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SHORT NOTE

At-sea spatial usage of recently weaned grey seal pups in Iceland

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Abstract

Although grey seals (*Halichoerus grypus*) are the focus of considerable research effort throughout much of their North Atlantic breeding range, little is known about grey seal movement ecology in Iceland. This is surprising given the long history of grey seal exploitation in Iceland and because grey seals are common bycatch in commercial fisheries. Here, for the first time, we deployed satellite tags on five grey seals in Iceland to quantify the at-sea spatial usage of recently weaned pups during their first year of life. Maximum foraging trip distance ranged from 20 to 160 km for individual pups, while maximum duration ranged from 4.3 to 20.8 days. Individual differences in foraging trip metrics indicated two broad strategies. Specifically, pups either remained near the deployment location or dispersed to the east of Iceland, reaching a total distance of > 300 km from the deployment location. Foraging trips were, however, typically restricted to the continental shelf, which presumably reflects a preference for benthic foraging, as is reported for grey seals at other breeding locations. Our preliminary findings highlight the importance of near-shore waters to recently weaned grey seal pups in Iceland and suggests that coastal fisheries are a prevalent threat. However, additional research is required to quantify interactions between grey seals and commercial fisheries, which in turn, would improve the efficacy of conservation and management efforts.

Keywords Juvenile dispersal · Immature survival · Telemetry · Iceland · Grey seal

Introduction

The transition from nutritional dependence to independence is a crucial life-history phase in many animals. In pinnipeds (seals, sea lions and walruses), weaning is governed by two life-history strategies that are broadly divided along phylogenetic lines (Houston et al. 2007). Specifically, otariids (fur seals and sea lions) are income breeders that have extended lactation periods (4 months to > 1 year), during which time nutritionally dependant pups develop the skills and physiological capacity required to successfully forage (Oftedal et al. 1987; Raum-Suryan et al. 2004; Baylis et al. 2005; Fowler et al. 2006). In contrast, many phocids (true seals) are capital breeders, characterized by short lactation periods (4 to 60 days), after which pups are abruptly weaned and undergo an often prolonged post-weaning fast (Oftedal et al. 1987; McConnell et al. 2002; Carter et al. 2017). Given the post-weaning fast is typically on land or ice, phocid neonates are naïve when they depart their natal colony and have limited time to find profitable foraging areas before protein reserves are diminished and the onset of terminal starvation (McConnell et al. 2002; Bennett et al. 2007; Noren et al. 2008; Blanchet et al. 2016; Carter et al. 2017). Accordingly, the at-sea spatial usage of recently weaned pups represents habitat that is critical to survival.

Grey seals (*Halichoerus grypus*) are a widely distributed capital breeding phocid. Consistent with other phocids, grey seal lactation is short (~ 18 days) after which pups undergo a post-weaning fast that lasts between nine and 40 days (Noren et al. 2008; Bennett et al. 2010). First-year mortality in grey seal pups is high, and ranges from 38% for females to 80% for males at some breeding locations (Hall et al. 2001). Grey

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seal pup mortality can therefore play a key role in the regulation of population dynamics, and quantifying habitat use during this vulnerable life stage is useful for assessing and mitigating threats (Harwood and Prime 1978; Sjöberg and Ball 2000; Carter et al. 2017). Consequently, grey seal pups (and juveniles) have been the focus of considerable tracking effort throughout much of their North Atlantic breeding range (Sjöberg and Ball 2000; Breed et al. 2011; Russell et al. 2015; Carter et al. 2017). Nevertheless, little is known about the ecology of grey seals breeding in Iceland and at-sea spatial usage is presently unknown. This is surprising given the long history of grey seal exploitation in Iceland, which includes hunting for subsistence and culls (a bounty system was initiated in 1982 to limit the perceived negative impact of seals on commercial fisheries) and because grey seals are common bycatch in commercial fisheries (Hauksson 2007; Marine and Freshwater Research Institute 2018). The Icelandic grey seal population has, however, been regularly censused since 1982 (Granquist and Hauksson 2019). Grey seals in Iceland increased to about 11,000 in 1990 but declined rapidly between 1990 and 1998 to < 6000 grey seals (Hauksson 2007). Since 1998, the population has fluctuated between 4000 and 6000 grey seals and is currently listed as vulnerable under the Icelandic Red List of Threatened Species (Granquist and Hauksson 2019). Data on the at-sea movements of grey seals could provide insights into the factors that have shaped recent population trends and will improve knowledge of important at-sea habitat. Accordingly, for the first time, we deployed satellite tags on grey seals in Iceland. Our aim was to quantify the movement and at-sea spatial usage of recently weaned grey seal pups during their first year of independence.

Methods

Approximately 140 pups or 10% of the total number of grey seal pups in Iceland are born in the Standir region (66.21°N, − 21.91°E), which is one of 21 sites where grey seals currently breed in Iceland (Granquist and Hauksson 2019). In late October, five moulted grey seal pups were captured using a hoop net, weighed (Salter hanging-scale 100 ± 0.5 kg) and manually restrained. Satellite tags (Wildlife Computer SPOT 287), which were approximately 0.2% of body mass, were attached to the neck of pups using a two-part epoxy glue (Devcon 5-min epoxy). Tags transmitted location data at 45 s intervals when at the surface and had an estimated battery life of 6 months. We defined a foraging trip as excursions > 4 km from land because the error associated with Argos locations made identifying foraging trips of short distance and duration challenging, and at other NE Atlantic breeding locations grey seals can remain in the water and close to shore when tidal haul-out sites are submerged (Costa et al. 2010; Carter et al. 2017). Hence, foraging trips were biased toward trips of longer distance and duration. Location outliers were removed by running a speed filter (3 m/s) implemented within the R package Argosfilter (Freitas et al. 2008). To more accurately estimate the locations of each animal along its trajectory, we fitted a continuous-time correlated random walk model implemented through the R package CRAWL (v2.1.1) (Johnson et al. 2008). The model accounted for error associated with the six Argos location classes (3, 2, 1, 0, A, B) and produced a best-fit track, with locations predicted hourly along the track. The best-fit track was used for all subsequent analysis. For each foraging trip, we calculated the maximum distance from the coastline (km), maximum distance from the deployment location (km), duration (d) and bathymetry (m). To characterize where individuals spent time, we calculated 50% (core area used) and 90% utilization distributions (UDs), using ad hoc kernel methods implemented within the R Package adehabitatHR (Calenge et al. 2009). We used bathymetry as a habitat grid to avoid UDs being projected over land.

Results and discussion

A total of 196 foraging trips were recorded for three male and two female grey seal pups (Table 1). Tracking duration ranged from 4 months to 1.2 years for individual grey seal pups (Table 1). All pups entered the water within 3 days of tag deployment, although days to first foraging trip (> 4 km) ranged between 12 and 52 days (Table 1). Foraging trips were predominantly restricted to continental shelf waters, with the exception of pup 164876 (average depth was 63 ± 30 m, range 38–112 m) (Fig. 1). These findings are unsurprising given adult grey seals at other breeding locations are characterized by a predominantly benthic foraging mode, and the proportion of benthic dives increases over time in recently weaned grey seals pups (Austin et al. 2006; Carter et al. 2017). Therefore, depth is an important habitat constraint, particularly for pups that have limited physiological capacity when compared to adults (Bennett et al. 2010; Carter et al. 2017). Maximum foraging trip distance from the coastline of Iceland ranged from 20 to 160 km for individual pups, which, along with bathymetry, highlights the importance of near-shore coastal waters to recently weaned grey seal pups (Table 1). Maximum duration ranged from 4.3 to 20.8 days (Table 1). At other grey seal breeding locations in the NE Atlantic, pup foraging trip distance and duration initially increased during the first two months of the post-weaning period, and subsequently declined, which likely reflects improved foraging efficiency with age and experience (Carter et al. 2017). Foraging trip distance and duration of grey seal pups in Iceland were variable over time (additional data are provided in Online Resource 1). However,

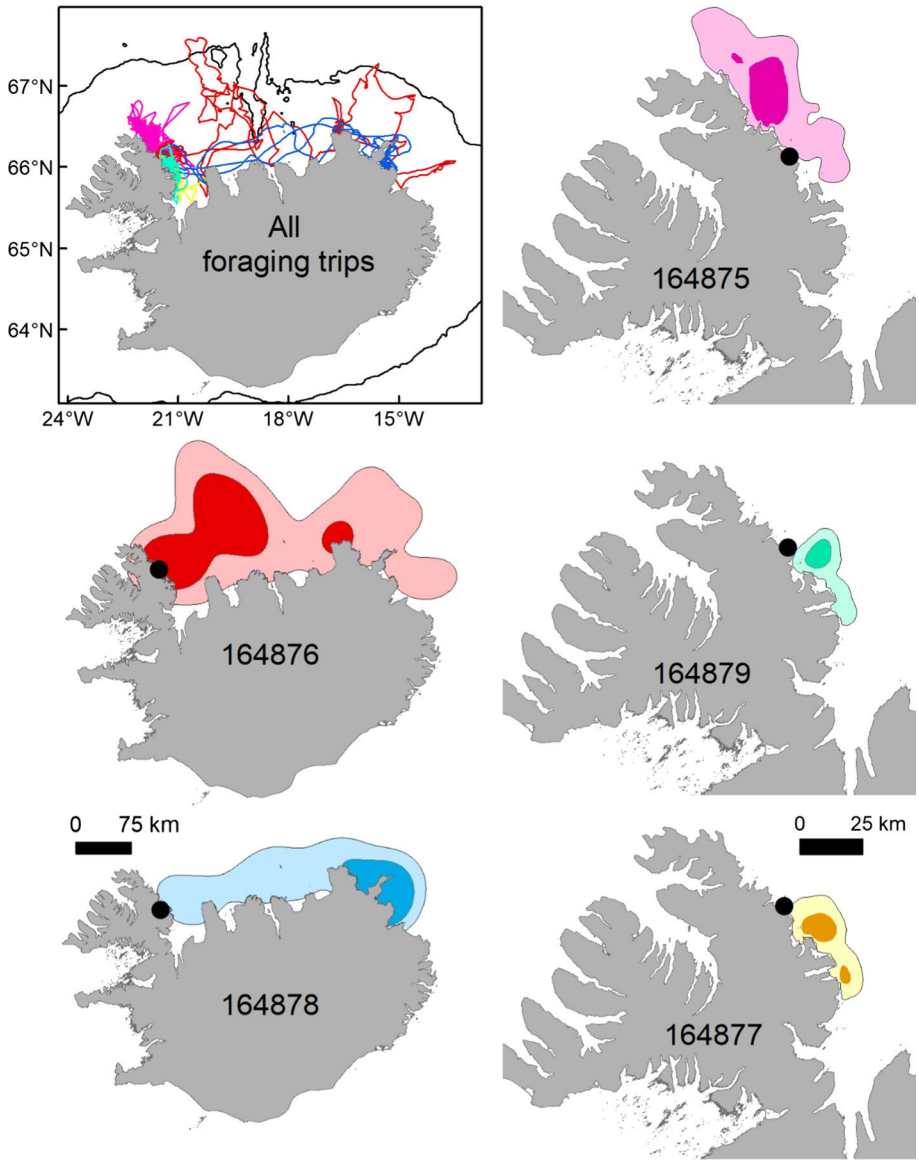

Fig. 1 The at-sea spatial usage of five grey seal pups post weaning. The upper left panel are foraging trips coloured by individual. The thin black line represents the 400-m bathymetric contour. The remaining panels are the 90% and 50% utilization distributions for each individual grey seal pup (lighter and darker colour shades, respectively). The black dot is the deployment location in the northwest of Iceland. (Color figure online)

our foraging trip definition (> 4 km from land) may have obscured trends and our small sample size limits robust analysis required to identify patterns over time in foraging trip metrics.

Two grey seal pups (one of each sex, pup ID 164876 and 164878) dispersed eastwards along the coast of northern Iceland in December and February, and reached distances of over 300 km from the deployment location (Fig. 1, Table 1). It is unclear why both pups dispersed to the east of Iceland. However, the North Icelandic Irminger Current, which predominantly flows eastwards, may facilitate dispersal, given current direction is associated with the movements of other marine predators (Cotté et al. 2007; Hunegnaw et al. 2009). The three other pups tracked remained near the deployment location and performed foraging trips of short distance and duration (Fig. 1, Table 1). At other NE Atlantic breeding locations, the movements of grey seal pups are also variable in the first few months after weaning, with some individuals remaining within 50 km of their natal colony while other individuals disperse and travel distances > 300 km (Carter et al. 2017). Hence, the movements of grey seal pups in Iceland are broadly consistent with grey seal pups at other NE Atlantic breeding locations. Limited sample size notwithstanding, our findings suggest at least two general grey seal post-weaning movement strategies exist in Iceland—to remain within close proximity to natal colonies or to disperse.

The factors that contribute to individual differences in the post-weaning movements of grey seal pups are unclear. Presumably, as grey seal pups gain experience and their foraging skills improve, they could adjust or acquire foraging strategies quickly, and track resources. For example,

Table 1 Deployment details and foraging trip metrics for five grey seal pups equipped with satellite tags in Iceland

Pup	Sex	Deployment date and days to first trip	Length (cm)	Mass (kg)	Foraging trips	Mean duration (d)	Max duration (d)	Mean max distance from coastline (km)	Max distance from coastline (km)	Max distance from natal colony (km)	Final foraging trip end date
164875	Male	22-Oct-16 (16)	117	–	73	2.19 ± 2.08	11.0	19 ± 13	95	100	26-Dec-17
164876	Male	23-Oct-16 (20)	117	50	19	3.03 ± 3.17	20.8	40 ± 45	165	409	16-March-17
164877	Male	23-Oct-16 (12)	119	51	27	1.35 ± 1.08	6.0	10 ± 5	23	79	24-June-17
164878	Female	22-Oct-16 (52)	117	52	25	1.41 ± 1.11	4.3	17 ± 15	46	339	26-Feb-17
164879	Female	22-Oct-16 (34)	122	–	52	1.36 ± 1.13	6.0	10 ± 5	28	52	04-July-17

grey seal pups rapidly increase diving capacity, as is evident from an increase in dive duration and depth in the first 40 days post weaning at other NE Atlantic grey seal breeding locations (Bennett et al. 2010; Carter et al. 2017). Improved physiological capacity combined with foraging success could influence whether pups disperse away from their natal colony, given pups must successfully forage to compensate for the energy expended in traveling extended distances over the duration of our study period. However, we acknowledge that unsuccessful pups might also disperse. In addition, dispersal could be a strategy to reduce intraspecific competition, which is likely to be higher in areas around breeding colonies, as is hypothesized for juvenile seabirds (Riotte-lambert and Weimerskirch 2013). Alternatively, the pre-weaning behaviour of pups could influence their post-weaning movements. Specifically, we observed grey seal pups voluntarily entering the water prior to weaning. This behaviour is also reported at grey seal breeding colonies in Norway, where two strategies are described—either neonatal pups remain ashore for the entire fasting period, or neonatal pups enter the water and develop swimming skills early (Jenssen et al. 2010). The latter is suggested to influence whether pups disperse (Jenssen et al. 2010). Finally, body condition or composition at weaning may have also influenced dispersal, given larger pups can fast for longer than smaller pups and have greater dive capability (Bennett et al. 2010). However, body mass was similar for the three grey seal pups weighed (Table 1). Although pups in Iceland were heavier at weaning than the average weaning mass reported at other breeding locations (e.g. Bennett et al. 2010), body mass offers little insight into individual variation in the movements that we report.

Finally, of the five pups tracked, one male pup (164876) was reported as bycatch in the lumpfish (*Cyclopterus lumpus*) gillnet fishery, a mainly shallow water fishery that operates between March and August (Marine and Freshwater Research Institute 2018). Coincidently, transmissions from pup 164878, which also dispersed to the east, ceased earlier than the estimated tag battery life, implying death or tag failure (Table 1). The remaining pups survived until tag batteries were expended. Pups that dispersed may have had lower survival probability because, by dispersing, they could have been more prone to fishery interactions. However, bycatch is estimated to be higher in the northwest of Iceland (northwest Iceland being the general region that includes Breiðarfjörður) rather than to the east, which is unsurprising given this region accounts for 76% of the total grey seal pup production (Marine and Freshwater Research Institute 2018; Granquist and Hauksson 2019). Estimates of grey seal bycatch are, however, impeded by compliance and reporting issues, which makes it difficult to assess seal–fishery interactions. The incidental bycatch of grey seals between 2014 and 2017 was estimated between 1034 and 1907 grey

seals annually for the lumpfish fishery. However, grey seals also interact with the Atlantic cod (*Gadus morhua*) gill net fishery, for which bycatch data are limited (Pálsson et al. 2015; Gascoigne et al. 2017; Marine and Freshwater Research Institute 2018). In addition to operational interactions, trophic interactions between grey seals and fisheries exists, given grey seal diet includes commercially important fish such as lumpfish and cod (Hauksson and Bogason 1997). Hence, fisheries are likely to be a prevalent threat to recently weaned grey seal pups, particularly when considering inexperienced juveniles are often more vulnerable to fishery bycatch than adults (Bjorge et al. 2002). Other potential threats include hunting (no formal reporting system exists, but anecdotal reports suggest hunting has declined in recent decades) and environmental change (Granquist and Hauksson 2019). Specifically, profound oceanographic changes have occurred around Iceland since the mid-1990s, such as the warming of sea water temperature related to an influx of warm Atlantic water, and concurrent shifts in the distribution and biomass of fish and krill (Víkingsson et al. 2015). In turn, this is associated with large declines in some seabirds and changes in the distribution of cetaceans around Iceland, which implies ecosystem wide changes from prey to predators (Víkingsson et al. 2015; Linnebjerg et al. 2018). Our preliminary findings provide baseline data on the at-sea spatial usage of grey seals and highlight the importance of near-shore waters to recently weaned grey seal pups. Additional research is required to quantify seal-fishery interactions in particular, which will ultimately improve the efficacy of management and conservation initiatives.

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Compliance with ethical standards

Conflict of interest The authors have no conflict of interests to declare.

Ethical approval Research was approved by the Icelandic Food and Veterinary Authority Animal Welfare Council, and conducted under permit MAST1608242 issued by the Icelandic Food and Veterinary Authority to AMMB.

Research involving animal rights All animal handling guidelines were followed.

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