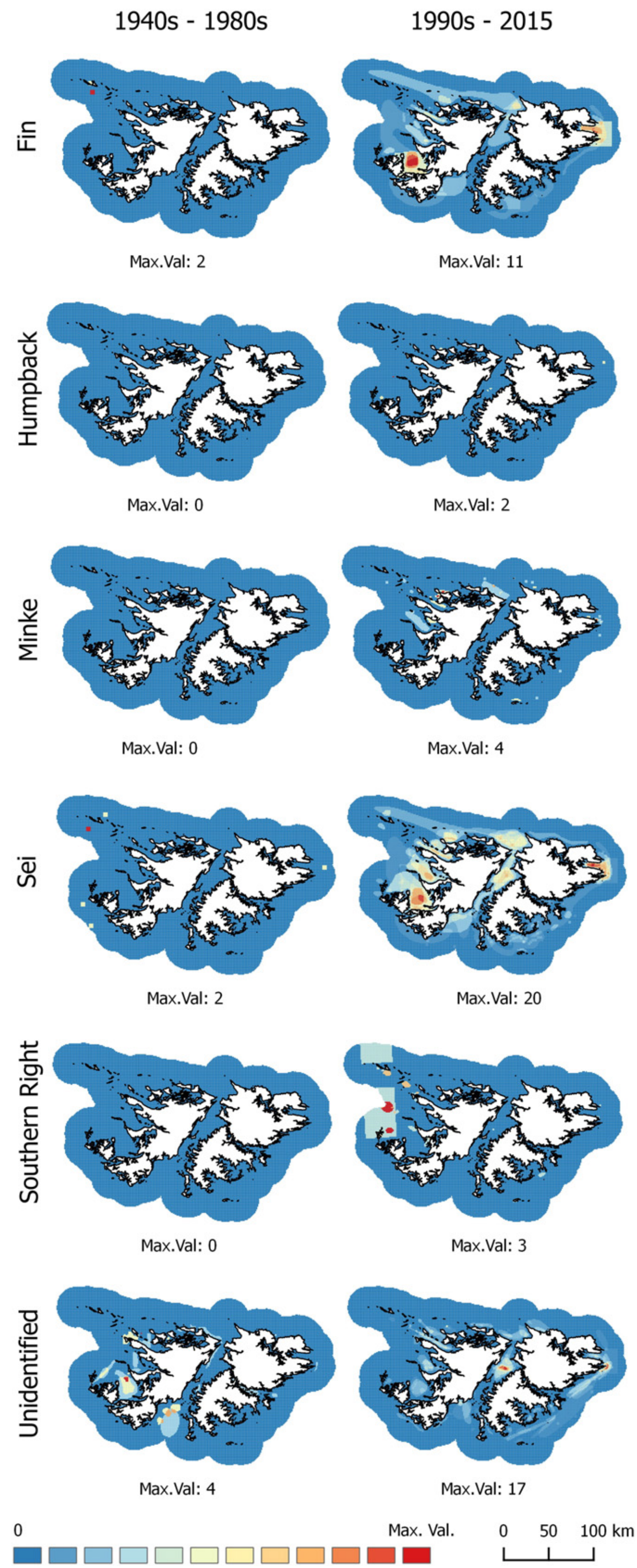

Fig. 4. Changes in the count of whale observations and their spatial distribution in the Falkland Islands' inshore waters between the whaling and post-whaling eras. 'Max. Val.' is the maximum number of observations within a 1 km^2 grid cell over the period. Each row shows results for a different species, as indicated on the left.

Table 4
Inshore and offshore species composition during the whaling and post-whaling eras. Additional inshore species composition is provided for New Island whaling station catch data from 1909 to 1915. No values indicate a complete absence in data.

	1905–1980s							1990s–2015						
Data types	Blue	Fin	Humpback	Minke	Sei	S. Right	Unidentified	Blue	Fin	Humpback	Minke	Sei	S. Right	Unidentified
Inshore														
Empirical data	–	25.0%	–	–	75.0%	–	–	–	25.6%	0.4%	6.1%	62.7%	2.7%	2.5%
Local ecological knowledge	–	–	–	–	–	–	100%	–	12.1%	0.2%	5.2%	49.8%	1.2%	31.6%
New Island only	1.1%	16.2%	12.5%	–	63.8%	0.1%	6.4%	–	–	–	–	–	–	–
Offshore														
Empirical data	5.3%	71.9%	–	0.1%	22.4%	0.2%	–	0.5%	34.9%	4.3%	24.0%	14.9%	3.5%	17.9%
Falklands' Waters														
All data	1.6%	28.3%	3.1%	–	40.3%	0.1%	26.6%	0.2%	24.2%	1.6%	11.8%	42.5%	2.4%	17.3%

abundant species across data types and years for both the inshore and offshore waters (<3%). Over 17% of the composition for each era contained unidentified species.

3.4. Seasonal change in whale observations

A seasonal pattern of whale observations in the inshore study area was revealed for all whale species (Fig. 5). These were consistent across data types and across all decades studied. Eighty-seven percent of inshore baleen whale observations were in the austral summer and autumn months (Fig. 5). All species had peak numbers of observations in March, except for the minke whale, which has been mostly observed in February.

3.5. Whale observation hotspots

Fig. 6a presents the distribution of all recorded inshore whale observations for the post-whaling era. The map displays hotpots of whale observations in seven regions, with the highest values (i.e. values of 20–34) within these regions covering 1.3% of the study area. Fig. 6b shows the distribution and intensity of visits as a proxy to the effort related to the hotspots. Over 19% of the study area had high effort (i.e. average visit value ≥4). Four out of the seven hotspot regions also correspond to these areas of high effort, and therefore exhibit high confidence.

4. Discussion and conclusions

In the absence of systematic survey data, the results from this study strongly suggest that there has been a post-whaling era return of baleen whales in the Falkland Islands' waters after an almost complete absence over the 1970s and 1980s. Endangered sei whales and fin whales are the main species that showed an extensive increase in sightings after the 1990s. This first-time collation of pre-existing data, along with recording and digitising of LEK, showed that not only has there been a resumed presence of whales in the area, but also a substantial recovery in species composition. Sei whales were found to have been the most successful. Fin whale numbers are also increasing, but the percentage of whale sightings that the species represents is still low compared to the percentage from commercial whaling catch data in offshore areas. It is also reflective of its population status for the rest of the southern hemisphere, as it is still in the midst of recovery after a 70% global decline over three generations (Reilly et al., 2013). The significant presence of minke whales in the post-whaling era, compared to their previous near absence, is also of interest, as Antarctic minke whales (*Balaenoptera bonaerensis*) are internationally classified as Data Deficient (IUCN; Reilly et al., 2008). This species, as opposed to the common minke whale (*Balaenoptera acutorostrata*), could be what is currently being observed in the Falkland Islands' waters, but this has yet to be confirmed (Otley, 2008). The species identified in our study also mirrors the species composition derived from a previous stranding study (Otley, 2012) and historical descriptions (Hamilton, 1952).

In the absence or lack of empirical data, LEK has previously been used to understand population statuses and abundance (Anadón et al., 2009; Nash et al., 2016). In the case of the Falkland Islands, LEK was essential in understanding temporal changes in whale presence and composition because the only existing empirical data were from commercial catch data mainly focused offshore, or from sporadic survey events that were not consistent in methodology, sampling area or seasons. Using LEK thus provided the opportunity to use a uniform and dedicated methodology to compare sighting rates across decades. The high success rate in participation has also allowed us to gain knowledge from expert residents across the Islands; it contributed to the high distribution of inshore observation effort over decades. This large amount of spatial coverage also led to an increased confidence in the observation hotspots that we identified. The recording of LEK is also important to ensure that this knowledge is not lost, as the generation who has witnessed the whale recovery from the whaling era is becoming older. The starting point of this study was a retired local FIGAS pilot, who mentioned that in the 1980s he saw his first whale and decided to record his sightings because it was something so special. He then concluded that, just over 10 years later, he stopped because there were too many whales to take notes while flying. No scientific study monitored this phenomenon, but recording and analysing LEK allowed us to use such unique information in a scientific context, along with information from many other local residents, to describe this whale recovery.

Increasingly, standard protocols are being created to make use of LEK for ecological and conservation studies (Biró et al., 2014; Davis and Wagner, 2003; Huntington, 2000). Our method of assessing the participants' ability in species identification, mapping their hand-drawn observations into a GIS, and subsequently combining the observations with the empirical dataset through reliability ranking, could be applied to future studies. In other LEK studies, the reliability of LEK data is assessed at the level of the participant or expert (Davis and Wagner, 2003). Here, although we initially assessed each participant, we further assessed LEK at the observation level, allowing for a range of reliability, ranked according to experience, understanding of the mapping task, and verbal cues on the accuracy of each memory. We suggest that for future studies where the local experts are initially unknown, this concept could be adopted to make the most use of all attainable information, despite the amount of experience each participant offers. Ranking each observation also allows for the LEK dataset to be homogenised with other existing data. There are also benefits in obtaining LEK from as many participants as possible, as opposed to relying on the knowledge of one or few key experts in the community (Olsson and Folke, 2001).

Similar to the Falkland Islands, there may be other small islands or remote communities where wildlife recovery has been occurring, but no scientific studies took place. We have thus reiterated that a lack in empirical data does not imply a lack in historical knowledge to detect patterns of wildlife recovery or decline (Ziembicki et al., 2013). By using LEK with the supplement of existing empirical data, we showed similar patterns to other studies on baleen whale recovery

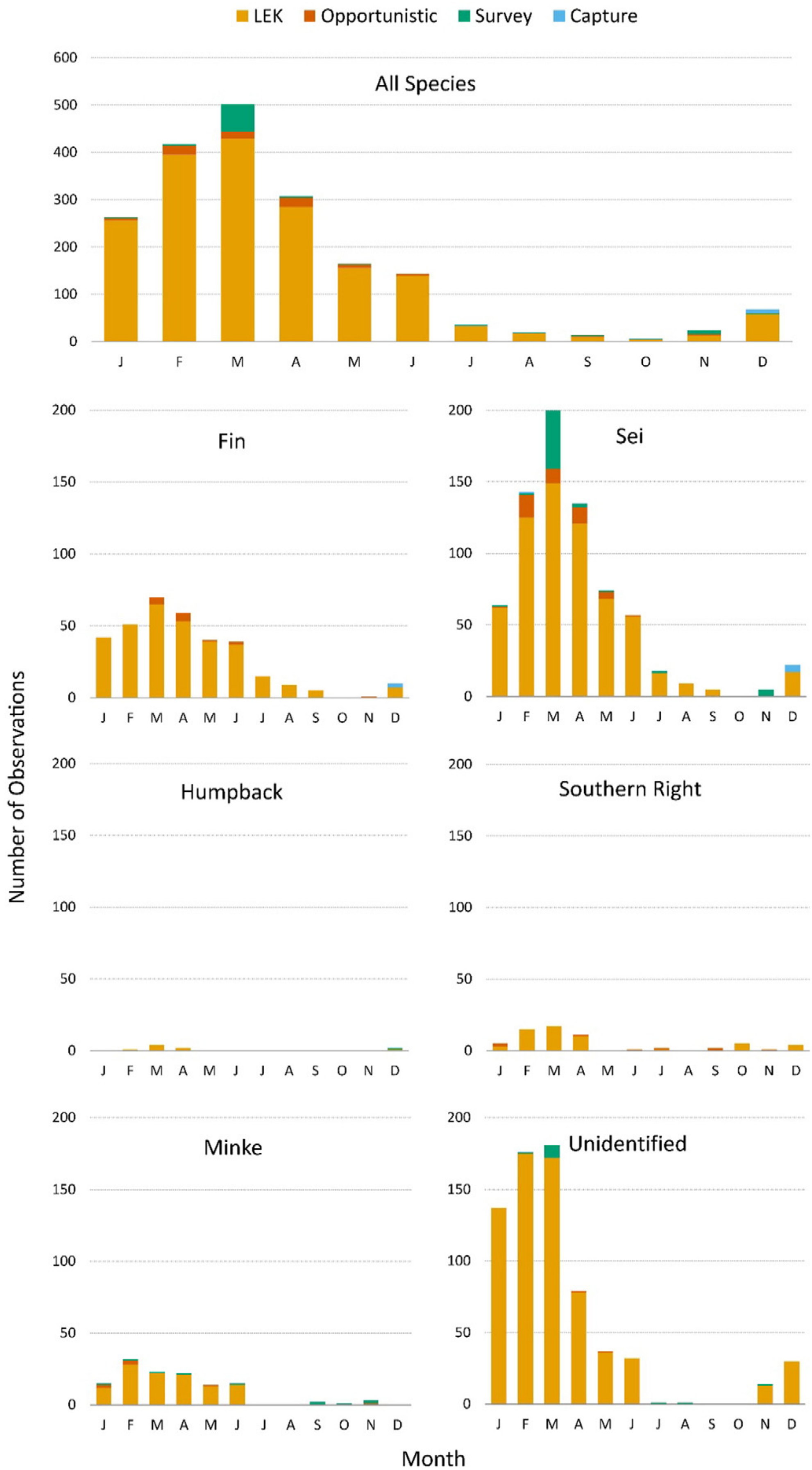

Fig. 5. Seasonal occurrences of baleen whales in the Falkland Islands' waters.

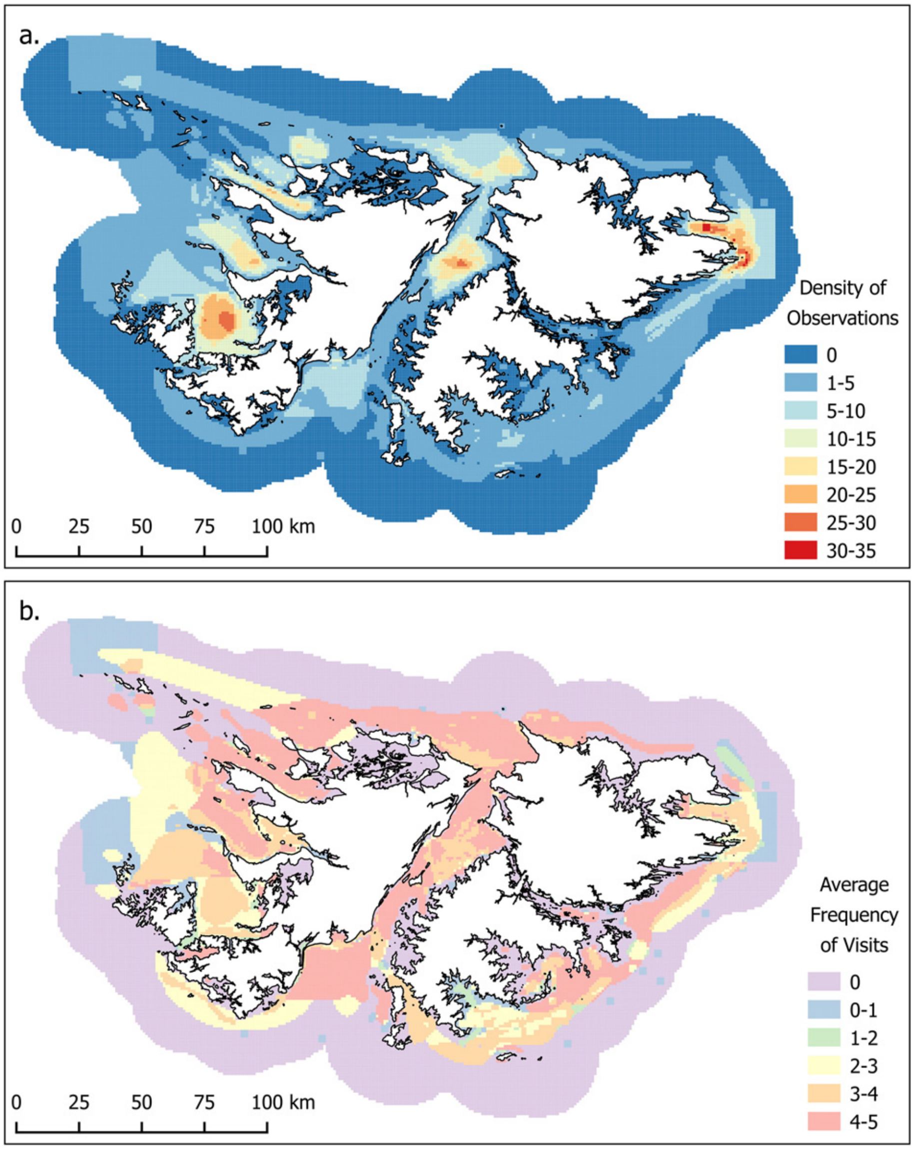

Fig. 6. Hotspots of whale sightings in the post-whaling era (a) and relative observation effort based on the frequency of visits to an area (b).

worldwide—including in other areas of the South Atlantic—since the 1990s (Carroll et al., 2014, 2015; Richardson et al., 2012). Similarities between LEK and empirical findings have also been seen in other assessments of population recovery (Service et al., 2014). There are, however, limitations to using LEK.

As with other LEK studies, a limitation of the knowledge gathered here is that it is based on one's memory (e.g. Coll et al., 2014). To limit such bias, we asked for more generalised, decadal, observations to be drawn by the participants, as opposed to specific sighting events. As this consequently created a much coarser temporal resolution, we also used verbal cues of visits to an area to quantify sighting effort across time, which helped to prioritise amongst the observations to define hotspots. As the quality of the results was dependent on the quality of the data gathered, filtering by reliability served as a way for only the most reliable occurrences to be used (Frey et al., 2013). The reliability ranks further allowed for the LEK data to be incorporated with the pre-existing empirical data. We also had to limit the sample area to the inshore waters (as opposed to the entire EEZ) for the interviews, as the Falkland Islands' landscape provided points of reference for the participants, and few participants were offshore marine users. Further, as cetaceans have different surfacing behaviours (i.e. some are more elusive than others), it is possible that the likelihood of observing each species could vary, so the presence of some species could have been emphasised more than others. Finally, what we have been able to identify here are observation hotspots, and as such, there may be other hotspots that are unidentified here due to lower visit frequencies (i.e. effort) in some areas. Despite these limitations, our study provides essential pioneer information on the whaling and post-whaling era presence of baleen whales in the Falkland Islands' territorial waters, and the dataset that has been created here can be useful for other studies and management initiatives.

As the Falkland Islands is in the midst of economic development, threats to marine mammals are increasing. It will be important for future development not to impede the recovery of these species, as it has been shown that precautionary management could ensure the cohabitation of maritime activities and marine mammals (e.g. Augé et al., 2012). However, at this point in time, there is no cetacean monitoring program in place. The data collected in this study and the results can thus be used as a guideline for future cetacean monitoring. For example, the hotspots identified near the coastline through LEK could be selected as areas for land-based surveys (Grech et al., 2014). The seasonal patterns identified in this study could also be used to select the times of year to conduct such surveys. Until such monitoring occurs, the data collected here could also be used in a predictive niche model to determine habitat suitability and preference for the inshore and offshore waters.

In conclusion, baleen whale populations are increasing around the world; our study is the first documentation of such an increase in the Falkland Islands' waters. Sei whales and fin whales are the two main species with indication of significant recovery in numbers, principally in inshore and offshore waters, respectively. With increased maritime use and development around the Islands, potential threats will increase, such as ship strikes, habitat loss, accidental bycatch, and pollution (noise, plastic, or chemical; Otley, 2008). The findings from this study should serve as an encouragement for future studies in these waters, as well as highlight the need for the local government to establish a cetacean monitoring program. The large success rate in participation in this study, as well as feedback received during the interviews, also indicate that monitoring through citizen science could be a possibility. Until further studies take place, marine spatial planning can use the information provided to inform management and limit negative interactions between increasing whale numbers and activities such as shipping. The historical data presented here can now be used to manage the future.

Acknowledgements

We would like to give our most profound gratitude to all the Falkland Islands' residents who took the time to do an interview, including for all the discussions that ensued about their experience with whales around the islands and their enthusiasm for our research. The Falkland Islands Museum and National Trust Archives are also thanked for providing documents, guidance and office space to search these. Whaling and sighting databases were accessed thanks to the cordial and helpful staff in each organisation (Cherry Allison and Marion Hughes, IWC; Mark Lewis, JNCC; Andy Black, GSGSSI; Grant Munro and Sarah Crofts, Falklands Conservation; Joost Pompert, Falkland Islands Fisheries Department; Tomio Miyashita, National Research Institute of Far Seas Fisheries). We also thank Will Rayment (University of Otago), two anonymous reviewers, and the editor for providing helpful feedback on the manuscript. We are also grateful to graphic designer, Bryan A. Frans (beazietheartist.com), for contributing the graphical abstract accompanied with the digital version of this paper. The study was funded by the Falkland Islands Government Environmental Studies Budget and the Darwin Initiative (Darwin Plus project, 'Marine Spatial Planning for the Falkland Islands'; grant number DPLUS027).

Appendix A

The raw data and results from this study have been stored at the South Atlantic Environmental Research Institute Information Management System—Geographic Information System (IMS-GIS) Data Centre. Metadata can be found in the online catalogue (http://www.south-atlantic-research.org/metadata-catalogue; search term: 'whales') and data are available upon request.

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