SC/66b/SH/28

Research update on satellite tracking studies of the Arabian Sea humpback whales in the Sultanate of Oman.

Andrew Willson, Robert Baldwin, Salvatore Cerchio, Tim Collins, Ken Findlay, Howard Gray, Brendan Godley, Suaad al Harthi, Amy Kennedy, Gianna Minton, Fed Sucunza, Alex Zerbini and Matthew Witt.

INTERNATIONAL WHALING COMMISSION

Research update on satellite tagging studies of the Arabian Sea humpback whales in the Sultanate of Oman

A. Willson[1,2,3], R. Baldwin[3], S. Cerchio[4], T. Collins[5], K. Findlay[6], H.Gray[7], B. J. Godley[1], S. Al-Harthi[8], A. Kennedy[9], G. Minton[10], F. Sucunza[12], A. Zerbini[9,13], M. J. Witt[1]

[1] *Environment and Sustainability Institute, University of Exeter, Penryn Campus, Cornwall, UK*
[2] *Centre for Ecology and Conservation University of Exeter, Exeter, UK*
[3] *Five Oceans Environmental Services, PO Box 660, PC131, Ruwi, Sultanate of Oman*
[4] *New England Aquarium, USA*
[5] *Wildlife Conservation Society, Ocean Giants Program, 2300 Southern Blvd, Bronx, NY 10460-1099, USA*
[6] *Centre for Sustainable Oceans Economy, Cape Peninsula University of Technology, South Africa*
[7] *School of Biological and Biomedical Sciences, Durham University. UK*
[8] *Environment Society of Oman, PO Box 3955, PC 112, Ruwi, Sultanate of Oman*
[9] *Marine Mammal Lab, Alaska Fisheries Science Centre, Seattle WA, USA*
[10] *Megaptera Marine Conservation, Netherlands.*
[11] *Cascadia Research Collective, Olympia, WA, USA*
[12] *Instituto Aqualie, Rio de Janeiro, Brazil*
[13] *Cascadia Research Collective, Olympia, WA, USA*

Abstract

Three surveys focusing on Arabian Sea humpback whales (*Megaptera novaeangliae*) were conducted from two field sites off the southern coast of Oman between February 2014 and December 2015. We present a summary of boat-based survey data and satellite telemetry activities generated by these surveys. Our findings provide insight into the spatial ecology of Arabian Sea humpback whales (ASHW) and salient threats to the population. Ninety hours of on-effort vessel-based surveys resulted in 29 sightings of ASHW groups. Analysis of fluke and dorsal fin images indicates that these sightings involved 40 different individuals. Tagging efforts resulted in successful deployment of nine satellite tags, six of which provided data on dive behaviour and vertical distribution within the water column. Tagged whales that were resighted (n = 5) during subsequent surveys exhibited signs of healing following tag rejection. Satellite tracking data reveals whales ranging within a 1,150 km corridor along the southern coast of Oman and northern Yemen, the first transboundary movement recorded for this population. Individuals spent an average of 83% (SD = 17%) of their time engaged in localised or 'area restricted search' (ARS) that is likely associated with foraging, breeding and resting behaviour. Tracked individuals spent much of their time over the continental shelf with 73% of satellite-derived locations attributed to waters <200 m depth. Gathered dive data reveal that tracked whales spent 83% of time in the top 20 m of the water column, most frequently (39%; SD = 11%) engaged in dives with durations between 5 and 10 minutes. The average maximum depth recorded by the tags was 199 m (SD = 95 m). Further spatial analysis indicated that 35% of location points in the study were within the Gulf of Masirah, habitat that co-occurs with emerging industrial activity and existing artisanal fisheries. Dive behavior in offshore waters beyond the continental shelf also likely indicates foraging activity. The growing knowledge base for this population supports need for on-going research and putative mitigation measures to address a wide spectrum of anthropogenic threats for humpback whales in Oman and the wider region.

Introduction

Reeves *et al.* (1991) and Mikhalev (1997) were the first to postulate the hypothesis that the humpback whales found in the Northern Indian Ocean form an isolated, non-migratory, population. Further work conducted in Oman led to the designation of this population as 'Endangered' on the International Union for the Conservation of Nature (IUCN) Red List based on a mark-recapture population estimate of 82 individuals (95% CI 60-111; Minton *et al.* 2008). Recent genetic analysis supports the isolated status of these whales and indicates that they diverged from Southern Hemisphere populations ~70,000 yrs BP (Pomilla, Amaral *et al*. 2014). The population is demonstrably vulnerable to anthropogenic threats (Baldwin *et al.* 1999, Minton *et al.* 2008; Baldwin *et al.* 2010), with evidence that fishing, commercial vessel traffic and oil and gas exploration and production are increasing within habitats associated with higher whale sighting densities (Corkeron *et al*. 2012; Willson *et al*. 2014).

Boat-based surveys conducted between 2000 and 2012 focused on two main study areas off the coast of Oman, the Gulf of Masirah and the Hallaniyats Bay[1], (Figure 1). Genetic sampling of ASHW's and behavioural cues (e.g. singing or the presence of a calf) observed at these sites indicated a near parity of males and females in the Gulf of Masirah and a male bias in the Hallaniyats Bay (Minton et al 2011, Willson et al 2014). Feeding was observed in both of these areas during February-March surveys in the Hallaniyats Bay and October-November surveys in the Gulf of Masirah. However, limitations to the timing and geographical coverage of previous surveys led the IWC to recommend further investigation of this population, including the use of satellite telemetry techniques (IWC, 2011).

State space behavioural movement models used to analyse location data collected from satellite tagged animals have become an important tool to analyse data and can provide additional insight on the spatial ecology and habitat use of animals and may contribute conservation planning activities (Jonsen et al., 2007). These models are useful given their ability to model statistical noise and observation error (Breed et al., 2009); they are able to determine behaviour modes and as such can capture plausible behavioural states (e.g. transiting and area restricted movement). Biotelemetry data collection platforms instrumented with pressure sensors have also been used to evaluate diel patterns of feeding activity (Friedlander et al., 2013) and to investigate whale foraging behaviour to prey abundance and distribution (Goldbogen et al., 2013). Garrigue et al., (2015) used location outputs from a SSSM to evaluate areas of higher usage by calculating occupancy times of animals within grid cells.

The IWC Scientific Committee endorsed the use of satellite telemetry to study humpback whales in the Arabian Sea in 2013 according to a set of preconditions (IWC, SC/65a/ Rep1, Annex H). Research updates on the first two seasons of work have since been delivered to the IWC Scientific Committee and analyses of habitat utilisation were identified as critical for the development of measures to mitigate existing and emerging anthropogenic threats to ASHW (Willson *et al.* 2013, 2014). Here we present a research update from three ASHW tagging surveys from southern Oman, including analysis of whale movements and habitat utilisation, spatial and temporal analysis of dive characteristics and the priorities for future research and management within the context of research findings.

Methods and Materials

Boat surveys

Two boat-based surveys took place in the months of February and March in 2014 and 2015, and were conducted from a base camp situated at Ra's Hasik (Hallaniyats Bay) on the Dhofar coast. A third survey was conducted from a live-aboard vessel during the last 2 weeks of November (2015) in the Gulf of Masirah (GoM) (Figure 1). Surveys were coincident with peak breeding on the Dhofar coast and at the beginning of the breeding season in the GoM (Mikhalev 1997; Minton *et al.*, 2010; Corkeron *et al.*, 2012). In the first two surveys observers worked from two 6.5 m rigid hulled inflatables (RHIBs), and searched for whales using paired saw-tooth transects in near-shore waters. In the third season search effort included the use of a 28 m traditional fishing boat (dhow) flanked simultaneously (at a distance of 3 km) by the same pair of RHIBs navigating parallel line transects. Survey methods were consistent with previously used protocols (Minton *et al.*, 2010; Corkeron *et al.*, 2012; SC/65a/SH06) although offshore effort along the Dhofar coastline was restricted due to piracy concerns. Due to low whale densities and the need to locate whales for satellite tagging, search effort in the Hallaniyats Bay was also supported by cliff-top observers guiding vessels to sightings via VHF radio. Omni-directional dipping hydrophones (High Tech Inc., HTI-96) were also employed in both survey areas to guide research vessels towards singing males. During tagging work each vessel had a clearly defined role; one RHIB was dedicated to the application of satellite tags (crewed by tagger, biopsy specialist, cameraman and driver) and the other acted as a support and safety vessel for the overall mission. Each vessel utilised pre-agreed protocols for reducing risk during tag deployment. In the GoM the dhow acted as the primary search vessel and continued search effort while other vessels were engaged with tagging or biopsy work.

Whale encounter data collected from a seismic survey in the Gulf of Masirah conducted in December 2015 was used to guide the timing and location of satellite tag deployments. Marine mammal observers collected sightings location data and photographs from humpback whale encounter between 23rd of November and the 29th of December 2015.

[1] Referred to locally as the *Ghubbat ad Dawm* and previously as *Kuria Muria Bay*

Satellite tag design and deployment

The Argos satellite platform terminal transmitters used in this study were manufactured by Wildlife Computers (Redmond, WA, USA). In 2014, SPOT5 tags were deployed, and in 2015, SPLASH10 tags, which incorporate a pressure sensor for recording dive profile information, were used. For both models, each transmitter is contained within an implantable, cylindrical steel housing. Tags and their associated housings are designed to penetrate the epidermis and blubber of the whale. Target location for tag insertion was the area of the flank just forward of the dorsal fin. Tags are anchored in the fascia (variable muscle and connective tissue matrix) that underlies the blubber. Tag retention is maintained by two sets of passively deployed barbs that release once the tag is embedded. All external components are made of surgical-grade stainless steel and tags were sterilised using ethanol and stored in a sterile box prior to deployment. Tagging and survey activities were carried out under permit from the Oman Ministry of Environment and Climate Affairs.

Once sighted, humpback whales were approached for the collection of identification images (tail flukes and dorsal fins) and other pertinent data. Images were compared *in situ* using an electronic version of the Oman humpback whale photo-ID catalogue (including sighting history, biopsy and sex data - where available). The decision on whether or not to tag encountered whales was subject to a set of evaluation criteria, including the apparent health and positive identification of the individual against the humpback whale photo-identification catalogue. Mothers with calves and juveniles were avoided. If the animal met with predetermined criteria attempts were made to deploy a satellite tag on the animal, typically during the final surfacing prior to a dive in order to ensure maximum exposure of the dorsal/flank area. Tag deployment was carried out from the modified bow of the tagging RHIB at distances of five to eight metres with a pneumatic tag application system (a modified version of the Air Rocket Transmitter system 'ARTs', Heide-Jørgensen *et al.* 2001). A biopsy was collected simultaneously using a crossbow and modified dart (Lambertsen 1987). Video and photographic records were collected throughout the tagging process; vessels followed tagged whales for a minimum of one hour after each tagging event in order to record behaviour and to further photograph implanted tags. Satellite tagged whales that were resighted on subsequent days were approached for additional photographs to record information on any movement of tag at the site of insertion or local tissue responses (e.g. inflammation, erythema).

Data Collection

Satellite tags were configured based on advice from the Marine Mammal Laboratory, (Alaska Fisheries Science Center) and product manufacturers. In 2014, tags were programmed to deliver up to 700 transmissions per day. Tag programming was modified during 2015 and was based on realised tag performance in 2014. A primary consideration was the addition of a depth/pressure sensor requiring increased data transmission and associated power demands. The pressure sensor was programmed to provide time at depth, depth time-series and depth behavioural log information. Tags deployed in 2015 were programmed to achieve a maximum of 400 transmissions per day. Transmission periods were programmed to coincide with Argos satellite overpasses, with three periods, four-hours in duration, set on a daily schedule. The daily transmission schedule of tags deployed in the first two field seasons (2014) was modified to every other day from the 31st of May onwards with the objective of maintaining sufficient power to capture movements during the southwest monsoon period (May-September) if tag life extended into this period. Humpback whale spatial data during the monsoon is limited as high sea-states preclude small vessel surveys.

Data Processing – Best Daily Location

Processing of tag location data into a single *Best Daily Location* (highest spatial accuracy) format was performed to enable pairing of dive behaviour data and thus provide spatial reference to for these data each day.

Spatial datasets of humpback whale distribution and movement were generated from location data received from the Argos System. Location data were filtered using R (R Development Core Team 2013). Argos locations with spatial error classes '0' and 'Z' were removed. Locations occurring on land were similarly removed. Implausible locations based on speed and turning angles were removed through the 'sdafilter' from the package 'argosfilter' (Freitas *et al*., 2008). The default parameters of this package were used apart from the speed, which was set to 3.33 $m.s^{-1}$ ($12 km.hr^{-1}$) based on plausible maximum speeds of humpback whales reported by Garrigue et al. (2015).

Combined best daily location data from all individuals were plotted and enumerated using the ArcGIS point count tool using a hexagonal cell grid (25 km minimum diameter).

Data Processing – Switching Space State Modelling
To process satellite location data using a Bayesian approach we selected the behaviourally switching space-state model (SSSM) developed by Jonson (2005) and modified by Breed (2009) as it uses data from the speed and turning angles of the tag track (related to behaviour) to predict the probability of an animal being found at a certain location (Jonson et al., 2003). This process yields more accurate estimates of locations and the uncertainty in those locations than the raw tracking data. To prepare data for the model an automated script was applied to all files using R (R Development Core Team 2013). Location class (LC) fields were filtered with Z and 0 removed, but no subsequent filters were applied (e.g. speed and turning angle filters).

We used R v.3.2.3 (R Core Team) and WinBUGS v1.4 (Bayesian inference using Gibbs Sampling) for SSSM. Modelling parameters were estimated by Markov Chain Monte Carlo methods using Argos-derived locations from each tag. The procedure generates a model of observation error and a mechanistic model of animal movement that are solved simultaneously during processing of the data (Jonsen et al., 2005). A correlation random walk model is used within this process that switches between two behaviour states; state 1 relating to 'area restricted search' (ARS) behaviour and state 2 to transient behaviour. ARS is suggestive of foraging, resting or breeding behaviour (Bailey et al. 2009). States were based on four parameters including; mean turning angle ARS, mean turning angle transiting, autocorrelation in speed and direction for ARS and transiting behavior. A conservative approach was applied to assigning mean model values split between three classification states; state '1' related to values between 1 and 1.25, and state '2' to values between 1.75 and 2. Resulting SSSM locations assigned behavior values between 1.25 and 1.75 were classified as undetermined behavior (Garrigue et al. 2015). The duty cycle (operational periods) of tags and temporal gaps between received locations were considered in test runs of the SSSM resulting in the selection of a time step interval of 12 hours. The model was run with 2 MCMC chains for 10,000 iterations after a burn in of 5000 (Rosenbaum et al., 2014).

Processed Pressure Sensor Data
The SPLASH10 satellite tags were programmed to generate histogram data for time at depth, dive counts within predefined depths and dive counts within predefined periods and were summarised at a 24 hour resolution (Table 1). These tags were also programmed to record dive behaviour, expressed as the shape of dive profiles as either 'V', 'U' or square shaped. Processed data were stored on board the tag for a maximum of 2 days for transmission. Dives were assigned when recorded depths exceeded 15 m for a period greater than 1 minute.

Table 1 Configuration of pressure sensor histogram data collection in the SPLASH MK10 tags.

Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time at depth (m)	10	20	30	40	50	75	100	125	150	200	250	300	350	>350
Dive duration (min)	2	3	5	10	15	20	25	30	>30	/	/	/	/	/

Results

Effort and Sightings
On-effort vessel surveys within each region (Figure 1) and season ranged between 22 hours and 44 hours covering between 362 km and 594 km (Table 2). In total, 87 'primary' sightings of humpback whales were made over the course of three surveys with the highest number recorded between 11th-28th of February 2014 (n=47), and the highest number of individuals (n=21) during the November survey within the Gulf of Masirah.

Sighting rates by hour and by kilometre presented in the table are not directly comparable due to the use of shore-based search effort to detect whales during the first two surveys and the addition of the larger survey vessel to support the two smaller RIBs during the last survey in November 2015.

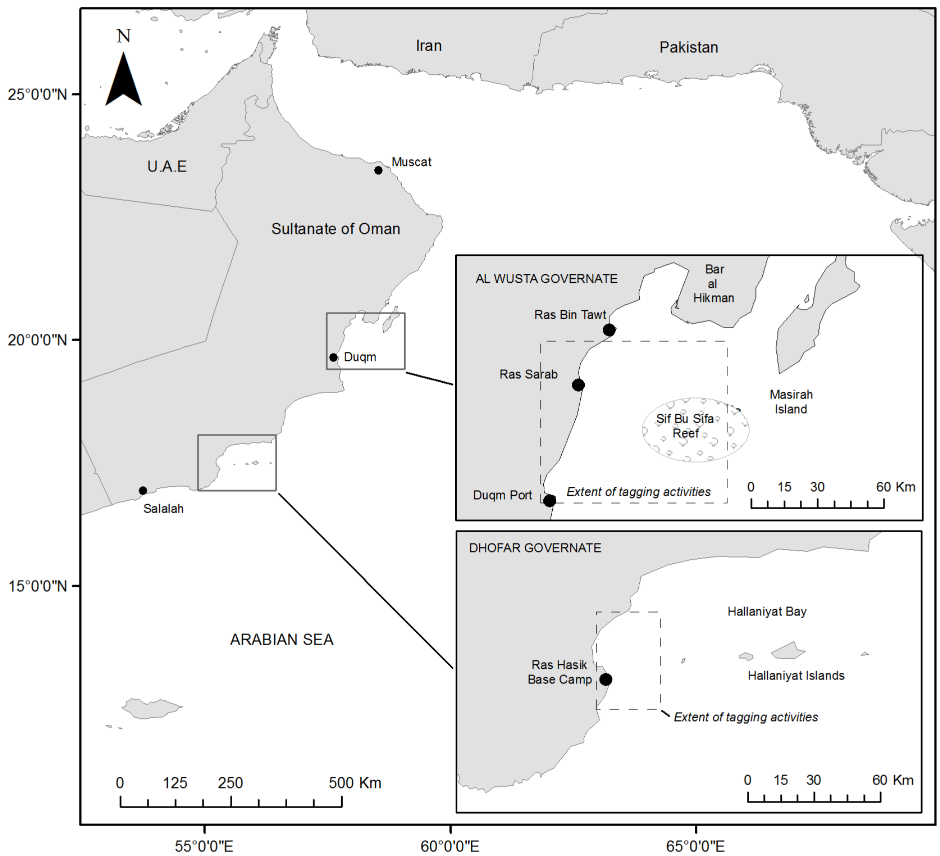

Figure 1 Location of tagging activities from a base camp in Hasik (February 2014 & 2015) and mobile research vessel in the Gulf of Masirah (November 2015) mobalised from Port of Duqm.

Table 2 Summary of vessel effort and all sighting information (vessel and shore based) for each field season in 2014 and 2015.

Survey Dates	Survey Location	Time on effort (hours)	Distance on effort (km)	Total Number of 'primary' sightings *	Number of on-effort 'primary' sightings	Number of Individuals
11 – 28 Feb 2014	Hasik	23.65	361.99	47	11	11
17 Feb – 19 Mar 2015	Hasik	21.8	422.84	14	4	8
23 -30 Nov 2015	Gulf of Masirah	43.6	593.7	26	14	21

*Includes shore based sightings

Genetic sample collection

A total of 16 successful biopsies and 5 sloughed skin samples were collected across all periods. This includes a sample from each of the whales instrumented with satellite tags, Table 3. These samples were pooled with a further 33 samples collected since 2006 and are being processed by WCS at the American Museum of Natural History.

Table 3 Summary of samples acquired for genetic analysis during each field season in 2014 and 2015.

Survey Dates	Survey Area	Biopsy Sample	Sloughed Skin Samples
11 – 28 Feb 2014	Hasik	3	4
17th Feb – 19 March	Hasik	4	0
23 -30 Nov 2015	GoM	9	1

Tagging activities

Five known males were tagged between the 21st and 28th of February in 2014 and three additional known males between the 10th and 14th March 2015 at the Hasik field site. A further three animals were tagged in the GOM between the 21st and 23rd of November 2015, two of which had not previously been encountered and were of unknown sex, (Table 4). One animal tagged in 2015, OM02-019, was also tagged in 2014 (the opposite flank). Nine of eleven tags were optimally placed below the dorsal fin.

Animals tagged off Hasik were all known males, occurring either as single individuals or in adult pair social categories. All whales reacted to tagging, with displays including tail slaps, quick dives and in two cases breaching (whales OM01-006 and OM15-004). Four animals in the study were singing prior to tagging and resumed this behaviour within 20 minutes of tag deployment.

Operational periods for tags ranged from 1 to 163 days duration. Two tags did not implant sufficiently and detached on the day of deployment; these were excluded from subsequent data processing and analyses. The average operational period was 56 days (SD = 44; n = 9). Satellite tags provided usable locational data for 330 cumulative tracking days (as determined by 'best daily location' processing). A summary showing the seasonality of tag deployments (**Table 5**) reveals that tag operation has been most limited (<2 tags) between July and October, a period that coincides with adverse weather during the summer monsoon. Comparison of these constraints with data gaps indicates that any future tag deployments would be best in either April or September.

Table 4 Summary of tag deployment and encounter details (sex determined by molecular identification or behaviour).

Argos PPT Number	Whale Permanent ID Code	Deployment Date	Deployment Location	Sex	Social Category	Tag Longevity (days)	Best daily location point count
121192	OM02-020	21/02/2014	Hasik	Male	Adult Pair	1	NA
87759	OM11-002	23/02/2014	Hasik	Male	Single	1	NA
87624	OM14-013	22/11/2015	GoM	Male	Single	18	18
120952	OM15-004	23/11/2015	GoM	Unknown	Single	23	22
87777	OM01-014	10/03/2015	GoM	Male	Adult Pair	25	23
87766	OM02-019	25/02/2014	Hasik	Male	Adult Pair	41	102
121194	OM00-003	28/02/2014	Hasik	Male	Single	42	45
121193	OM10-001	22/02/2014	Hasik	Male	Single	55	44
120951	OM15-002	21/11/2015	GoM	Unknown	Adult Pair	62	54
81126	OM02-019	13/03/2015	GoM	Male	Adult Pair	77	66
87625	OM01-006	14/03/2015	GoM	Male	Adult Pair	163	147

Table 5 Summary of seasonality of tag deployments to evaluate temporal gaps in the telemetry dataset. Blue cells indicate months in which tag data has been successfully collected. Sea-state conditions favorable to tagging are noted as good (green), moderate (orange) and adverse (red).

Tag Location	Tag Number	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Halaniyats Bay	121192												
	121193												
	87759												
	87766												
	121194												
	87777												
	81126												
	87625												
GoM	120951												
	87624												
	120952												
No. of active tags		2	3	6	6	2	2	1	1	0	0	3	3
Suitable tagging conditions													
Preferential deployment dates					Y					Y			

Resighting events of tagged individuals

Satellite tagged animals (n = 5) were resighted on 20 occasions within the survey period of initial tag deployment, and on 16 occasions in surveys subsequent to tag deployment (Table 6). These re-sighting events provided photographic evidence of tag penetration and movement in the hours and days after tagging as well as evidence of healing in subsequent surveys. Photographic records and metadata are undergoing detailed analysis.

Table 6 Number of resighting events of whales after tagging within surveys (boxed), and for subsequent surveys (unboxed).

Tagging Season	Whale Permanent ID Number	Re-sighting Season			
		Feb 2014	Seismic Survey Nov-Dec 2014**	Feb-Mar 2015	Nov 2015
Feb 2014	OM02-020	10	1	1	2
	OM10-001	7	0	5	0
	OM11-002	0	0	0	0
	OM02-019	0	1	2	1
	OM00-003	2	0	0	2
Feb-Mar 2015	OM01-014	/	/	0	0
	OM02-019	/	/	0	1
	OM01-006	/	/	0	0
Nov 2015	OM15-002	/	/	/	0
	OM14-013	/	/	/	1
	OM15-004	/	/	/	0

** Photographs were opportunistically taken by a Marine Mammal Observer (MMO) during a seismic survey that took place in the Gulf of Masirah between 30 November and 29 December 2014. While the quality of photos was not of the same standard as those taken during dedicated whale surveys, some photos allowed for recognition of tagged individuals.

Switching Space State Modelling
SSSM analysis revealed that tracked whales spent an average of 83% time (while being actively tracked) in ARS mode and 2% in transient mode. Undetermined behaviour accounted for 15% of the total deployment time of all tags (Table 7). Three whales (depicted in plots C, G and H below) spent 100% of their time in ARS state, with no whale engaging in transiting behaviour for more than 9% of the deployment period.

SSSM-derived location data revealed that seven out of nine tagged whales ranged between the GoM and Halaniyats Bay (Figure 2). Males tagged in February and March of 2014 and 2015 moved northwards from the Hallaniyats Bay after tagging. Whales G and I (Figure 2) tagged in the GoM in November remained in this area with whale H (Figure 2) swimming to the Halaniyats before returning to the GoM. All whales predominantly moved over the continental shelf (light grey background shading). The most wide ranging animal (individual F) moved between the east coast of Masirah Island and Yemeni waters. This whale was also associated with the highest proportion of time in transient mode (9%) and is the first definitive transboundary movement identified for whales in this population.

Table 7 Summary results of switching state space model classified into three behavior modes; ARS (1-1.25), unsure (1.25-1.75) and transient (1.75-2).

Individual Code	**Permanent ID Number**	Point Count			Percentage		
		Restricted Area Search	Unsure	Transient	Restricted Area Search	Unsure	Transient
A	OM00-003	55	23	0	71	29	0
B	OM10-001	84	17	5	79	16	5
C	OM02-019	17	0	0	100	0	0
D	OM02-019	24	21	0	53	47	0
E	OM01-014	186	6	2	96	3	1
F	OM01-006	206	83	29	65	26	9
G	OM15-002	33	0	0	100	0	0
H	OM14-013	41	0	0	100	0	0
I	OM15-004	96	16	9	79	13	7
		Standard Deviation			17	16	4
		Average			83	15	2

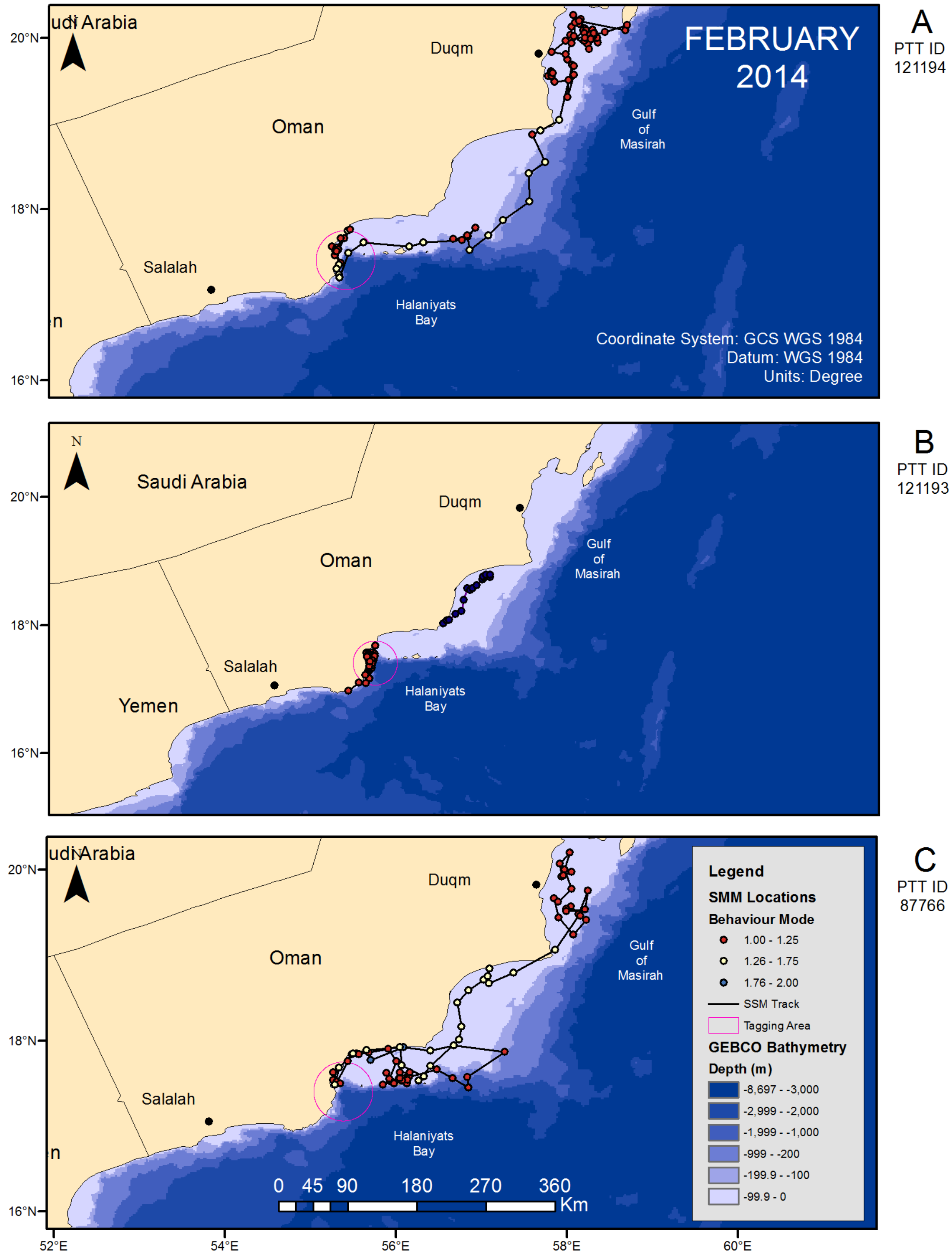

Figure 2 Switching state-space model (SSSM) derived locations and tracks for whales instrumented in February 2014.

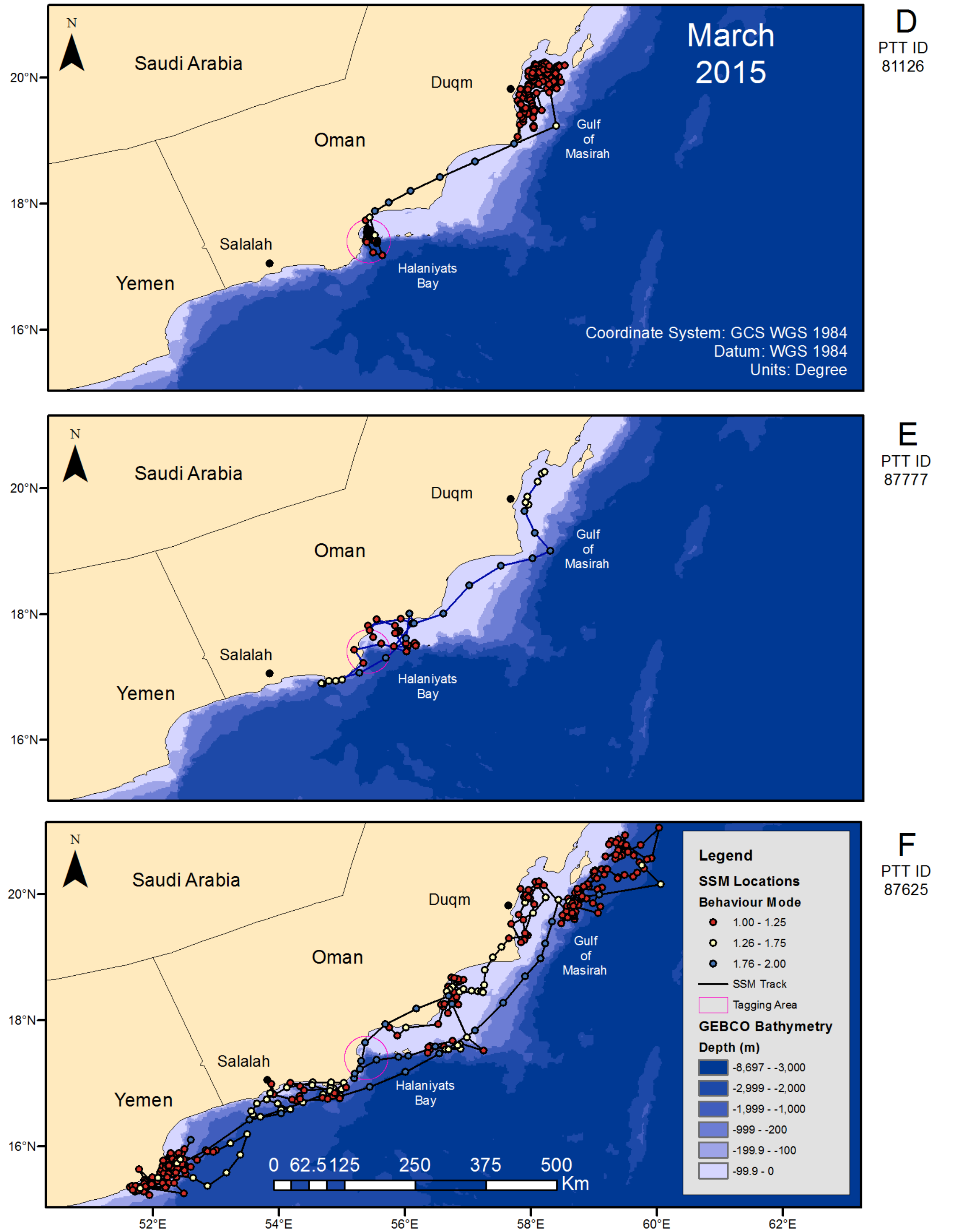

Figure 2 (continued) Switching state-space model (SSSM) derived locations and tracks for whales instrumented in February and March 2015.

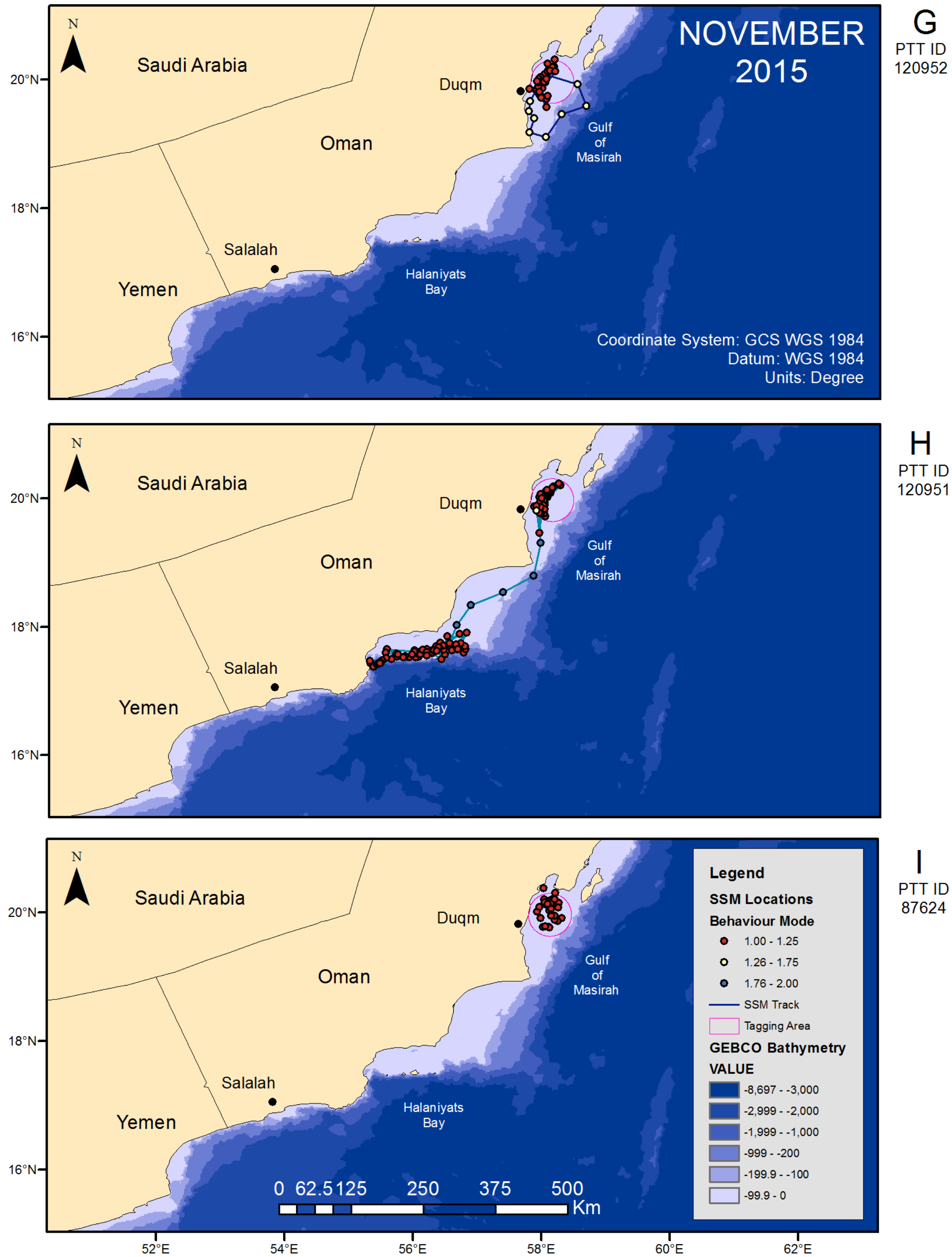

Figure 2 (continued) Switching state-space model (SSSM) derived locations and tracks for whales instrumented in November 2015.

Habitat utilisation

Whale distribution was assessed using pooled point counts of SSSM locations within predefined strata defined by bathymetry and coastal geography (i.e. by *embayments*). Tagged whales spent 72% of their time over the continental shelf and 28% in waters deeper than 200 m. Of the time spent on the shelf in depths of less than 200 m 35% of location points were within GoM and 22% within the Halaniyats Bay (Table 8). The remaining 15% of time on the shelf was spent in the intervening Saquira Bay and other areas.

Highest concentrations of SSSM locations (*high-use area*) occurred in the Gulf of Masirah and the Halaniyats Bay (Figure 3). This high-use area formed a 1,150km-long corridor of increased occupancy parallel to the Oman coastline. Two noteworthy *localised* high-use areas were also revealed. Area A (Figure 3) highlights a site surrounding Hasik and the main island Halaniyah, which was most frequented by whales within Halaniyats Bay. Area B in the GoM d (Figure 3) represents a focal yet more diffuse utilisation, with the area of highest density between Duqm Port, Bar al Hikman and the Sif Bu Sifa reef complex.

Table 8 Compilation of SSSM location point counts over selected strata including continental shelf (<200m) and off the shelf break (>200m).

Selected Strata	Bathymetry Range (m)	SSSM Counts	Percentage of Counts (%)
By defined shelf areas			
Gulf of Masirah	<200	348	35
Halaniyats Bay	<200	217	22
Other Shelf Areas	<200	77	8
Saquira Bay	<200	65	7
***By depth** categories*			
All Areas	<200	707	72
All Areas	>200	277	28

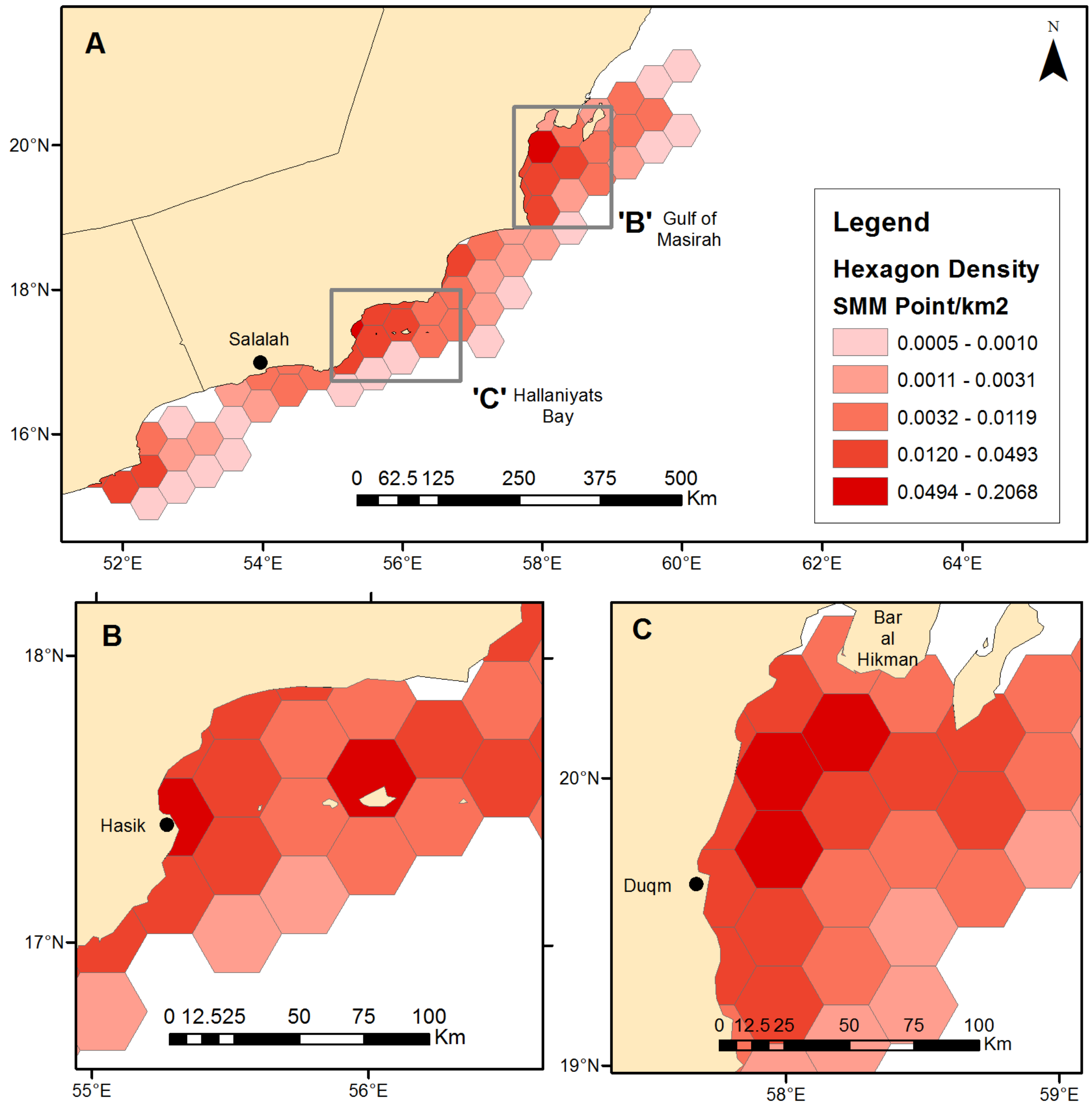

Figure 3 Habitat utilization derived from counts of SSSM locations within a hexagon grid network. Full extent of the study area defined by whale movement (upper panel; this should be A; cell size 25 km min. radius) and selected high-use areas (bottom plots 'B' and 'C'; cell size 15 km min. radius). Density classification consistent across all figure parts.

Co-occurrence of habitat with anthropogenic activities

Annotation of threats over a kernel density plot of SSSM outputs for the GoM (Figure 4) reveals whale habitat is within range of fishing activities launched from landing sites around the periphery of the GoM, including that of small open-decked fiberglass vessels ('skiffs' <9m length) with an approximate range of 50 km, as well as traditional fishing launches ('dhows' <28m length). A 2011 survey documented 2695 skiffs and 142 dhows were active from Masirah Island and the Al Wusta Governorate surrounding the GoM, (Ministry of Agriculture and Fisheries, 2012). Details of industrial facilities documented in Table 9 shows oil and gas test wells are located in central and northern areas of the habitat with new shore based industrial infrastructure along the western periphery.

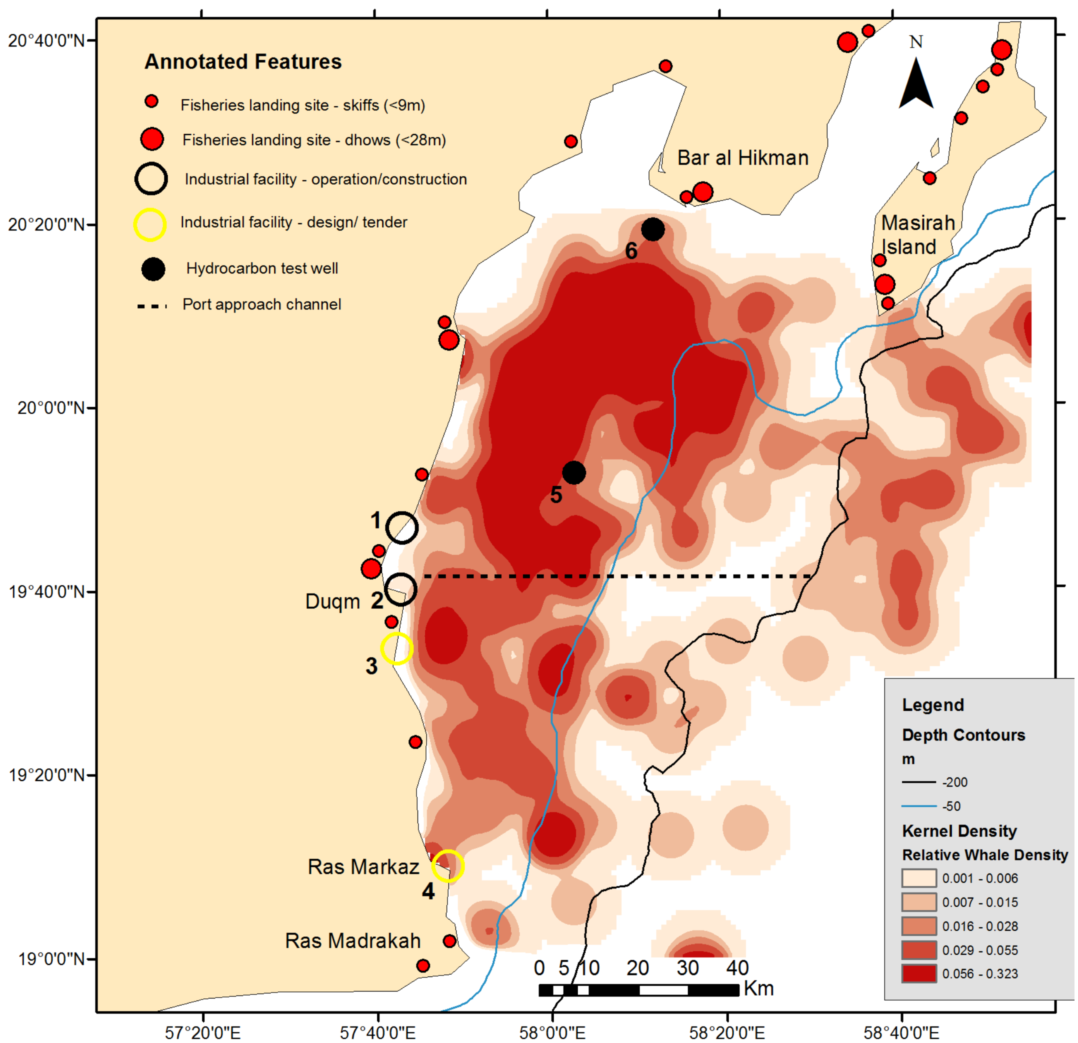

Figure 4 Kernel density ASHW habitat utilization derived from SSSM location points within the Gulf of Masirah with annotated artisanal fisheries, shipping and industrial activities within range of the study area (obtained from third party sources). Refer to Table 9 for description of features.

Table 9 Details related to features of facilities annotated in Figure 4

Annotation Number	Facility	Details	Phase	Reference
1	Duqm Refinery	Naptha, jetfuel, diesel and LPG refinery, (230,000 Bpsd)	Construction	Construction Weekly (22nd November 2015)
2	Duqm Port	Multipurpose port and dry-dock facility. Capacity 800,000 metric tonnes of cargo, 3.5 million TEU, 5 million tonnes dry bulk per annum. Hydrocarbon liquid loading terminal.	Operation	Oman Observer (8th November 2015)
3	Duqm Fishing Harbour	OMR 100 million Largest fisheries harbour in Oman	Tender (Jan 2016)	Oman Observer (10th January 2016)
4	Ras Markaz Crude Oil Park	Strategic Oil Storage and offshore loading facility Target capacity 25m barrels.	FEED and tender (June 2015)	Construction Weekly (2nd June 2015)
5 & 6	Masirah Oil Limited.	Hydrocarbon exploration and offshore oil reservoirs.	Completion of test wells in three locations with promising outlook, for production.	Bloomberg (22nd April 2016)

Depth utilisation
Transmission of histogram data on depth utilisation from six tags enabled with pressure sensors ranged between 13 and 82 days (203 cumulative days). Data on dive behaviour (*dive shape*) were received from 4112 dives (Table 10).

Table 10 Summary of data attained from pressure sensor logs including histograms and dive behavior.

Individual Code	PPT Number	Histogram data (days)	Dive (shape) behaviour (n)
D	81126	34	534
E	87777	13	268
F	87625	82	1775
G	120952	13	129
H	120951	47	986
I	87624	14	430

Whales spent an average of 83% (SD = 12%; Figure 5a) of their time in the top 20m of the water column with the most frequent average dive duration for all animals lasting between 5 to 10 minutes (Figure 5b). The mean of maximum depths of all tags was 199 m (SD = 95 m; min=135m; max=320m). Preliminary analysis suggests mean dive duration per day was approximately 7 minutes (SD = 0.9). Maximum dive duration was 30.2 minutes. The summarised frequency of U, V and square shaped profile dives reported by all tags indicated that square-shaped profiles represented 63% of all dives, with U and V profiles at 27% and 8% respectively.

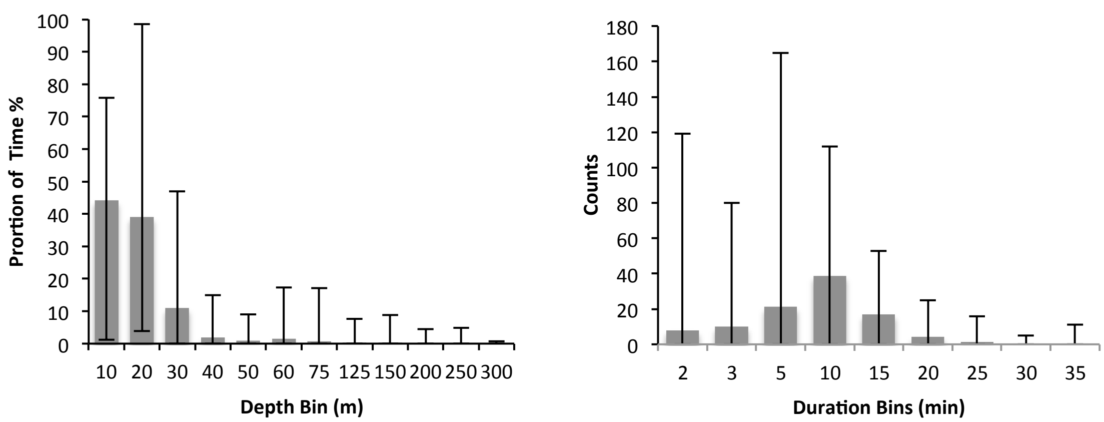

Figure 5 Summary of dive histogram data for all tags deployed in 2015; (a) left average time at depth for all tags deployed in 2015, and; (b) right number of dives logged within dive duration bins. Whisker plots represent maximum and minimum values reported by all individuals.

The locations of daily maximum depths for all individuals (Figure 6) indicates a predominance of dives to less than 50 m in shallow coastal waters and between 50 m and 100m, close to the shelf break. Data for one individual reveals deep diving between 150 m and 248 m on multiple days in waters of over 1000 m depth. These dives were made between the 1st May and 9th June 2015.

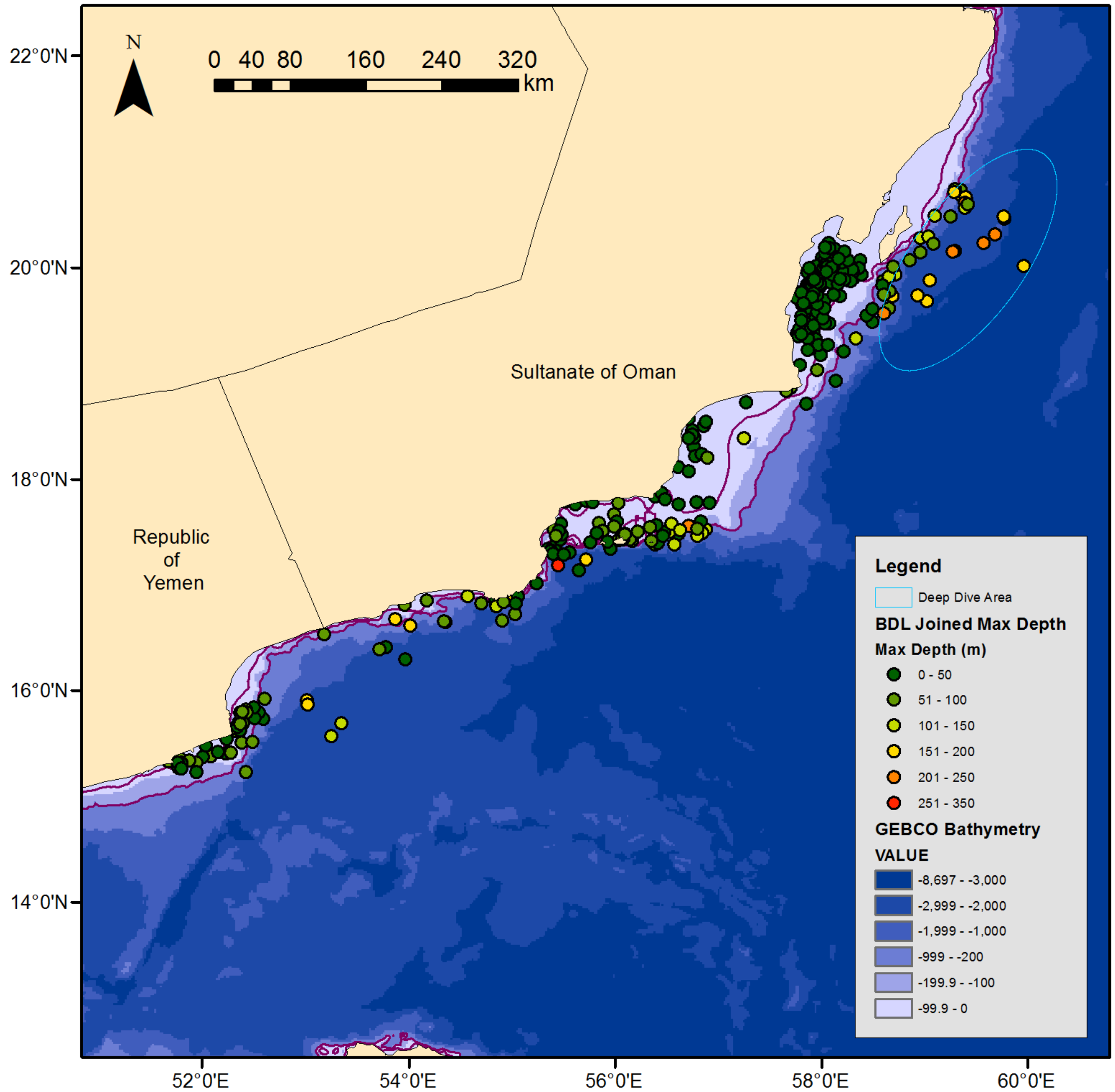

Figure 6 Best Daily Locations (BDL) of telemetry plots joined with maximum depths for each day.

Discussion

Survey approach

An adaptive approach to fieldwork has resulted in the successful deployment of 9 tags over three field seasons, despite logistical constraints from adverse weather and the challenges of working with a small population and low encounter rates. Efforts to maximise the opportunities for tagging have resulted in some biases, both temporally and spatially. There is also a predominance of males tagged in the study. The review presented in Table 5 indicates that the spatial dataset would be enhanced by additional tagging events in April and Septermber to account for seasonal gaps and capitalise on high encounter rates and increased presence of females within the GoM. Additional consideration should also be given to new, unsurveyed regions given the apparently limited propensity of tagged animals to move beyond the range of well-studied survey sites in Oman. Scoping work would help to identify candidate sites.

Insights into foraging ecology?

The foraging ecology of the ASHW remains poorly understood, and is of interest given the population's unique non-migratory status (Minton et al., 2008; Pomilla Amaral et al. 2014). Minton (2011) and Reeves (1991) hypothesised that energy requirements within the Arabian Sea may be met by increased productivity generated by nutrient rich upwelling water off the southern Arabian Peninsula during the summer monsoon period. Sardines and euphausids were present in the stomach contents of captured animals (Mikhalev, 2000). Vessel surveys off southern Oman have previously documented feeding in shallow coastal waters (Minton et al. 2011, Willson et al. 2012). The locations of maximum dives detailing repeated dives greater than 150m, correspond with an area of the Arabian Sea where association has been found between seasonal shoaling of the oxygen minimum zone and increased productivity detected in artisanal fisheries (Piontkovski and Al-Oufi, 2014). Echograms taken during scientific cruises have revealed a concentrated layer of mychtophids just above the oxycline at a depth of approximately 200 m (Baird et al. 2009). Baleen whales are documented to have a preference for foraging areas where prey aggregations are most dense (Dolphin 1987; Baumgartner et al. 2003; Witteveen et al. 2008) and the it is possible that the oxycline acts as a false bottom concentrating ASHW prey species in areas offshore from the shelf break.

The historical whaling records and new lines of evidence suggest behavioural plasticity in ASHW foraging strategies between coastal and offshore waters. The strategy may be driven by necessity given that annual landings of sardines in the Arabian Sea are known to fluctuate by as much as 39% and likely determined by the strength of the summer monsoon, (George et al. 2012). Further investigation is warranted considering reporting of a basin scale decline of sardine landings off the coast of Oman between 2001 and 2011 (Piontkovski et al. 2011).

Threats and vulnerabilities

Industrial and artisanal fishing activities occurring within the GoM have previously been documented to overlap with the presence of whales in the area (Minton et al., 2011; Willson et al. 2014; Willson et al. 2015; Baldwin et al. 2015). The landing sites of artisanal vessels plotted in Figure 4 are for vessel known to predominantly use gillnets, a gear responsible for high rates of cetacean entanglement around the world (e.g. Read et al 2013). Analysis of the Oman ASHW photographic catalogue previously revealed that 30-40% of encountered whales are likely to have been involved in entanglements with fishing gear (Minton et al. 2011).

Industrial development around the new city development in Duqm has also been previously documented (Willson et al. 2014; Willson et al. 2015 and Baldwin et al. 2015). Industrial developments planned for the GoM present a complex array of threats requiring consideration of a holistic approach to developing mitigation measures. In a review of conservation issues facing the most endangered baleen whales, Clapham (1999) proposed that oil spills and entanglement in fishing nets and ship strikes presented the most significant population level threats to small populations. Thomas (2015) found that the same threats remained the most serious 15 years on. Studies of increasing vessel traffic through humpback whale habitat along the Great Barrier Reef has documented the increased risk of strike to whales (Smith et al. 2012). Investigations into the effect of seismic surveys on humpback whale singing activity off the coast of Angola revealed that breeding displays significantly decreased during these operations Cerchio (2014). All of these activities exist within the GoM. Currently voluntary mitigation measures are only in effect for the 12 nm surrounding the port in Duqm due to active promotion by the Port of Duqm Company.

ASHWs could be particularly at risk given that telemetry results reveal that tagged whales spent 35% of their time in the GoM and 83% of time within the top 20 m of the water column where they are most likely to be exposed to vessel strike and entanglement in gillnets. In 2015 the IWC Scientific Committee supported the proposal for the establishment of an 'Advisory Panel' to provide technical support and guidance for mitigation of industrial activities in the GoM. The requirements for implementing this concept are currently being investigated by the Environment Society of Oman with support from WWF International and the IUCN (Environment Society of Oman, 2015). Additional specialised oversight of emerging activities is a pressing requirement considering that tendering and construction phases are currently underway for large infrastructure development on this coastline and positive results posted from offshore well testing performed by Masirah Oil Limited represented as feature '5' in **Error! Reference source not found.**, (Bloomberg, 22 April 2016).

Recommendations

Future tagging and other research

Significant gaps in the knowledgebase remain including identifying habitats used by females. Further telemetry work could continue to support the refinement of spatial knowledge to improve risk assessment, and an increased sample size would likely provide the opportunity to reveal more broad ranging movements beyond Oman that are apparent from soviet whaling data (Mikhalev, 2000). The combined telemetry and depth profiling capabilities of tags also provide the opportunity for further investigations of foraging ecology. Any extension of the tagging campaign should also consider the range and relative costs of priorities identified by the participants of the first Arabian Sea Whale Network meeting (Minton et al. 2015). Current progress towards these is provided at this meeting in a *For Information* document (Minton and Antonopolou). Any further tagging should also be subject to critical review by the IWC Scientific Committee, including consideration of the number of whales already tagged (as a proportion of total population size), as well as the additional risks, costs and benefits that future tagging could bring.

Management
The results presented here continue to support the hypothesis that the GoM is a primary and critical habitat for the ASHW. While a mitigation plan is in place for the 12 nm surrounding Duqm Port, a detailed risk assessment is required for the rest of the GoM with a view to promoting the adoption of a broader management plan. Such specialised work would benefit from a framework that supports technical experts to play a formal role advising on and reviewing the implementation of mitigation measures as endorsed in IWC/SC/66a. Additional efforts are also required to inform planning and development activities elsewhere along Oman's coastline, and in other countries of the suspected range. Such efforts could be boosted by the completion of an initial broad scale sensitivity mapping exercise for the ASHW and other large whale species in the Arabian Sea.

Conclusions

The current survey approach employed by the field team, and completion of analytical work through external partnerships, presents a functional model for conducting research on the ASHW in Oman, and perhaps the region. Genetic, acoustic, population assessment and spatial ecology have been conducted in conjunction with the satellite tagging campaign and demonstrate that several objectives can be achieved with relatively modest field commitments. This work has clearly demonstrated that the occurrence of ASHW overlaps to a significant degree with current and emerging fisheries and industrial activities and has acted as the driver for stimulating the localised mitigation of anthropogenic activities. The absence of a broader mitigation program for the Gulf of Masirah is considered a major conservation concern however and requires a formal technical framework and resources to develop further. This work also represents a sizeable contribution to the regional Arabian Sea Whale Network. Although the conservation of this unique population remains a significant challenge success relies upon the development of initiatives throughout the range of this population and a broader acknowledgement of potential threats posed by ongoing industrial and fisheries activities.

Acknowledgements

We are grateful to the Ministry of Agriculture and Fisheries Wealth & Ministry of Environment and Climate Affairs, Oman, for participation of staff in field activities and issuing of permits to conduct field research, sampling and analysis. We thank all staff at the Environment Society of Oman (www.eso.org.om) through whom the research project is run and the network of volunteers for continued support of the Renaissance Whale and Dolphin Project in Oman. The team would also like to recognise the outstanding professional support of Darryl (MacGyver) MacDonald, for contribution of his wide ranging paramedic, photographic, mechanical and whale-finding expertise. Appreciation is expressed for the staff at Five Oceans Environmental Services working in the background for provision of expertise, time and patience in dealing with off the clock whale team related demands. The Wildlife Conservation Society is thanked for supporting the on-going participation of team members in support of field activities, data analysis and reporting. The work is also deeply indebted to the technical expertise, resources and patience of the Marine Mammal Laboratory of the Alaska Fisheries Centre and Instituto Aquali without which the tagging work would not have been possible. Finally sincere thanks are given for the unwavering faith and financial support provided to this project by Rennaisance S.A.O.G since 2011.

References

Bailey H, Mate B, Palacios D, Irvine L, Bograd S, Costa D. 2009 Behavioural estimation of blue whale movements in the Northeast Paci c from state-space model analysis of satellite tracks. *Endangered Species Res.* **10**, 93–106. (doi:10.3354/esr00239)

Baird, S.J., N. Bagley, J.A. Devine, S. Gauthier and J. McKoy *et al*., 2009. Fish resources of the Arabian Sea coast of Oman: Habitat, biodiversity and oceanography. Technical Report 5, Final Report Prepared for the Sultanate of Oman, Ministry of Fish Wealth (MFW), Muscat, pp: 1-163.

Baldwin, R. M. 2003. Whales and Dolphins of Arabia. Mazoon Printing Press, Muscat, Oman. 116pp.

Baldwin, R.M., Gallagher, M.D. and Van Waerebeek, K. 1999. A review of cetaceans from waters off the Arabian Peninsula. In: Oman's Natural History, eds. Fisher, M., Spalton, A. and Gazanfar, S., Backhuys Publishers, Leiden. Pp. 161-189.

Baldwin, R. M. Collins, T., Minton, G., Willson, A., Corkeron, P. 2011. Arabian Sea humpback whales 2011 update: Resights bubble feeding and hotspots. Paper submitted to the International Whaling Commission Scientific Committee, IWC Norway, 30 May – 11 June. SC/63/SH27 (Available from IWC Office)

Bloomberg (22nd April 2016) Masirah Oil Limited Completes Drilling of the Manarah-1 Well in Block 50. http://www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=252127255

Breed, G. A., Jonsen, I. D., Myers, R. A., Bowen, W. D., & Leonard, M. L. (2009). Sex-specific, seasonal foraging tactics of adult grey seals (Halichoerus grypus) revealed by state-space analysis. *Ecology*, *90*(11), 3209-3221.

Breed, G. A., Costa, D. P., Jonsen, I. D., Robinson, P. W., & Mills-Flemming, J. (2012). State-space methods for more completely capturing behavioral dynamics from animal tracks. *Ecological Modelling*, *235*, 49-58.

Breed, G. A., Costa, D. P., Goebel, M. E., & Robinson, P. W. (2011). Electronic tracking tag programming is critical to data collection for behavioral time-series analysis. *Ecosphere*, *2*(1), art10.

Brown, S.G. 1957. Whales observed in the Indian Ocean. Notes on their distribution. Mar. Obs. 27(177): 157–65.

Cerchio, S., Strindberg, S., Collins, T., Bennett, C., and Rosenbaum, H. 2014. Seismic surveys negatively affect humpback whale singing activity off northern Angola. PLoS-ONE 9(3): e86464.

Cerchio, S., Trudelle, L., Zerbini, A., Geyer, Y., Mayer, FX., Charrassin, JB., Jung, JL., Adam, O. and Rosenbaum, H. 2013. Satellite tagging of humpback whales off Madagascar reveals long range movements of individuals in the Southwest Indian Ocean during the breeding season. Paper submitted to the International Whaling Commission Scientific Committee, IWC Korea, 22 May – 2 June. SC/65a/SH22 (Available from IWC Office)

Clapham, P.J., Young, S.B. and Brownell, R.L., 1999. Baleen whales: conservation issues and the status of the most endangered populations. *Mammal review*, *29*(1), pp.37-62.

Construction Weekly (22nd November 2015). Duqm refinery; 7 firms invited to submit tenders. http://www.constructionweekonline.com/article-36409-duqm-refinery-7-firms-invited-to-submit-tenders/

Construction Weekly (2nd June 2015). Bidders invited for 1600ha crude oil park. http://www.constructionweekonline.com/article-33895-bidders-invited-for-1600ha-oman-crude-oil-park/

Corkeron, P, Minton, G., Collins, T., Findlay, K., Willson, A., and Baldwin., R . 2011. Spatial models of sparse data to inform cetacean conservation planning: an example from Oman. Endangered Species Reseearch Vol. 15:39-52.

Costa DP, Robinson PW, Arnould JPY, Harrison A-L, Simmons SE, et al. (2010) Accuracy of ARGOS Locations of Pinnipeds at-Sea Estimated Using Fastloc GPS. PLoS ONE 5: e8677.

Coyne, M. & Godley, B. 2005. Satellite Tracking and Analysis Tool (STAT): an integrated system for archiving, analyzing and mapping animal tracking data. Marine Ecology Progress Series, 301, 1-7.

Curtice, C., Johnston, D. W., Ducklow, H., Gales, N., Halpin, P. N., & Friedlaender, A. S. (2015). Modeling the spatial and temporal dynamics of foraging movements of humpback whales (Megaptera novaeangliae) in the Western Antarctic Peninsula. *Movement ecology*, *3*(1), 13.

Energy-pedia. 2014. 'Masirah Oil announces oil discovery offshore Oman in Block 50', 4th February 2014. http://www.energy-pedia.com/news/oman/new-157958.

Environment Soceity of Oman, 2015. Annual Report pp18.

Freitas, C., Lydersen, C., Fedak, M.A. and Kovacs, K.M. 2008. A simple new algorithm to filter marine mammal Argos locations. Marine Mammal Science, 24: 315-325.

Friedlaender, A.S., Tyson, R.B., Stimpert, A.K., Read, A.J. and Nowacek, D.P., 2013. Extreme diel variation in the feeding behavior of humpback whales along the western Antarctic Peninsula during autumn. *Mar Ecol Prog Ser*, *494*, pp.281-289.

Gales, N., Double, M. C., Robinson, S., Jenner, C., Jenner, M., King, E., Gedamke, J., Childerhouse, S., and Paton, D. 2010. Satellite tracking of Australian humpback (Megaptera novaean- gliae) and pygmy blue whales (Balaenoptera musculus brevicauda). Paper submitted to the International Whaling Commission Scientific Committee, IWC Morocco, 30 May – 11 June. SC/62/SH21 (Available from IWC Office)

Gales, N., Double, M. C., Robinson, S., Jenner, C., Jenner, M., King, E., Gedamke, J., Paton, D., and

Raymond, B. 2009. Satellite tracking of southbound EastAustralian humpback whale (Megaptera novaean- gliae): challenging the feast or famine model for migrating whales. Paper submitted to the International Whaling Commission Scientific Committee, IWC. SC/61/SH17 (Available from IWC Office)

George, G., B. Meenakumari, M. Raman, S. Kumar, P. Vethamony, M. Babu, and X. Ver- lecar. 2012. Remotely sensed chlorophyll: a putative trophic link for explaining variabil- ity in Indian oil sardine stocks. J. Coast. Res. 28:105–113.

Goldbogen, J.A., Friedlaender, A.S., Calambokidis, J., McKenna, M.F., Simon, M. and Nowacek, D.P., 2013. Integrative approaches to the study of baleen whale diving behavior, feeding performance, and foraging ecology. *BioScience*, *63*(2), pp.90-100.

Heide-Jørgensen, M.-P., Kleivane, L., Øien, N., Laidre, K.L., and Jensen, M.V. 2001. A new technique for deploying satellite transmitters on baleen whales: track- ing a blue whale (*Balaenoptera musculus*) in the North Atlantic. Mar. Mamm. Sci. 17(4): 949–954. doi:10.1111/j.1748-7692.2001.tb01309.x.

Jonsen, I. D., Flemming, J. M., & Myers, R. A. (2005). Robust state-space modeling of animal movement data. *Ecology*, *86*(11), 2874-2880.

Jonsen, I.D., Myers, R.A. and James, M.C., 2007. Identifying leatherback turtle foraging behaviour from satellite telemetry using a switching state-space model. *Marine Ecology Progress Series*, *337*, pp.255-264.

Kennedy, A.S., Zerbini, A.N., Vásquez, O.V., Gandilhon, N., Clapham, P.J. and Adam., O. 2013. Local and migratory movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the North Atlantic Ocean. Canadian Journal of Zoology, 2014, 92:9-18, 10.1139/cjz-2013-0161

Lagerquist BA, Mate BR, Ortega-Ortiz JG, Winsor M, Urbán-Ramirez J (2008) Migratory movements and sur- facing rates of humpback whales (Megaptera novaeangliae) satellite tagged at Socorro Island, Mexico. Mar Mamm Sci 24:815−830

Lambertsen, R. H. (1987). A biopsy system for large whales and its use for cytogenetics. Journal of Mammalogy, 443-445.

Mate, B., Mesecar, R., & Lagerquist, B. (2007). The evolution of satellite-monitored radio tags for large whales: One laboratory's experience. *Deep Sea Research Part II: Topical Studies in Oceanography*, *54*(3), 224-247.

Maxwell, S. M., Breed, G. A., Nickel, B. A., Makanga-Bahouna, J., Pemo-Makaya, E., Parnell, R. J., ... & Coyne, M. S. (2011). Using satellite tracking to optimize protection of long-lived marine species: olive ridley sea turtle conservation in Central Africa. *PLoS One*, *6*(5), e19905.

Mikhalev, Y. A. 1997. Humpback whales *Megaptera novaeangliae* in the Arabian Sea. Marine Ecology Progress Series 149:13-21.

Mikhalev, Y. A. 2000. Whaling in the Arabian Sea by the whaling fleets Slava and Sovetskaya Ukraina. In: Tormosov, D.D., Mikhalev, Y.A., Best, P.B., B., Zemsky, V.A., Sekiguchi, K., and Brownell Jr, R.L., editors. Soviet Whaling Data [1949-1979]. Moscow: Center for Russian Environmental Policy, Marine Mammal Council. p 141-181.

Minton, G., Collins, T. J. Q., Pomilla, C., Findlay, K. P., Rosenbaum, H. C., Baldwin, R., and Brownell Jr, R. L. 2008. *Megaptera novaeangliae*, Araiban Sea subpopulation. IUCN Red List of Threatened Species http://www.iucnredlist.org/details/132835.

Minton, G., T. J. Q. Collins, K. P. Findlay & R. Baldwin (2010) Cetacean distribution in the coastal waters of the Sultanate of Oman. Journal of Cetacean Research and Management, 11, 301-313.

Minton, G., T. J. Q. Collins, K. P. Findlay, P. J. Ersts, H. C. Rosenbaum, P. Berggren & R. M. Baldwin (2011) Seasonal distribution, abundance, habitat use and population identity of humpback whales in Oman. Journal of Cetacean Research and Management, Special Issue on Southern Hemisphere Humpback Whales, 185–198.

Minton, G., Reeves, R., Collins, T. and Willson, A. 2015. Report on the Arabian Sea Humpback Whale Workshop: Developing a collaborative research and conservation strategy. Dubai, 27-29 January 2015

National Ferry Companies Website, 2012. http://www.nfc.om/ennew/content.aspx?id=97

Payne RS, McVay S. 1971. Songs of humpback whales. Science 173: 585–597.

Noad, M. J., & Cato, D. H. (2007). SWIMMING SPEEDS OF SINGING AND NON‐SINGING HUMPBACK WHALES DURING MIGRATION. *Marine Mammal Science*, *23*(3), 481-495.

Oman Observer (8th November 2015). Duqm port gears up for early phase container operations. http://omanobserver.om/duqm-port-gears-up-for-early-phase-container-operations/

Oman Observer (10th January 2016). Tenders floated for Oman's largest fishing harbour. http://omanobserver.om/tenders-floated-for-omans-largest-fishery-harbour/

Piontkovski, S.A., Al-Oufi, H.S. and Al-Jufaili, S., 2014. Seasonal and Interannual Changes of Indian Oil

Sardine, Sardinella longiceps, Landings in the Governorate of Muscat (the Sea of Oman). *Marine Fisheries Review*, *76*(3), pp.50-60.
Piontkovski, S.A. and Al-Oufi, H.S., 2014. Oxygen minimum zone and fish landings along the Omani shelf. *Journal of Fisheries and Aquatic Science*, *9*(5), p.294.
Pomilla, C. Amaral, A., Collins, T., Minton, G., Findlay, K., Leslie, M., Ponnampalam, L., Baldwin, R., Rosenbaum, H. 2014. The World's Most Isolated and Distinct Whale Population? Humpback Whales of the Arabian Sea. *PLoS ONE*, 9(12), p.e114162. Available at: http://dx.plos.org/10.1371/journal.pone.0114162.
Read, A.J., 2008. The looming crisis: interactions between marine mammals and fisheries. *Journal of Mammalogy*, *89*(3), pp.541-548.
Reeves, R.R., Leatherwood, S. and Papastavrou, V. 1991. Possible stock affinities of humpback whales in the northern Indian Ocean. pp.259–70. In: Leatherwood, S. and Donovan, G. (eds). Cetaceans and Cetacean Research in the Indian Ocean Sanctuary: Marine mammal technical report number 3. UNEP, Nairobi, Kenya. United Nations Environment Programme, Marine Mammal Technical Report Number 3.
Robbins, J., Zerbini, A. N., Gales, N., Gulland, F. M. D., Double, M., Clapham, P., Andrews-Goff, V., Kennedy, A.S., Landry, S., Matilla, D. K. and Tackaberry, J. 2013. Satellite tag effectiveness and impacts on large whales: preliminary results of a case study with Gulf of Maine humpback whales. Paper SC/65a/SH05 presented to the International Whaling Commission Scientific Committee, Jeju, South Korea, June 2013. 10pp. (Available from the IWC Office)
Rosenbaum, H. C., Maxwell, S.M., Kershaw, F., Mate, B. 2014. Long-range movement of humpback whales and their overlap with anthropogenic activity in the South Atlantic Ocean. Conservation Biology. 2014 Apr;28(2):604-15. doi: 10.1111/cobi.12225. Epub 2014 Feb 4.
Sherman, L., 2006. Tracking the great whales. Terra. Oregon State University 1 (2), 1–8.
Slijper, E.J., van Utrecht, W.L. and Naaktgeboren, C. 1964. Remarks on the distribution and migration of whales, based on observations from Netherlands ships. Bijdr. Dierkd. 34: 3–93.
Thomas, P.O., Reeves, R.R. and Brownell, R.L., 2015. Status of the world's baleen whales. *Marine Mammal Science*.
Vincent C, McConnell B, Ridoux V, Fedak M (2002) Assessment of Argos location accuracy from satellite tags deployed on captive gray seals. Marine Mammal Science 18: 156–166.
Weller, D., Brownell, R.L., Jr, Burdin, A., Donovan, G., Gales, N., Larsen, F., Reeves, R. and Tsidulko, G. 2009. A proposed research programme for satellite tagging western gray whales in 2010. Paper SC/61/BRG31 presented to the IWC Scientific Committee, June 2009, Madeira, Portugal (unpublished). 3pp. [Paper available from the Office of this Journal].
Willson, A., Baldwin, R., Minton, G., Gray, H., Findlay, K., Collins, T. 2013. Arabian Sea humpback whale research update for 2012/13. Paper SC/65a/SH06 presented to the International Whaling Commission Scientific Committee, Jeju, South Korea, June 2013. 08pp. (Available from the IWC Office).
Willson, A., Collins, T. Baldwin, R., Cerchio, S., Geyer, Y., Godley B., Gray, H., Al-Harthi, S., Minton, Al-Zehlawi, N., M.Witt., Rosenbaum, H., Zerbini, A. 2014. Preliminary results and first insights from satellite tracking studies of male Arabian Sea humpback whales. Paper SC/65b/SH19 presented to the International Whaling Commission Scientific Committee, Slovenia, May 2014. (Available from the IWC Office).
Witt, M.J. Broderick, A. C., Coyne, M. S., Formia, A., Ngouessono, S., Parnell, R. J., Sounguet., G., and Godley. 2008. Satellite tracking highlights difficulties in the design of effective protected areas for Critically Endangered leatherback turtles Dermochelys coriacea during the inter-nesting period. Oryx, 42(02), pp.296-300.
Witteveen, B.H., Foy, R.J., Wynne, K.M. and Tremblay, Y., 2008. Investigation of foraging habits and prey selection by humpback whales (Megaptera novaeangliae) using acoustic tags and concurrent fish surveys. *Marine Mammal Science*, *24*(3), pp.516-534.
Wray, P. and Martin, K.R. 1983. Historical whaling records from the western Indian Ocean. Rep. int. Whal. Commn (special issue)(5): 213–41.
Zerbini AN, Andriolo A, Heide-Jørgensen MP, Pizzorno JL .2006. Satellite-monitored movements of humpback whales Megaptera novaeangliae in the South - west Atlantic Ocean. Mar Ecol Prog Ser 313: 295−304.