Tracking grey seals on Irelands' continental shelf

Report to National Parks & Wildlife Service,
Department of Arts, Heritage and Gaeltacht

November 2011

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Background

The Higher Education Authority (HEA) invested in a study of the risks to marine mammal and seabird populations in southwest Ireland (RAMSSI) under the PRTLI3 funding mechanism. Many seabird and marine mammal species have special conservation status under international and national legislation. They also share resources in the coastal zone with man and therefore the demands of resource use and conservation often come into conflict. Despite this, limited baseline information exists on the distribution, abundance and habitat use of these key marine species in Irish waters and the RAMSSI project addressed this (Roycroft et al. 2007). The study also provided the mechanism for a feasibility study on using telemetry technologies to study harbour seal behaviour and habitat use. The successful outcome of this study was instrumental in securing funding from the Marine Institute under the NDP funding programme to develop further this area of research and to strengthen international links with leading experts (Cronin et al. 2008).

Southwest Ireland was found to have a high diversity of seabird and marine mammal species. A total of 21 seabird species and 8 marine mammal species were recorded over a 3 year study period and relative abundance of many species was higher on the outer headlands of Bantry Bay and during the Autumn months. Vulnerable concentrations of seabirds in areas of high risk from oil pollution were identified (Roycroft et al. 2007).

Seasonal patterns in harbour seal (*Phoca vitulina vitulina*) abundance at haul-out sites were noted with peaks in the Autumn months. The haul-out behaviour of tagged seals varied over the tagging period with seals spending a higher proportion of time ashore post moult in October and decreasing over the winter months to a minimum in February. The effect of variables such as time of day, tide and weather on seal abundance was studied and the findings improved the accuracy of survey design to estimate the number of seals in the area, necessary to meet requirements under the EU Habitats Directive 92/43/EEC (Cronin 2007, Cronin & Ó Cadhla 2009).

Subsequent funding under the PRTLI4 mechanism, with ancillary funding for telemetry devices from National Parks and Wildlife Service (NPWS), has built further on this work through the current project on biotelemetry of marine megafauna (BioToMM). Telemetry technologies are employed to study the distribution, movements and behaviour of a key top marine predator, the grey seal (*Halichoerus grypus*). This information was then integrated with environmental and oceanographic data in an ecosystems approach. The marine predators themselves acted as oceanographic sensors, gathering data (e.g. water temperature) over wide spatial and temporal scales providing critical environmental data to help us understand the effects of climate change in the coastal zone. Outcomes of the research dovetail with the Beaufort initiative on Ecosystems Approach to Fisheries Management, a significant element of which is to ascertain the impact of top predators on Irish fisheries. In this report to one of the co-funders (NPWS) we will present the results of the telemetry elements of the study. The environmental data collected by the seals will be presented in a comprehensive report to the HEA at the end of the project (May 2012).

The study

The inshore waters of southwest Ireland have been recognised as important areas for many marine mammal species and particular hotspots of sensitivity identified, with valuable conservation management implications (Roycroft et al. 2007). The scope of previous research effort in this area was limited to inshore waters and did not encompass the full geographical range of these mobile marine species. Identifying important/key habitats across these protected species ranges is essential for the effective delineation and designation of marine SACs, required under the EU Habitats Directive. Information on key species' population size, range, at-sea distribution and habitat use is necessary to effectively assess conservation status of Annex II species, a further requirement under the Habitats Directive. Furthermore the information is important for monitoring changes in population, behaviour and habitat use as a result of ecosystem/climate change. The status of top predator populations reflect the health and sustainability of the ecosystem, thereby acting as high-trophic level indicators that can be used to inform management in an ecosystem approach to managing marine ecosystems. It is now accepted that top predators in marine ecosystems are responsive to changes in their environment, and that these can be measured and used to inform management (Boyd et al. 2006). Pinnipeds are accessible during important stages of their life histories because they have terrestrial breeding seasons, making it possible to provide consistent indices of population size and estimation of regional productivity from the productivity of the seals themselves.

Reliable population estimates now exist for both species of seal in Ireland (Cronin et al. 2007, Ó Cadhla et al. 2007). Information on harbour seal at-sea movements and habitat use in southwest Ireland suggests a limited range, generally staying within 20km of their haul-out site (Cronin et al. 2008). Grey seals can range widely and remain at sea for extended periods when foraging, using haul-out sites up to several hundred miles from breeding areas (e.g. Stobo *et al.*, 1990; McConnell *et al.*, 1992; Thompson *et al.*, 1996; Kiely *et al.*, 2000). Heretofore however, no studies have been conducted on the at-sea behaviour and movement patterns of grey seal in

Irish waters, resulting in critical gaps in our knowledge of the species foraging behaviour and offshore distribution in Irish waters.

The ability to conduct research on the behaviour and movements of marine species has significantly improved in recent years with advances in telemetry techniques. Sophisticated tags combining Global Positioning System (GPS) technology and data sensors attached to marine species provide valuable data on feeding ecology, home ranges, and habitat use. Due to a high degree of site-fidelity and the fact that they come ashore to breed and moult, seals lend themselves to telemetry studies as they can be captured once they come ashore and fitted with tracking devices. Grey seals were tagged in this study with GPS devices to provide critical data on range, distribution and habitat use in waters off the west coast of Ireland.

The study aims to (i) identify the geographical range of female grey seals tagged in southwest Ireland; (ii) identify areas of high usage or offshore 'hotspots' of habitat use by grey seals; (iii) examine foraging trip duration and extent and influence of season and body size and (iv) investigate seasonal change in haul-out patterns and search for evidence of potential pupping related behaviour.

Material & Methods

Study site

Capture of grey seals and deployment of GPS/GSM tags was carried out at haul-out sites in southwest Ireland on An Trá Bán on the Great Blasket Island (Fig. 1) in Co. Kerry in February 2009. Grey seals use the beach as a moult site between November-April/May each year (Fig. 2). The site is of national importance, being the second largest moult colony of grey seals in the country. During the 2007 national moult census 947 grey seals were counted in March 2007 on An Trá Bán (Ó Cadhla & Strong 2007). The site was chosen because of its national importance, and its location in southwest Ireland where previous tagging efforts on harbour seals have been conducted (Cronin & McConnell 2008).

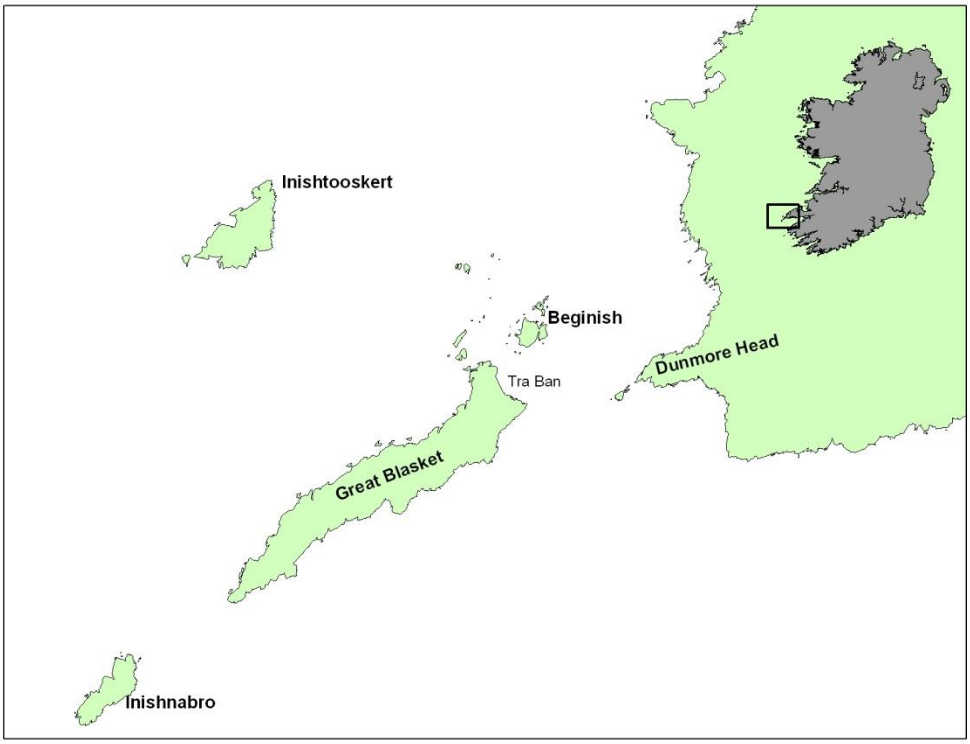

Fig 1. Location of tagging of female grey seals, An Trá Bán, Great Blasket Island, Co. Kerry

Fig. 2. Grey seals hauled out at the tagging site on the Trá Bán, Great Blasket Island, Co. Kerry.

Seal capture and tag deployment

Tagging was conducted on An Trá Bán in February 2009 to coincide with the completion of the female moult. Grey seals undergo an annual moult and according to background data gathered in the Republic of Ireland, the annual moult season for grey seals occurs somewhat earlier than generally described (Bonner 1990), beginning as early as November for adult females and juveniles and continuing up to April for adult males (Kiely 1998). As the tags were glued to the animals fur and therefore shed during the moult, tagging is conducted post moult to maximise the period of tag attachment. Females complete the moult earlier than males and in Ireland females are mostly moulted by February.

Seals were captured at the haul-out site using hoop nets. These consisted of a 1m diameter hoop made of 20mm plastic hosing and a funnel net of 10mm mesh attached. Researchers approached the haul-out site by sea using zodiac boats and an approximation of group size was obtained by at least 2 researchers from the boats 200-300m from shore using Leica 10 x 42 binoculars. Once a count was obtained the boats rushed towards the seal colony, selecting adult female seals from the group and captured individuals in hoop nets ashore. The captured seals remained in the hoop nets throughout the administration of the anaesthetic and prior to the tagging procedure. All seal handling and tagging procedures were conducted under NPWS License No C35/2008.

Seals were weighed using a Salter spring balance (accuracy ± 0.2kg) to the nearest 1kg and anaesthetised using 0.05ml of Zoletil (© Virbac) per 10kg, delivered intravenously. If intravenous administration of the anaesthetic proved difficult (as with a struggling animal) an intra-muscular dose of 0.1ml of Zoletil per 10kg was delivered instead. A subsequent dose of anaesthetic was administered if necessary during the handling and tagging procedure but at half the dilution of the initial dose. Length (from nose to end of tail) and girth (immediately posterior to the fore-flippers) of the animal were measured to the nearest cm and the sex recorded. A blubber core (approximately 10mm x 6mm), skin sample (taken from the tip of the blubber core), blood sample (taken during administration of the anaesthetic) and vibrissae were taken from each animal for stable isotope analysis (as part of an on-going diet study). A sub-section of the skin sample was retained for genetic analysis; all samples were stored in 70% alcohol. The blubber core was taken using a Schuco acu-punch 6mm biopsy corer. The area was pre-treated with alcohol and post-treated with a topical tetracycline (Terramycin spray).

Measurements of blubber thickness along the length of each animal were obtained using a portable ultrasound unit (Aloka SSD 500) to assess body condition. A transrectal ultrasonographic examination was also conducted to examine the reproductive tract to assess reproductive status of the female seals (e.g. Adams et al. 2007). The technique is rapid and non-disruptive (Singh et al. 2003). Handling time for this procedure ranged between 10-15 minutes. Ultrasonography was performed by an experienced operator from the Sea Mammal Research Unit (SMRU) St. Andrews University. There was no evidence of pregnancy in the females scanned, but this was non-conclusive as the ultrasound imagery was unclear (P. Pomeroy, SMRU, *pers. comm.*).

Body composition analysis using deuterium oxide (^2H_2O) dilution as described in Reilly & Fedak (1990) was conducted. After each seal was weighed, a plasma sample was taken from the extradural vein into a sterile 10ml heparin treated vacutainer (Becton Dickinson, Cowley, Oxon, UK) to measure background ^2H_2O enrichment in body fluids. A pre-weighed dose of 3-5ml ^2H_2O (99.9%; Sigma-Aldrich Chemicals, Gillingham, Dorset, UK) was injected and a second plasma sample taken approximately 3 hours later to determine ^2H_2O enrichment after equilibration with body water compartments. After centrifugation in the laboratory, four 50µl aliquots of each sample were flame-sealed into capillary tubes, and stored at room temperature until analysis which will be carried out by the SMRU (these data are not presented in this report). Absolute mass and percentage of each of the body components (fat, protein, water and ash) will be determined from body water content, using equations derived by comparison of ^2H_2O

dilution with chemical composition of grey seal carcasses (Reilly & Fedak 1990). This procedure was performed by an experienced operator from the Sea Mammal Research Unit (SMRU) St. Andrews University. Following the aforementioned procedures the fur was dried with paper towels and degreased using acetone and the tag was secured in place using fast setting epoxy resin at the base of the skull (Figs. 3 & 4). The animal re-entered the water once the epoxy resin had set (approximately 15 minutes).

Fig. 3. Researchers glue a GSM/GPS tag to seals fur

Fig. 4. Grey seal tagged with GSM/GPS tag on Great Blasket Island Co. Kerry

Tag hardware design

The GPS/GSM tag was developed at the Sea Mammal Research Unit (SMRU), St. Andrews University, Scotland in two stages. The first (phase I) was successfully deployed to provide data to determine first year survivorship in grey seal pups in Scotland in 2003. In essence, the mobile phone system has been exploited to develop a phone-tag that automatically attempts to send text messages ashore to a central phone in the lab. The success of this system validated the concept of using the GSM mobile phone system to efficiently relay data ashore from free-ranging seals when they are within coastal GSM coverage zones (McConnell et al. 2004). Ten phase I tags were successfully deployed on harbour seals in southwest Ireland in 2004-2005, in a collaborative exercise between SMRU and CMRC, to obtain data on haul-out behaviour (Cronin 2007; Cronin & McConnell 2008). Such information will help to improve the accuracy of aerially acquired census data for the species (Cronin et al. 2007). These tags however did not provide information on the at-sea movement or behaviour of the seals, as there is no GPS facility in the Phase I tag.

A Phase II tag (Fig. 5) incorporates a novel hybrid GPS system called Fastloc (Wildtrack Telemetry Systems, Leeds). The surfacing periods of most marine mammals are insufficient to acquire GPS location fixes using conventional GPS engines. Fastloc overcomes this constraint by only capturing GPS pseudo-range data that are then compressed into 30 byte records. When these records are relayed ashore they are post-processed with archived orbitography data to calculate location. The significant advantage of this system is that the required data capture requires less that half a second at the surface. This has opened up the exciting possibility of frequent and accurate positions being acquired at sea. The tags are programmed to attempt a location fix every 30 minutes. The tag also measures conductivity, temperature and depth providing valuable haul-out and dive behaviour information. The tag records when the seal is 'hauled-out' using data from a wet/dry sensor. A haul-out event starts when the tag is continuously dry for 10 minutes and ends when continuously wet for 40 seconds. The location, dive and haul-out records are stored onboard the tag. When the seal comes within range of the coastal GSM zone, after a period of perhaps days, weeks or even months offshore, the records are sent ashore to a dedicated computer via a data link call. These tags have been successfully deployed on harbour seals in the Kenmare River Co. Kerry, providing fine scale information on dive and movement patterns of harbour seals in the area (Cronin et al. 2008).

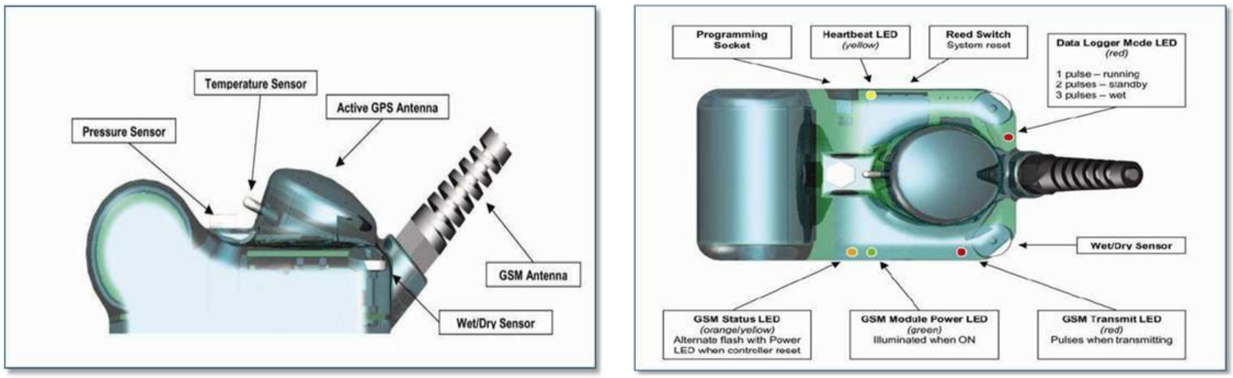

Fig 5. GPS/GSM Phase II tag design deployed on seals (Source: SMRU).

Data retrieval and analysis

The location and dive data from the GPS/GSM tags were relayed to a base phone at the SMRU, St Andrews, Scotland. Static maps of seal movement were created at the SMRU and updated daily. A web-link facility enabled direct access to the raw data (Access database) and the static maps of movement data and dive profiles of the tagged seals.

Location data in the Access database was filtered at the CMRC. The frequency and extent (defined as the distance from a haul-out site to the furthest at sea location) of 'foraging trips' to sea were recorded for all seals. These trips were defined as starting and ending when the seal crossed a certain threshold based on distance from the haul-out cluster and only when the seal was determined to be not hauled-out (from the wet/dry sensor data). This was to avoid inflating the number of trips as a result of seals using the water in the immediate vicinity of the haul-out as a result of disturbance or shifting position with changing tide height. A foraging trip was denoted as when the seal was not hauled out and was greater than 1km from the departure haul-out site for a period of longer than one hour. This apparent arbitrary distance and duration was selected based on findings by Cunningham et al. (2009) who used a range of thresholds between 1-10km and 1-10 hours with no significant difference in results. The extent and duration of foraging trips of individual seals were determined and any potential influence of season, sex and age on these parameters explored.

The track and dive data were integrated into ArcGIS. Extensions within ArcMap enable the creation of raster maps of distribution based on kernel density estimation. Kernel density estimation (KDE) involves the creation of isopleths or contours of intensity of utilization by calculating the mean influence of data points at grid intersections. Each isopleth contains a fixed percentage of the utilization density suggestive of the amount of time that the animal spends in the contour (Hemson et al. 2005).

Data visualisation

A dedicated project website was designed to allow public access to information on the project and to enable visualisation of the seal movement and dive data. The GIS data was exported in KML format for viewing in Google Earth and a link created in the website to Google Earth (http://sealtrack.ucc.ie/viewer.html. The data integration and visualisation process is detailed in Fig. 6.

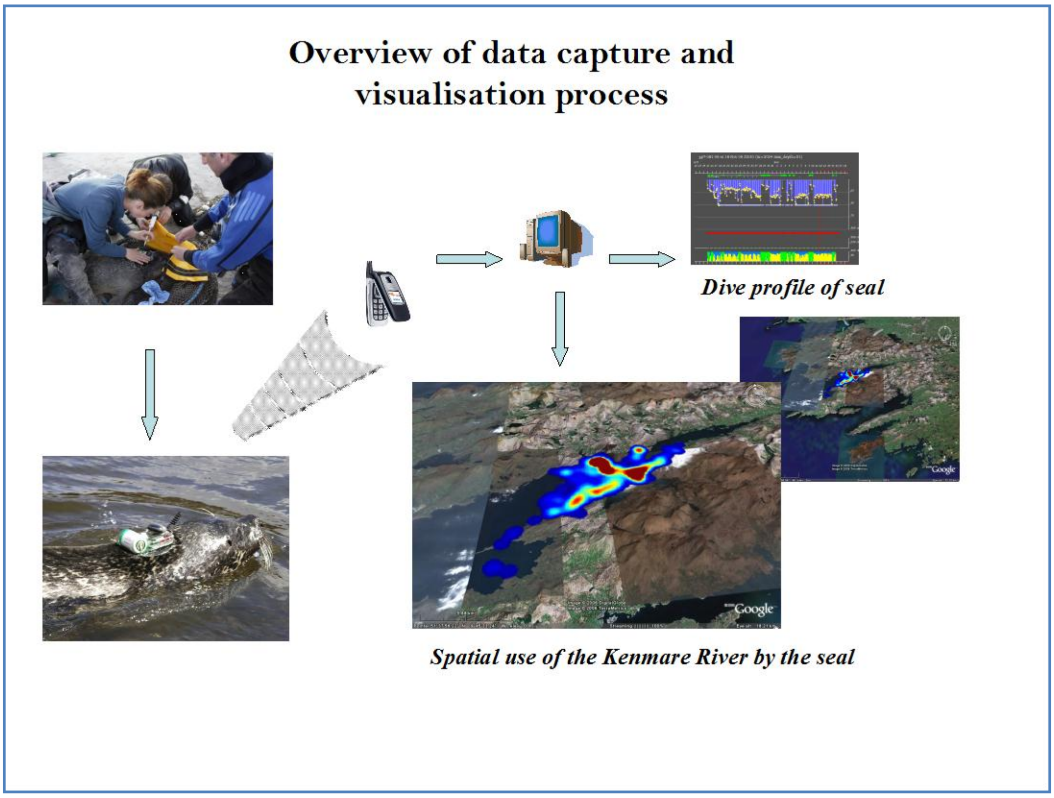

Fig. 6. Data integration and visualisation process

Outreach

An educational outreach element of the project was developed. The program targeted secondary level science students who are introduced to the concepts of telemetry and the technologies used to study the behaviour of seals in Irish waters. The children were encouraged to track the tagged seals in Google Earth via the dedicated website. Furthermore it provided an opportunity for raising awareness of the Irish marine environment, marine mammals, climate change and the importance of conservation.

Results

Seal capture and tag deployment

Grey seal group size on an Trá Bán was estimated to be approximately 1200. This is not directly comparable to the 2007 moult count (Ó Cadhla & Strong 2007) as the techniques used during the 2007 survey (counts obtained from digital images acquired aerially) provided a more accurate count. It is difficult, if not impossible, to accurately estimate group size of seals ashore from a boat, particularly when the group size is large and animals are tightly aggregated on the beach. The count of 1200 obtained during this study therefore should be cautiously treated as an approximate count.

A total of 8 female grey seals were successfully captured and tagged on the Great Blasket Island on February 24th and 25th 2009. Weights of captured seals ranged from 68.2kg to 121.2kg. Four of the seals weighed less than 100kg (Table I). Tags operated for approximately 7-8 months (mean duration 226 days; maximum 325 days). In total 1813 days of data were collected from the 8 grey seals (Table 1). The distribution of data coverage was not equal for all months and few data exist for December 2009 due to moult associated tag loss.

Trip extent and duration

There were a total of 529 foraging trips made by the tagged seals over the tagging period, 56% (297) of the trips were return trips (to the same haul-out site). The furthest foraging trip was 511km, made by seal 8 in September 2009. The mean distance travelled away from the haul-out cluster by tagged seals was 50.85km. There was a significant amount of variation between individual seals in trip extent ($p<0.001$; Kruskall Wallis $H=68.64$).

The mean foraging trip duration was 40.44 hours and some trips lasted several days, the longest being over 15 days which was made by seal 8 in May 2009. Seals 1 and 6 had higher mean trip durations than the other seals, their mean trip durations were over 86 hours (Table II). Overall trip duration varied significantly between individuals (($p<0.001$; Kruskall Wallis $H=58.35$).

Four of the eight seals tagged (seals 2, 3, 4 and 8) made trips to Scotland, some of which made repeat trips. The remaining four seals made trips as far as Galway and Mayo (Fig. 7). In general there were no similarities between individuals in patterns of movement/habitat use with high variation between individuals in their at-sea movement patterns. A summary of individual seals' trips is given in Table III.

Space Use

Marine usage by tagged grey seals is shown in Fig. 8. Kernel density estimation techniques were applied to the location data to show the percentage of time individuals spent in different areas over the tagging period. Inter-seal variability in space usage is evident and hot-spots' of usage varies between individuals. The combined datasets were used to create a single map of space usage for the entire area (Fig. 9) showing the importance of waters between NW Kerry and SW Galway up to 100km west and including the waters surrounding Loop Head in Co. Clare. Some of the seals spent a high proportion of their time around the Inishkea Islands in Co. Mayo and the western Scottish Islands including Colonsay, Barra and St Kilda.

Table I. Details of seals on which tags were deployed

Seal Number	Tag Number	Date of tagging	Date of last transmission	Tagging duration (days)	Sex	Weight (kg)	Length (cm)	Girth (cm)
1	10957	24/02/2009	23/07/2009	149	F	121.2	170	122
2	11093	24/02/2009	16/10/2009	234	F	78	141	108
3	11113	24/02/2009	30/07/2009	156	F	69.8	138	109
4	11101	24/02/2009	02/10/2009	220	F	68.2	141	101
5	11108	24/02/2009	17/05/2009	79	F	119.2	159	125
6	11100	25/02/2009	16/01/2010	325	F	115.2	166	122
7	11095	25/02/2009	07/10/2009	224	F	110.6	159	121
8	11015	25/02/2009	22/12/2009	302	F	90.2	152	109

Table II. Details of foraging trip extent and duration

Seal Number	Weight/kg	Mean trip duration/hr (+SE)		Mean trip extent/km (+SE)	
1	121.2	86.54839	6.58376	91.01935	8.875171
2	78	59.36986	8.372227	57.46301	10.42378
3	69.8	50.61	7.91	61.21	14.78
4	68.2	26.27	3.02	22.09	4.24
5	119.2	82	18.69	47.4	10.95
6	115.2	93.07	12.74	55.88	6.86
7	110.6	37.45	3.01	14.56	2.32
8	90.2	58.97368	7.443188	60.74605	12.84735

Table III. Summary of movement patterns of individuals during tagging period

Seal Number	Movement Patterns
Seal 1	Seal 1 spent the duration of the tagging period February 25 to July 23.in the area between the Blasket Islands and SW Connemara. The seal used haul-out sites on the Blasket Islands and haul-out sites south of Roundstone and Slyne Head Co. Galway.
Seal 2	Seal 2 spent the period of February 25 to May 26 travelling/foraging between the Great Blaskets, Slyne Head Co Galway and the Inishkea Islands Co. Mayo, following which it travelled to the outer Hebrides Scotland until June 21, utilising haul-out sites on the Monach Isles and Barra. It used the Inishkea Islands as a haul-out site over the Summer period, foraging in the area to the NW of the Inishkeas until August 7 after which it returned to Barra in the Hebrides and foraged from there until September 15. it then returned to Inishkeeragh in the Inishkea Island Group Co. Mayo. It continued to use that site as a base, foraging and travelling in the area NW of the Inishkeas right out to the shelf edge until at least October 16, when tag transmission ceased.
Seal 3	Seal 3 made lots of returns trips to the tagging site on the Great Blasket Island between February and April, foraging mainly in the region to the NW of the Blasket Islands but travelling as far as Slyne Head and Inishshark Co. Galway and the Inishkea Islands Co. Mayo.On April 30 it made a direct trip to Barra in the Hebrides over a 6 day period and onwards to the Monach Isles and St Kilda and on May 13 returned to the Inshkea Islands over a 7 day journey, some of which followed the shelf edge, It spent a 2 week period between the Inishkea Islands and Inishshark following which it returned to Scotland and spent the remainder of the tagging period, June until mid July, between St. Kilda and the Monach Isles.
Seal 4	Seal 4 spent the period from February 25 to May 1 in the area between the Great Blasket Island and Loop Head Co. Limerick. On May 1 to May 10 seal 4 travelled to Sanda in SW Scotland travelling in close proximity to the Irish coastline for the extent of the trip. On May 12 it returned to Loop Head via the Inishkea Islands arriving May 22. It spent the remainder of the tagging period (until Oct 2) travelling and foraging between Loop Head, Kerry Head and the Blasket Islands, the majority of this period was spent in the lower Shannon Estuary area, with occasional trips further into the Shannon Estuary. The last transmission was from the tagging site on the Great Blasket Island on Oct 2.
Seal 5	Seal 5 spent the tagging period mainly in the region NW of the Blasket Islands, up to 100km from the tagging site. Apart from Slyne Head it almost exclusively hauled out on the Blasket Islands. The last transmission was on Sept 15 approximately 10km west of the Blasket Islands.
Seal 6	Seal 6 mainly foraged and travelled in the waters west of Co. Clare between February and October, using haul-out sites in SW Connemara near Roundstone and Slyne Head. On October 18 it travelled to the Inishkea Islands and remained there until November 14, the majority of this period was spent on or around Duvillaun Beg, a possible pupping site for the seal. On November 15 the seal returned to foraging grounds west of Co. Clare until at least January 16, the last transmission was from SW Connemara.
Seal 7	Seal 7 foraged primarily in waters up to 25km south of the Blasket Island Group until April 1, following which it travelled to SW Connemara and, apart from one return trip to the Blasket Islands, foraged there until early October, utilising haul-out sites in Ballyconnelly Harbour.
Seal 8	Seal 8 remained in the vicinity of the Blasket Islands and Brandon Head in Co. Kerry between February 25-April 23 following which it travelled to Oban, Scotland, via Connemara and the Inishkeas over a 10 day period. It returned to the Blaskets over a 9 day period after remaining in Scotland for just one day. On May 27 it made another trip to Scotland foraging mainly SW of the Hebrides and moving between Colonsay and Barra until mid July. It then returned to the Blaskets via the Inishkeas and remained near the Blasket Island/Brandon Head region until mid September. It then returned to Colonsay in Scotland until mid October following which it returned once again to the Blaskets via the Inishkeas. It remained at the Blasket Islands until at least December 22, the date of the last transmission. It is possible this seal used the Blasket Islands as a pupping site.

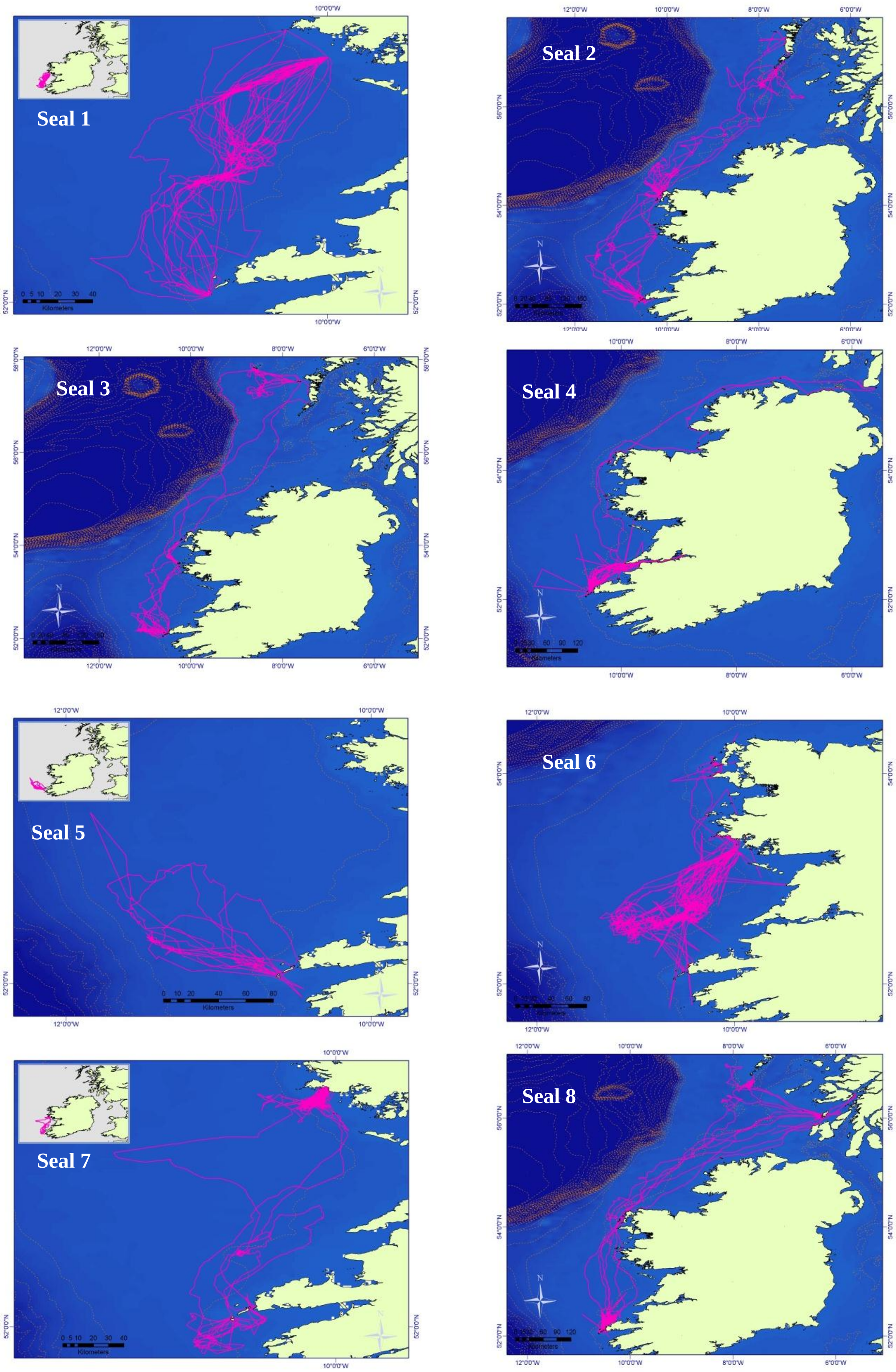

Fig. 7. Tracks of 8 seals tagged with GSM/GPS tags on Great Blasket Island Co. Kerry February 2009.

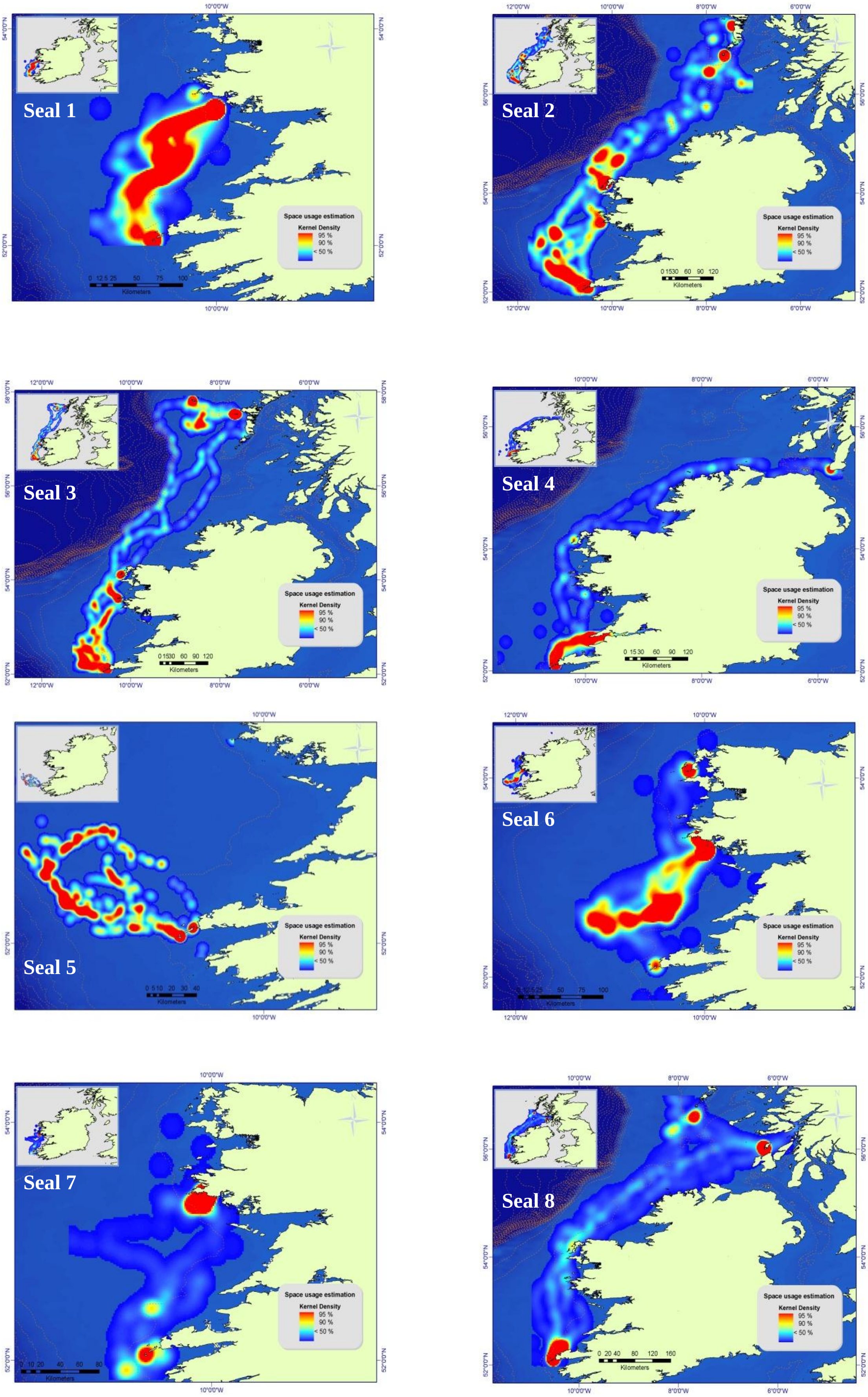

Fig. 8. Space use estimation of individual grey seals tagged on Great Blasket Island Co. Kerry, February – December 2009.

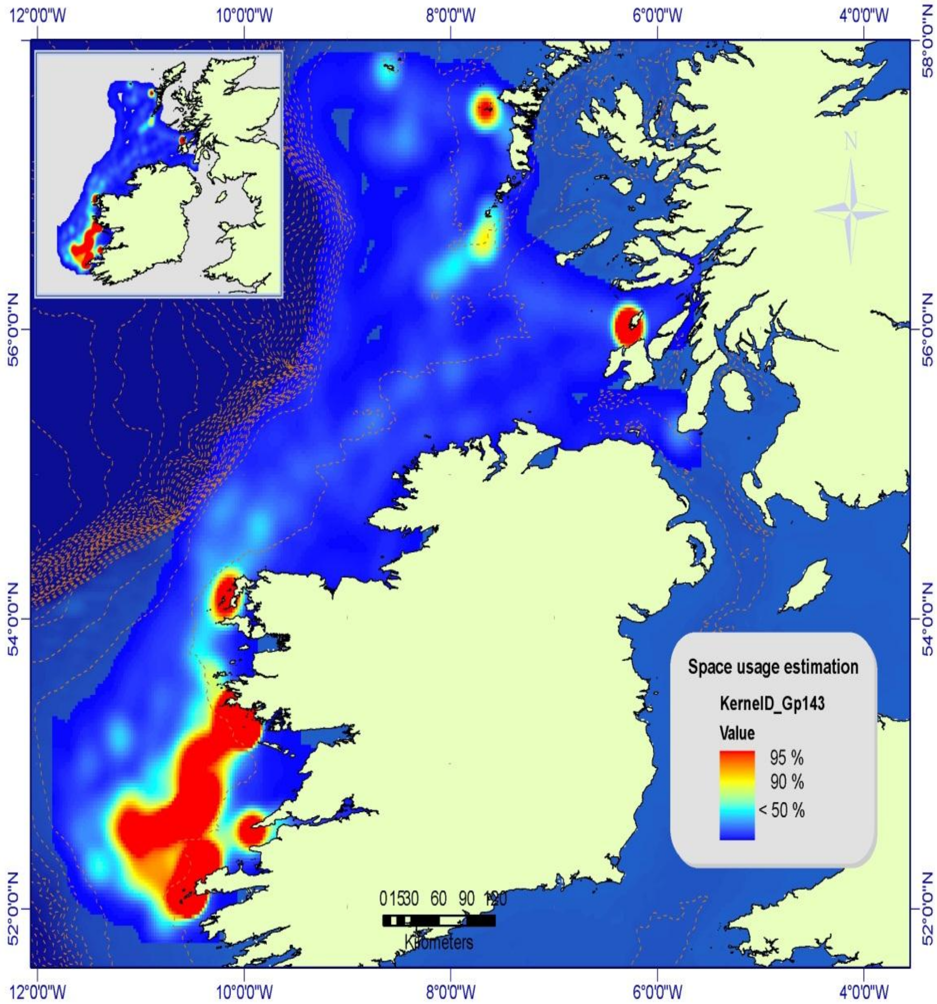

Fig. 9. Space use of all 8 tagged grey seals between February and December 2009

Seasonal variation

The duration and extent of foraging trips varied over the tagging period (Figs. 10 & 11). Mean trip duration increased steeply from February to March 2009, remained relatively constant until July where by it decreased from 55 hours to 40 hours in August and increased slowly to 50 hours throughout the rest of the study until November 2009. Confidence intervals in October and November are relatively large due to small sample size caused by moult associated tag loss. Overall however there was not a significant variation in trip duration across the tagging period ($p=0.144$, Kruskall Wallis, $H=16.48$) other than the initial increase between February and March which presumably marks the end of the moulting period of the females. Trip extent however varied significantly across the study period ($p<0.001$, $H=68.64$), peaking in May 2009 (68km) and decreasing across the Summer period to a minimum in August (20km).

Size variation

The tagged sample consisted of 8 seals that were separated into 2 categories for this analysis, those <100kg and those >100kg. Trips made by the larger (>100kg) seals were significantly longer ($p<0.001$) in duration than the smaller seals (<100kg) averaging 61.41hr and 45.79hr respectively. However smaller seals foraging trips were significantly longer in extent than the larger seals ($p<0.01$), averaging 45.99km and 38.44 km respectively. Notably the four seals that travelled to Scotland were <100kg.

Haul-out behaviour

The duration of haul-out events generally decreased from Spring over the Summer months, suggesting the seals spent more time at sea and less time ashore during this period (Fig. 12). Tags remained on only two seals until the end of the year. The duration of haul-out events of these two individuals increased during November and December.

Seal 6 spent an extended period ashore in early November (Nov 2-14) after which it alternated its time between shore and sea and then remained ashore from December 17 until end of transmission on January 16. Dive data from seal 6 (Fig. 13) suggests the female made shallow (<10m) dives prior to this extended period of haul-out, presumably around the haul-out site, and then did not return to the water until November 15. The haul-out site is Duvillaun Beg in the Inishkea Island Group Co. Mayo.

Seal 8 spent a 6 day period in November (23-28) ashore and a 5 day period December 8-12 (Figs. 12 & 14). The dive data from seal 8 (Fig. 14) suggest very little time was spent in the water from mid-November until end of the tagging period, and when the seal did enter the water dives were shallow (<5m). The final GPS location of this seal on 22nd December 2009 was from Oileán na nÓg, an island immediately northwest of the Great Blasket Island, where the seal was tagged in February 2009. A period of shallow dives combined with rest ashore is also evident in early-mid October, this occurred on Colonsay, an island in southwest Scotland.

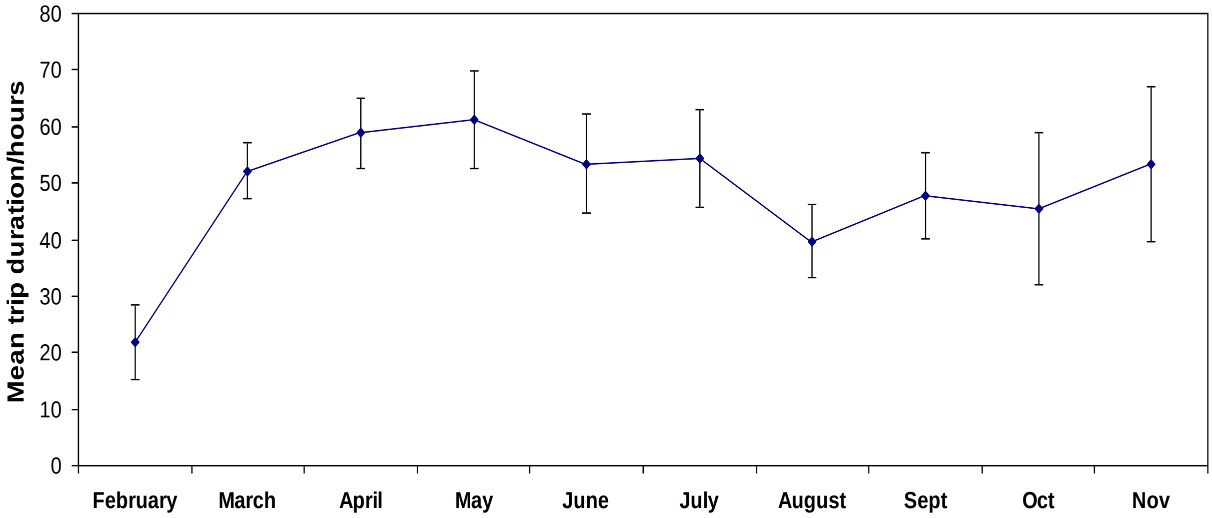

Fig. 10. Mean foraging trip duration of tagged seals

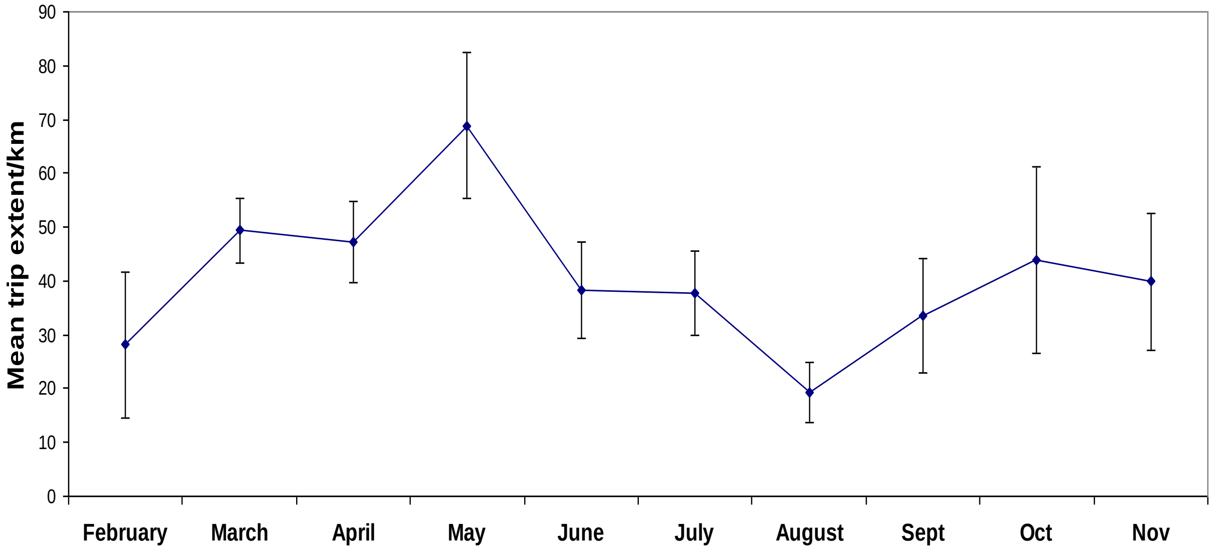

Fig. 11. Mean foraging trip extent of tagged seals

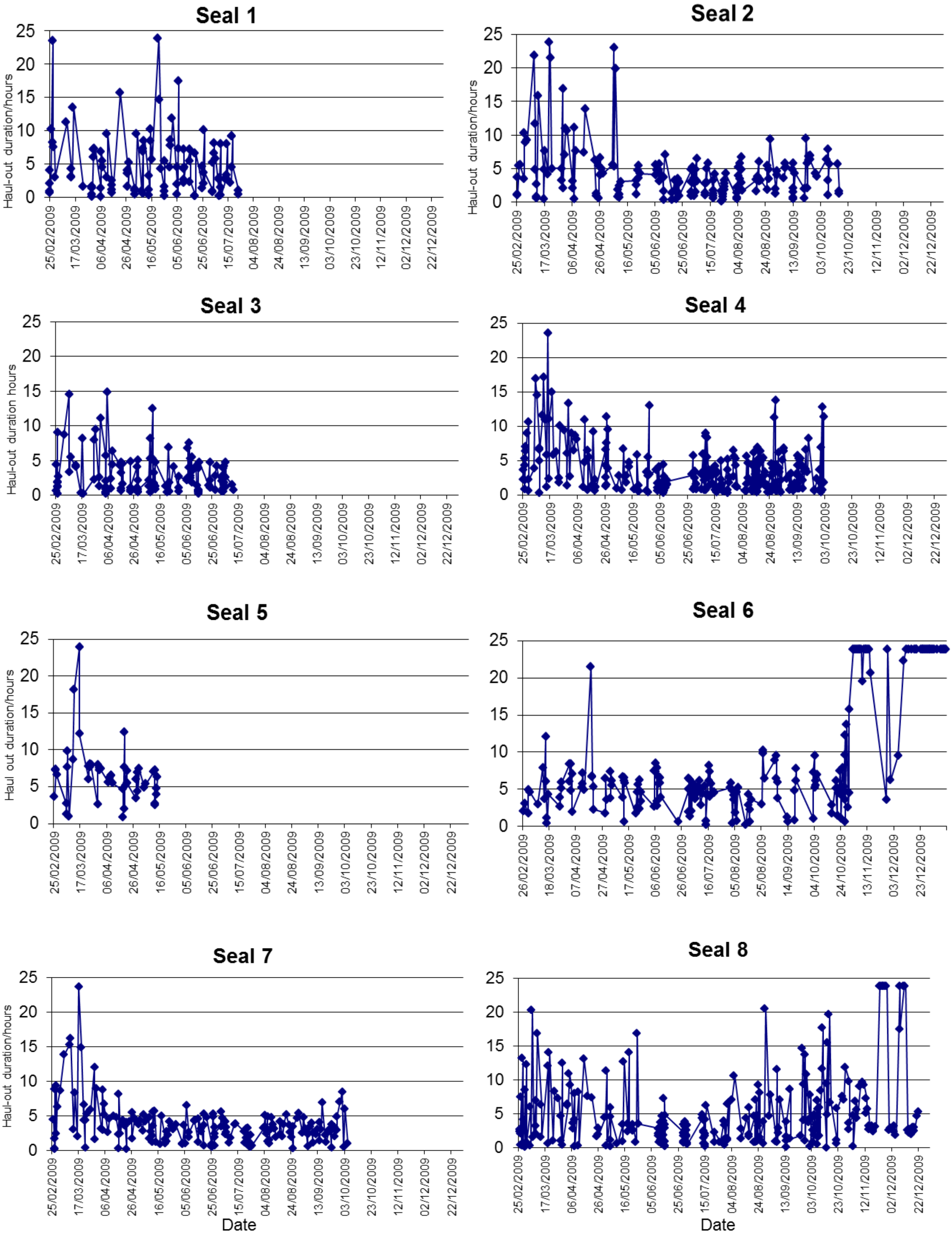

Fig 12. Duration of haul-out events (hours) for individual seals across the tagging period

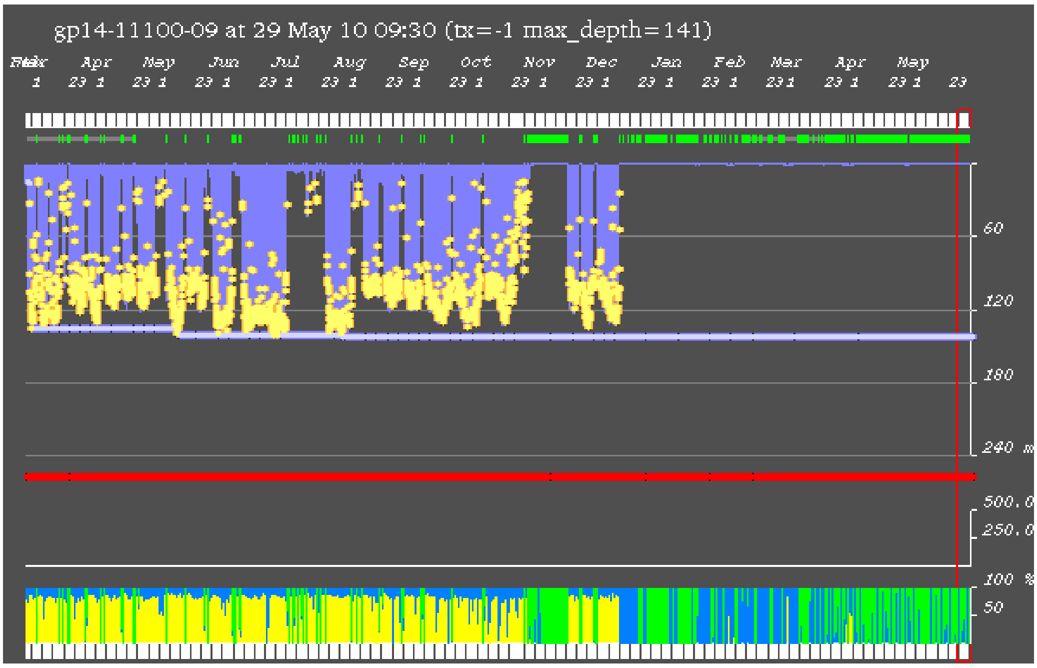

Fig. 13. Dive records of seal **6**; most dives 100-140m. % time hauled-out is shown on lower axis in green and suggests extended period of haul-out early to mid-November.

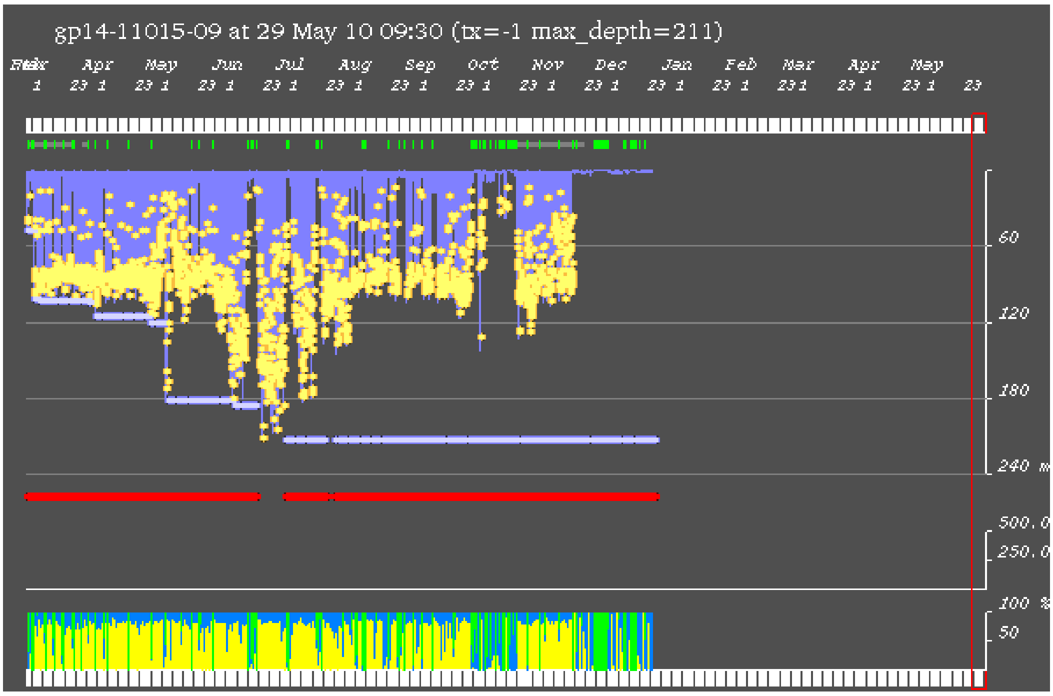

Fig. 14. Dive records of seal **8**; most dives 80-100m, some dives to 200m in the Summer period.

Discussion

Biotelemetry, the remote detection and measurement of biological data about animal function, activity or condition, provided a means of obtaining information, heretofore unavailable, on the at-sea movements and behaviour of a key top marine predator in southwest Ireland. Grey seals in Ireland generally select remote haul-out sites on rocky skerries, uninhabited islands, isolated mainland beaches and sea-caves and are found along virtually the entire coastline of the Republic of Ireland (Lockley 1966). Areas of haul-out concentration are along the southwest, west and northwest coasts and more patchy haul-out distribution along the eastern and southern coasts most likely due to reduced availability of uninhabited/undisturbed coastal habitat (Ó Cadhla et al. 2007) A national census of the grey seal in 2005 delivered a definitive breeding population estimate of 5,509-7,083 grey seals of all ages (Ó Cadhla et al. 2007). The number of grey seals present at Irish colonies has been shown to vary with season with annual peaks occurring during breeding and moult periods. While seasonal patterns in site use can be consistent between years, terrestrial habitats used during the moult and Summer in Ireland may not always be used for breeding (Kiely & Myers 1998, Kiely et al. 2000). Whilst information on population size and terrestrial distribution was available, prior to this study the species' at-sea distribution and range remained unknown. The grey seal is a key component of the marine ecosystem and this information is important for understanding ecosystem functioning. Changes in population structure, diet, habitat use and range of key marine species can all be important indicators of ecosystem or climate change. Furthermore, as an Annex II species under the EU Habitats Directive such information is required to assess the conservation status of the species, necessary under this Directive.

The telemetry elements in the current study build on previous research on harbour seals in southwest Ireland where the application of biotelemetry to study seals was first applied in Irish waters (Cronin et al. 2008, Cronin & McConnell 2008). The Blasket Islands, Co. Kerry were selected as the study area in the current study, as it is a site of national significance for breeding and moulting grey seals (Ó Cadhla & Strong 2007, Ó Cadhla et al. 2007). Furthermore the site is situated in southwest Ireland, an area where research on marine mammal distribution and abundance has been conducted in recent years under PRTLI3 funding (Roycroft et al. 2007) and therefore where reliable baseline data exist.

Female grey seals were captured and tagged when they had completed their moult in February. The tags remained attached to the fur for approximately 7-8 months. The seals often re-visited the site on the Great Blasket Island where they were first tagged, the majority of trips in fact were return trips to this haul-out site. On average foraging trips were approximately 50km from haul-out sites however, it was evident that there was a significant amount of variation between individual seals in trip extent with trips of up to 511km recorded. Four of the eight seals tagged made trips to Scotland, some of which were repeat trips. The remaining four seals made trips as far as Galway and Mayo on the west coast of Ireland. In general there were no similarities between individuals in patterns of movement/habitat use with high variation between individuals in their at-sea movement patterns. Seals remained at sea for approximately 40 hours and some trips lasted several days, the longest being over 15 days. Overall there was no significant variation in trip duration across the tagging period, however the extent of trips varied significantly, peaking in May (68km) and decreasing across the Summer period to a minimum in August (20km). Trips made by larger seals (>100kg) were significantly longer in duration than the smaller seals (<100kg), however smaller seals foraging trips were significantly longer in extent than the larger seals. The four smaller seals made the trips to Scotland, whilst the four larger individuals remained in waters along the west coast of Ireland throughout the study period. Size related differences in foraging behaviour are evident in seals. The proportion of time spent at sea, mean trip duration and mean foraging range were all positively related to body size in harbour seals in Scotland (Thompson et al. 1998). Comparison with data from other study areas suggests that both environmental and endogenous factors shape foraging characteristics in this species. Body size determines where, how, and what kind of prey can be eaten. Differences in body size presumably enable larger animals to dive deeper and forage more efficiently by targeting different and perhaps larger prey items. The longer duration yet shorter foraging range evident in the current study may be evidence of a more efficient foraging strategy in the larger seals. The occurrence of foraging specializations within a species and age class has implications for quantitative modelling of population-level predator–prey interactions and ecosystem structure (Weise et al. 2010). Potential benefits of long distance travelling, as was evident in the four smaller females in the study, include the exploration of new foraging areas and the possibility of opportunistic foraging en route (McConnell et al. 1999). The influence of body condition on foraging behaviour will be examined in more detail when results from the body composition analysis are made available by the SMRU.

The duration of haul-out events generally decreased from Spring over the Summer months, suggesting the seals spent more time at sea and less time ashore during the Summer period (May-July) decreasing in August. This is likely to be associated with the seals' annual cycle, where more time is spent at sea foraging between periods of moulting and breeding. This was also the case with harbour seals tagged in Kenmare River Co. Kerry, however longer periods were spent at sea during the Winter months by harbour seals as the timing of the moult and the breeding periods differ between the two species (Cronin et al. 2008). Breeding in grey seals in Ireland generally takes place between September and December each year. Tags remained on only two seals until the end of the year. One of these females (seal 6) spent an extended period ashore in early November after which it alternated its time between shore and sea and then remained ashore from mid-December until end of transmission in mid- January. It is possible that the tag was moulted from the seal above high tide mark during this period and it is unlikely that the data represent a haul-out event of a months duration. The extended haul-out periods of this individual in November is likely to represent pupping, when the adult female remained ashore in the days preceding and following pupping. Dive data suggests the female made shallow (<10m) dives prior to this extended period of haul-out, presumably around the haul-out site, and then did not return to the water until mid-November. Female grey seals spend time in the water in the immediate vicinity of a pupping site for a couple days prior to coming ashore to give birth (Fogden 1971). The haul-out site where the potential pupping took place is Duvillaun Beg in the Inishkea Island Group Co. Mayo.

The second female (seal 8) spent a 6 day period in November ashore and a 5 day period in December ashore. It is likely that one of these periods represents pupping and that this occurred on one of the islands in the Blasket Island Group as the final GPS location on December 22 was from Oileán na nÓg northwest of the Great Blasket Island, where the seal was tagged in February that year. The dive data from this female suggest very little time was spent in the water from mid-November until the end of the tagging period, and when the seal did enter the water dives were shallow (<5m). A period of shallow dives combined with rest ashore is also evident in early-mid October, this occurred on Colonsay, an island in southwest Scotland, a known haul-out site for grey seals. It is unlikely that this is associated with pupping however, as even though the seal spent extended periods ashore during a 3-4 day period, this was not exclusively ashore and periods were also spent in shallow water in the vicinity of the haul-out site during this time, following which the seal travelled back to Ireland. As the lactation period lasts approximately 18-20 days, if the seal had pupped on Colonsay during the extended haul-out period we would expect her to remain ashore/in the vicinity of the pupping site for at least 18 days.

It is not possible to conclude with certainty that these two females gave birth without direct observations at the breeding sites. We can make inferences however about potential pupping behaviour from the haul-out, dive and location data provided by the tags. The data provide some evidence to suggest that females moulting at the Great Blasket Island also use the area as a breeding site, but it also suggests females moulting at one site may breed elsewhere (e.g. Inishkea Islands, Co. Mayo). On-going research using photo-identification of individuals at breeding and moulting sites will provide further information on fidelity of seals to these sites throughout important parts of their annual cycle.

The reproductive status of the seals was not known, however sexual maturity may be inferred from capture mass. Pomeroy et al. (Pomeroy et al. 1999) reported postpartum mass in grey seal females ranging from 131-251kg. It is possible that the other female seals that made trips to Scotland used breeding sites on the Scottish coast but considering their capture mass it is unlikely they were sexually mature. Unfortunately the tags were moulted prior to the breeding season so it was not possible to determine evidence of breeding. On the basis of genetic differences there appears to be a degree of reproductive isolation between grey seals that breed in south-west Britain and those breeding around Scotland and within Scotland (SCOS 2009). The distant travel of seals in this study and in other studies (McConnell et al. 1992, Thompson et al. 1996, McConnell et al. 1999) however, indicates that grey seals in Scotland, the Faroes, France and off the west coast of Ireland are not ecologically isolated. This mixing has important consequences in modelling epidemiology, population management and fisheries interactions. Local population control measures for example will have a reduced effect due to interchange of seals from other regions (McConnell et al. 1999). There is currently no information on the genetic structure of grey seals using haul-out sites on the Irish coastline, current research efforts aim to address this, but sample size is limited to date. A dedicated research initiative would address this ideally with samples taken from pups and adults from the main colonies on the Irish coastline.

Individual grey seals of all ages can range widely and remain at sea for extended periods when foraging, using haul-out sites up to several hundred kilometres from breeding areas (McConnell et al. 1999). Grey seal distribution and movements have been extensively studied in the North Sea and around Scotland. Movements are generally on two geographical scales, long and distant travel (up to 2,100km) and local, repeated trips to discrete offshore areas which were considered to be foraging areas (McConnell et al. 1999). A number of grey seals tagged at Scottish haul-out sites have been observed to enter Irish waters and to haul-out at Irish sites during such movements (SMRU, pers. comm.). The current study is the first to provide evidence that the movement is reciprocal i.e. seals moulting in Ireland, travel to Scottish haul-out sites.

Prior to this study knowledge of grey seal distribution and movements in Irish waters was limited to mark-recapture efforts. The dispersal of grey seal pups and juveniles from the grey seal breeding colony on the Inishkea Islands Co. Mayo was studied in 1997-1998 by flipper tagging pups with plastic tags as part of a mark/recapture program. Re-sighting rates ranged from 15% for pups to 35% for juveniles with the mean distances travelled from tagging locations being 44km and 267km respectively (BIM 2001). Photo identification studies also suggest movement of individual grey seals between sites on the east and southeast coasts of Ireland and southwest Wales (Kiely et al. 2000). Other information on grey seal distribution in Irish waters includes qualitative data from sporadic sightings made by land and boat-based observers, and from incidental by-catch of seals in commercial fishing operations (BIM 1997, Berrow & Rogan 1998, Kiely 1998, BIM 2001).

Telemetry data are frequently used to generate surfaces of spatial usage that represent the proportion of time that animals spend at different locations in space. These usage surfaces are generally depicted as contour plots or density maps. Such surfaces are used to identify 'hot spots' or 'cold spots' of high or low usage by an individual or a population. Overlap with other individuals of the same or different species or with the distribution of environmental variables can then be assessed. This provides a means of understanding the determinants of habitat use of key species and of ecosystem functioning. Kernel density estimation (KDE) is widely viewed as the most reliable contouring method in ecology (Powell 2000, Kernohan et al. 2001) involving the creation of isopleths or contours of intensity of utilization by calculating the mean influence of data points at grid intersections. Each isopleth contains a fixed percentage of the utilization density suggestive of the amount of time that the animal spends in the contour (Hemson et al. 2005)

Marine usage by tagged grey seals in the present study was examined, and there was evidence of inter-seal variability in space usage. A single map of space usage for the entire area identified hot-spots for the seals offshore, in particular waters between NW Kerry and SW Galway up to 100km west and including the waters surrounding Loop Head in Co. Clare. Some of the seals spent a high proportion of their time around the Inishkea Islands in Co. Mayo and the western Scottish Islands including Colonsay, Barra and St Kilda, these areas of high usage are likely to be associated with travel to and from the haul-out sites but could also represent local foraging areas. Dive data collected by the tags will be examined in a future study to identify foraging behaviour and fine-scale habitat use.

The sample size of eight individuals is relatively small, and caution must be taken when interpreting the data and making inferences about the at-sea distribution and habitat use of the entire local, or national population. Efforts will be made to tag male seals to examine sex-related differences in habitat use and range. Moreover, efforts should be extended to other significant grey seal haul-out sites on the Irish coast (e.g. Inishkea Islands Co. Mayo; Saltee Islands Co. Wexford), as there may be site-related differences in foraging behaviour and range (e.g. Small et al. 2005). With the availability of telemetry data from seals tagged at other haul-out sites on the Irish coast in future studies, haul-out specific usage maps can be created and weighted by the estimated number of seals associated with each haul-out (e.g. Matthiopoulos et al. 2004) and combined into a single map of usage for seals around Ireland.

The dynamics of inter haul-out site use could be estimated by mark –recapture models based on photo-identification data (Hiby et al. 2007). This data, together with telemetry data, would enable the intensity of foraging to be estimated and along with diet data it should be possible to map predation pressure on different prey species (McConnell et al. 1999). The on-going contentious issue of seal/fishery interactions and competition is of mounting concern, with commercial fish stocks in global decline. A recent report to the European Parliaments Committee on Fisheries highlighted the urgency of the situation in Ireland, where the fishing industry claims seals are responsible for increasing levels of depredation of valuable commercial species (Cronin et al. 2010). Conversely fisheries affect seals through accidental by-catch, and overfishing can reduce prey availability. The situation is a complex one and has led to serious conflict between conservationists, members of the fishing industry, policy makers and resource managers (Cronin 2011). Overall, there is clearly a need for further research before the full extent of seal/fisheries interactions in Irish waters can be quantified and the situation adequately addressed. Specific recommendations on research priorities based on identified gaps in current knowledge in Ireland are provided in Cronin et al. (2010). The aforementioned telemetry studies along with the current study suggest grey seals from haul-out sites along their range on the northeast Atlantic fringe are not ecologically isolated, with individuals travelling between France, Ireland, the Faroe Islands and Scotland. Considering this, a transnational study on grey seal movements, habitat use, foraging behaviour and fishery interactions in the northeast Atlantic would be the most pragmatic approach to address current knowledge gaps. Resources and expertise would be shared to maximise efficiency and ensure research efforts are coordinated and complimentary. This study would provide highly valuable data for assessing overlap with fisheries, identifying critical habitat for the species and informing mitigation measures to minimise disturbance from surveys and activity associated with the oil and gas and the offshore renewable energy industries.

Acknowledgements

This study was facilitated by funding from the Higher Education Authority (HEA) under the PRTLI4 programme Environment and Climate Change and by the National Parks & Wildlife Service (NPWS). Research was also supported under the Beaufort Marine Research Award carried out under the Sea Change Strategy and the Strategy for Science Technology and Innovation (2006-2013), with the support of the Marine Institute, funded under the Marine Research Sub-Programme of the National Development Plan 2007–2013. The following peoples help was greatly appreciated during the seal capture and tag deployment process: Paddy Pomeroy and William Patterson (SMRU, St Andrews), David Thompson (National Trust, Co. Down), Declan O Donnell, Clare Heardman, Frank McMahaon, Pascal Dower, Tim O Donoghue, Danny O Keefe and Oliver Ó Cadhla (NPWS).

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