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Haul-out behaviour of walruses (*Odobenus rosmarus*) monitored by camera stations - potential disturbance by tourist visitations

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Front-page photo: A magnified section of one of the 66,365 images analysed in this study, showing tourists visiting walruses hauled out on Lågøya

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Preface

This thesis has been written as an article for submission to the journal "Polar Biology". The manuscript has thus been prepared according to the author guidelines for this journal.

I would like to thank my supervisors Kit M. Kovacs and Christian Lydersen for giving me the opportunity to work with such an interesting and important project. I feel very privileged to have worked with, and learned from, such experienced marine mammal scientists. The fieldwork opportunities they have provided for me have been the most incredible experiences of my life. During these excursions I have had some amazing encounters with Arctic wildlife.

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Contents

Abstract The rapid growth of tourism in Polar Regions stimulates a need for investigating potential impacts on targeted species and sensitive areas, such as walrus (*Odobenus rosmarus*) haul-out sites. This study examines effects of tourist visitations on haul-out dynamics and site use by walruses in Svalbard, Norway. Camera stations were established at five traditional walrus haul-out sites that experience variable levels of tourist visitation. The cameras took one photograph each hour, throughout June-November from 2007-2015 (3 sites) and 2010-2015 (2 sites). A total of 66,365 images were analysed in this study. The number of walruses on shore, and % sea ice cover was estimated for each image. Additionally, the presence/absence of tourists, boats and polar bears (*Ursus maritimus*) was recorded. A log-linear regression model was run on residuals from an ARIMA model fitted to the time series. Site use by walruses was sometimes restricted by sea ice cover, but walruses were also absent (or present rarely) at some sites, despite a lack of sea ice. Tourists and boats did not disturb walrus haul-out behaviour significantly ($p>0.05$) at any of the study sites. Additionally, most polar bear visits were not associated with any detectable disturbance. However, polar bears did significantly disturb walrus herds at Andréetangen (p=3.47^-5) and Storøya (p=1.52^-5) in some years. These disturbances were likely associated with predation attempts on calves. Given the increasing number of calves in Svalbard, and the high numbers of bears on shore during increasingly longer ice-free seasons, such disturbances are likely to increase in the future.

Key words Arctic, disturbance, pinnipeds, polar bear, predation, sea ice, Svalbard

Introduction

Tourism in the Arctic has increased markedly in the past few decades. Tourists are drawn to the region to explore this relatively pristine environment and its unique wildlife (Hagen et al. 2012). This rapid growth of tourism, including that taking place in the Svalbard Archipelago (Norway), stimulates a need for knowledge of the potential effects this industry may have on targeted species and sensitive areas, such as walrus haul-out sites. Walruses are highly social animals that assemble on land or sea ice (i.e. haul out) in densely packed groups (Gjertz et al. 2001). Walruses exhibit a strong preference for sea ice as a haul-out platform, but during the summer months, when sea ice over shallow coastal feeding grounds is not available, they rest on shore at traditional sites (Gjertz et al. 2001). In Svalbard, many of these sites are experiencing increased exposure to human activities, particularly during the summer season, when they are being visited more frequently by marine cruise tourist expeditions (Pedersen et al. 2015). Cruise operators conduct small boat tours away from the ships and undertake tourist landings on shore, where guided groups disembark near walrus haul-out sites. Little is known about the potential effects of these visitations.

Terrestrial walrus haul-out sites on the east coast of Svalbard are all located within nature reserves (Pedersen et al. 2015). The current management plan for these reserves includes guidelines for how visitors should behave near walrus herds, in order to prevent disturbance and potential harm to the animals, noting the particular sensitivity of herds that contain females and calves (Pedersen et al. 2015). Hauled out walruses typically rush into the water when alarmed (Salter 1979) and thus disturbances that cause the herd to panic may result in stampedes that can kill calves and yearlings. Demographic studies have shown that disturbance-related mortality can have negative impacts at the population level in walruses (Udevitz et al. 2013).

Walruses in Svalbard belong to a genetically distinct population that is distributed within the Svalbard and Franz Josef Land (Russia) archipelagos (Wiig et al. 1996; Andersen et al. 1998). Most of the males in this population summer in Svalbard, while most of the females and calves haul-out in Franz Josef Land over the summer months. Although it is common in walruses for adult males, and adult females with calves or yearlings to haul out in different areas (Fay 1982), the extreme male dominance seen currently in Svalbard is not typical for a population distributed over such a large area. Historically, females were much more common in the southeastern parts of Svalbard, prior to a period of extreme exploitation (Wiig et al. 2007). After almost 350 years of unregulated harvesting, walruses in Svalbard became protected in 1952, and the population is currently recovering (Kovacs et al. 2014). In recent years, the total number of walruses and the number of mother-calf pairs is increasing in Svalbard, and the animals have started to occupy haul-out sites in coastal areas that have not been used since the hunting period (Lydersen et al. 2008; Kovacs et al. 2014). The increasing presence of young animals in particular increases potential for disturbance, and disturbance-induced mortality.

Gilg et al. (2012) suggested that changes in behaviour, diets and ecological interactions, are expected short-term consequences of climate change on Arctic vertebrates. For walruses specifically, Kovacs et al. (2011) predicted that this species is likely to be impacted by climate change through declines in Arctic benthic production and reductions in sea-ice breeding habitats over shallow, coastal feeding grounds. Additionally, in terms of ecological interactions, it is likely that polar bears and walruses in Svalbard will interact more frequently in the future, as the retreating Arctic sea ice forces both these species to spend longer periods in coastal areas (Jay et al. 2012; Hamilton et al. 2017). Walruses rarely occur in the polar bear diet on Svalbard currently (Iverson et al. 2006), but the increasing numbers of calves present in the archipelago might result in polar bears targeting walrus herds more often.

In order to assess potential effects of disturbance on walrus haul-out sites in Svalbard, this study investigated the temporal dynamics of walrus haul-out behaviour at traditional haul-out sites. Selected study sites had variable levels of tourist visitation, ranging from undisturbed sites to sites that were visited almost daily during the summer months, in order to assess potential impacts of visitation. Furthermore, it was investigated whether the presence of polar bears and availability of sea ice affected the haul-out dynamics of walrus herds.

Materials and methods

Study sites

Automated camera stations were established at five traditional, land-based walrus haul-out sites on Svalbard, Norway at Lågøya, Storøya, Kapp Lee, Andréetangen and Havmerra (Fig. 1). The sites were selected based on previous knowledge that they were commonly used by walruses during summer (Lydersen et al. 2008; Kovacs et al. 2014), and because they were exposed to varying levels of tourist visitations (Pedersen et al. 2015). Topography also played a role in site selection. Study sites were chosen where it was possible to cover most of the potential haul-out area in one image taken from stationary cameras. At each site, a SONY cyber shot compact camera was attached toward the top of a 5 m high aluminium mast. The cameras were enclosed in a modified PELI case for waterproofing and attached to an external battery source. Due to sporadically occurring technical failures, a compact digital single-lens reflex camera with an 18-55mm lens was added to each camera station in 2010. The backup cameras were connected to batteries charged by solar panels. Each camera took one image per hour throughout the sampling period, with an image resolution of 1-5 megabytes. Images were taken from June/July until October/November, depending on the date the cameras were deployed in a specific season and the battery life. The camera station at Lågøya, Andréetangen and Havmerra were operative from 2007-2015, while the camera stations at Storøya and Kapp Lee were operative from 2010-2015 (see Table 1).

Photo-analysis and data collection

The total number of walruses hauled out on shore was estimated for each image. Due to the relatively low angle of view of the cameras and the tight clustering of the herds, it was often impossible to determine the exact number of animals. Thus, the number of walruses present was estimated and recorded in 12 numerical classes: 1) 0 walruses, 2) 1-10, 3) 11-20, 4) 21-30, 5) 31-40, 6) 41-50, 7) 51-60, 8) 61-70, 9) 71-80, 10) 81-90, 11) 91-100 and 12) >100.
In cases where animals hauled out far away from the camera, a zoom-in function was used to obtain a more accurate count. From June until early September, 24 hr daylight prevailed and the sites could be observed throughout the day and night. When day-night cycling began in September, dark periods were recorded as not available (NA). Additionally, when

sporadically occurring battery failures resulted in series of missing images, and when the camera field of view was impaired by fog or snow on the lens, the data points were recorded as NA.

In order to evaluate the availability to the land-based haul-out sites, the percentage of near-shore sea ice cover was estimated in each image. In addition, the presence/absence of people, boats and polar bears was recorded. Large ships observed far away, on the horizon were not recorded, as these boats were unlikely to have effects on the animals. Tourist site visitation records, provided by the Governor of Svalbard, were used to document the total number of people on shore at each haul-out site, each year. Additionally, the dates when tourist visited the sites from 2008 to 2015 were obtained from post-visitation reports, which tourist operators must report to the Governor of Svalbard each year.

Data Analysis

An Autoregressive Integrated Moving Average (ARIMA) model, implemented with the 'arima' function from the R 'stats' package in R version 3.2.5 (R Core Team 2016), was fitted to each walrus count time series. The counts (x) were log-transformed prior to analyses, and a log(x+1) transformation was selected due to zero inflation in the time series. The residuals were symmetrically distributed after transformation (Fig. 2a). Akaike's Information Criterion (AIC) was used for model selection, resulting in a model fitted with 1st order auto-regression, 1st order difference and a 2nd order moving average. These parameters did not produce the best fit for all of the time series, but they did produce the lowest, or second lowest, AIC scores for more datasets than models with more or less complex combinations of parameters.

The residuals from the ARIMA (1,1,2) model were assumed to appropriately represent the magnitude and direction of the deviation from the expected change by the model. Accordingly, changes in the number of walruses hauled out on shore between two time steps under non-disturbed conditions should be associated with small residuals. In contrast, abnormally rapid decreases and increases are expected to be associated with large, negative and positive residuals. Due to the high frequency of extremely small residuals (Fig. 2a), the walrus numbers were grouped into three numerical categories prior to analysis. The assignment of residuals to each category was based on the initial residual frequency distribution and the absolute change in walrus numbers associated with the residuals (Fig. 2a, b). The frequency distribution indicated that most residuals were distributed between ±0.25. This interval (±0.25) represents a deviation of -22% or 28% from the expected change in the number of walruses hauled out between two time steps (Fig. 2a). Residuals distributed from -1 to -0.25 (-63 to -22%) and from 0.25 to 1 (28% to 172%) were much less frequent, but still relatively frequent compared to the most extreme values recorded. Residuals distributed between ±1 were sometimes associated with no change in walrus numbers (Fig. 2b). Accordingly, any deviations less than -1 (-63%) or greater than 1 (172%) were considered rare and extreme enough to represent an abnormal change in walrus numbers, and thus were deemed representative of a disturbance event. Residuals distributed between ±1were classified as 0 (no disturbance), and the remaining negative and positive residuals were classified into negative and positive categories.

A log-linear regression model (Poisson distribution with a log-link) was implemented with the 'glm' function from the R 'stats' package (R Core Team 2016) on residuals, distributed over three categories. The model was used to test whether the distribution of residuals differed between the presence/absence of potentially disturbing factors (tourists, boats or polar bears). A Likelihood Ratio Test (which has a Chi-squared distribution under the null hypothesis of independence between disturbance and residual categories) was used to compare models (R Core Team 2016). The selected model included the interaction between year of study (as factor) and presence/absence of potentially disturbing factors, and the interaction between residual size (average=0, positive or negative) and presence/absence of potentially disturbing factors. Some large changes in walrus numbers were occasionally associated with polar bear presence in the image prior to or after the one where the observed change occurred, i.e. the bear was observed at time t-1 or time t+1 while the change in walrus numbers occurred at time t. By definition, the statistical analysis only associates polar bear presence at time t with residuals at time t.

Data from the tourist post-visit reports were used to calculate the percentage of tourist landings reported vs. visitations detected in the images taken by the camera stations, and vice versa.

Results

Twenty-eight sets of images (of a possible 39) were collected for the current study and 66,365 images were analysed (Table 1). Large deviations (residual size) in the change in walrus numbers between two time steps were rarely recorded; the norm was extremely small deviations (Fig. 2a). However, some abnormally rapid decreases (<-63%) and increases (>172%) were recorded. The absolute deviations in walrus numbers associated with these abnormally large changes ranged from -5 to -100, and from 5 to 90 animals (Fig. 2 a). Generally, once a walrus haul-out had been initiated at an empty beach, the number of animals increased gradually until it reached a turning point after which the number of animals hauled out began to decrease (Figs 3-7). The temporal fluctuations in walrus numbers sometimes resulted in a site becoming completely abandoned, while at others times the number of animals started to increase again before numbers reached zero. These gradual increases and subsequent decreases in the number of walruses hauled out resulted in sporadically occurring peaks of varying sizes throughout the sampling period at each site (Figs 3-7). The longest periods with animals continuously present on shore was 29 days at Andéetangen, 17 days at Lågøya, 5 days at Kapp Lee, 9 days at Havmerra and 4 days at Storøya.

No walruses were observed at Lågøya in 2009 or at Storøya in 2014. The shorelines at these two sites were covered by sea ice in the early part of the summer at these sites and intermittently thereafter (Fig. 8). At Andréetangen in 2008 and 2010, and at Havmerra in 2007, 2008 and 2015, walruses began to haul out on shore soon after there was open water in front of the beach. At Havmerra in 2010, 2012 and 2013, there was no near-shore sea ice for the majority of the sampling period. However, in 2010 and 2012 there were long periods with no animals hauled out, and in the rare cases when haul-out occurred it only involved small groups (1-10). In contrast, haul-outs were frequent and often large (>100) in 2013. In all recorded years at Andréetangen, walruses hauled out frequently and in large groups (>100) from late June until the end of the sampling period. Despite little sea ice cover at Kapp Lee, animals were rarely present at this site and occurred only in low numbers when they did haul out.

According to tourist records provided by the Governor of Svalbard, Kapp Lee was the most visited site by tourists, with an average of >1000 people on shore each summer (Fig. 1). Lågøya was the second most visited site (500-1000), followed by Andéetangen (100-500), Storøya (1-100) and Havmerra (0) (Fig. 1). Similar relative levels of human traffic were observed in the images collected in the current study. People were most frequently observed at Kapp Lee (Table 2). The number of images where human presence was observed within a season ranged from 0 to 49 among the various sites. People were never observed at Havmerra. On average, 46% of tourist landing dates recorded in post-visit reports corresponded with dates when people were observed on shore in images collected at the haul-out sites (Table 3). Moreover, 35% of days when people were observed in photos corresponded with days reported in post visit reports, on average.

Boats near the shoreline were observed most frequently at Andréetangen and Kapp Lee (Table 2). The total number of images where boats were observed ranged from 1-72 at Andréetangen and 11-21 at Kapp Lee among the sampling years. At Lågøya and Storøya, the total number of images where boats were observed ranged from 0-4, whereas no boats were observed at Havmerra throughout the study period.

Storøya experienced the highest number of polar bear visits within a season, with >100 images containing bears in both 2010 and 2012 (Table 2). However, no bears were observed at Storøya in 2014, when the walruses were absent and the shoreline was covered by sea ice throughout the majority of the sampling period. The number of images with polar bears were much lower at the other sites (Lågøya 0-22; Andréetangen 0-22; Havmerra 0-3; Kapp Lee 0-2).

Most tourist groups observed in the images remained at considerable distances (100+ m) to the walruses when animals were present on shore (Fig. 9a), but some smaller groups of people (not associated with official tourist cruise operators) were occasionally observed very close to the animals (Fig. 9b). Polar bears came close to hauled out walruses at all five sites, generally without causing obvious signs of disturbance (Fig. 9c). However, at sites where mother-calf pairs occurred, bears clearly induced panicked reactions in the herd, causing large and rapid decreases in the number of animals hauled out on shore (Fig. 9d). Walrus calves were commonly observed in the walrus herd at Storøya, with adults between them and nearby polar bears (Fig. 9e). At sites where mother-calf pairs occurred, small walruses were often found near or in the water when a polar bear was nearby, while large animals hauled out higher up on the beach remained on shore (Fig. 9f). Large walruses remained undisturbed, despite the presence of both polar bears and zodiacs nearby on occasion (Fig. 9g), and they also remained hauled out during periods with snowfall and windy conditions (Fig. 9h).

No significant effects were detected due to the presence of humans or boats on the number of walruses hauled out at any of the sampled sites (Tables 4, 5). However, at Andréetangen and Storøya, there were significant, negative effects associated with the presence of polar bears (Table 6). Presence of polar bears in time t was associated with residuals <-1 and >1 at Andréetangen in 2013, and at Storøya in 2010 and 2012 (Figs 10, 11). In these three time series, the relative frequency of large negative residuals (<-1) was higher when bears were present, compared to when they were absent (Fig. 10). In a few cases, large positive residuals (>1) were associated with large increases in absolute walrus numbers (>60 animals). These events were associated with build-ups of walrus herds immediately following a polar bear disturbance. However, most polar bear observations in the times series were associated with small residuals, including the three time series where negative effects were found. Moreover, residuals at time t were sometimes associated with bears observed at time t-1 or t+1, but not observed at time t (Fig. 11). Large positive residuals were also associated with groups initiating a haul-out event at a previously empty beach, with animals arriving in large numbers once a "seed-point" was set.

Discussion

This is the first study to use automated camera systems to monitor walrus haul-out dynamics at multiple terrestrial haul-out sites over multiple years during the summer and fall. Strong temporal trends were detected in haul-out dynamics of walruses in Svalbard, with gradual, or more rarely precipitous, increases and subsequent decreases in the number of animals on shore being the normal pattern. Similar temporal fluctuations in walrus numbers have been observed at a terrestrial haul-out sites in the Canadian Arctic (Salter 1979; Miller and Boness 1983). It remains uncertain what factors drive these natural fluctuations in group size, although plane overflights, dogs and polar bear attacks are known disturbance factors that cause declines in the numbers of animals at haul-out sites (e.g. Salter 1979; Miller 1982; Efroymson and Suter 2001).

The maximum number of sequential images where walruses were observed on shore varied between years and sites. Sometimes walruses were continuously hauled out only for a few hours or days, whereas at other times animals were observed on shore continuously for almost a month at a given site. It has previously been shown that walruses spend ~30% of their time hauled out (Born and Knutsen 1997), and that haul-out durations are longer during the summer months (Hamilton et al. 2015). The average individual terrestrial haul-out duration for adult male walruses in Svalbard ranges from ~20 hrs in August (Gjertz et al. 2001; Hamilton et al. 2015) to 16 hrs in September (Hamilton et al. 2015). Haul-out durations reported for male walruses in Svalbard during August and September are shorter than those reported for males in NE Greenland (38 hr; Born and Knutsen 1997). The relatively short times spent on shore by individual animals in Svalbard suggest that there must be a continuous exchange of individuals hauling out during times when animals are present on shore for long periods. Satellite relay data loggers attached to walruses have shown that individuals do move between different sites within a season (Lydersen et al. 2008), thus the total number of individuals visiting the sites monitored in the current study is likely vastly higher than the maximum numbers estimated by the hourly images.

Walruses in Svalbard are generally absent from terrestrial haul-out sites when near-shore sea ice is available for haul-out, with the exception of a few occasions when animals hauled out on the land-fast ice in the immediate area of a haul-out. At most sites, the walruses began to haul out on shore only when the ice disappeared and there was open water in front of the beaches. Despite the occurrence of long periods with no onshore sea ice cover, the walruses were almost completely absent at Havmerra in 2010 and 2012, a site that was frequently used in previous and subsequent years. This is the only study site that had no tourist visitations at all during this study, so the absence of walruses at this site was not human-disturbance related. The reason for this absence is probably that there are many islands with suitable haul-out sites very close by, so the animals have many opportunities to haul out in this general area without being detected by the camera stations. At Storøya, in 2014, when the shoreline was completely covered by ice throughout the majority of the season, no walruses were observed.

Previous studies have shown that weather parameters, such as wind speed, ambient temperature and wind chill, impact haul-out behaviour in walruses (Born and Knutsen 1997; Jay et al. 2017; Hamilton et al. 2015), similar to other pinniped species (Born and Knutsen

1997; Carlens et al. 2006; Hamilton et al. 2014). Walruses generally prefer to haul out during periods with warm temperatures and little wind (Salter 1979; Fay 1982; Udevitz et al. 2009), and the most obvious reason for this preference is their need to maintain thermal balance. However, several studies conducted on walruses in Svalbard have found that weather conditions in this region in summer do not impact haul-out behaviour of walruses (Lydersen et al. 2008; Hamilton et al. 2015), presumably because the weather is mild enough to represent no thermal challenge for the animals. In this study, even snowy and windy conditions did not seem to impact haul-out behaviour (Fig. 9h) and accordingly, weather parameters were not included in the analyses of haul-out behaviour.

The number of walruses hauled out in Svalbard in the summer months was not significantly influenced by the presence of people near the herds. However, on one occasion, a large rapid reduction in walrus numbers was associated with the presence of a zodiac at Storøya. This observation corresponds with reports from previous studies where walruses responded to motor-induced disturbance by retreating quickly into the water (Salter 1979), suggesting that improper approaches can result in disturbance. Despite the observed disturbance associated with this single zodiac incidence, no general effect of boats near the herds was detected in this study. According to guidelines provided by the Association of Arctic Expedition Cruise Operators (AECO), tourist groups should stay at least 30 m away from all-male walrus colonies and 150 m away from colonies containing females with calves (AECO 2017). These guidelines also state that visitors must disembark at least 300 m away from the haul-out site, and stay downwind from the animals. Although the temporal resolution of the current study was limited to one image each hour, observations of visitors at haul-out sites indicate that organised tour groups generally follow these recommended guidelines. However, other visitors from small private boats sometimes exhibited behaviour that did not follow AECO guidelines. Despite the occurrence of close approaches to the animals by these visitors, no significant disturbance events were detected involving people. Direct, intentional interactions with walruses for the purposes of scientific studies does induce behaviour changes in walruses, with increased alertness and dispersal in the herd taking place close to the disturbance site (e.g. Jay et al. 1998, pers. observations). However, walrus behaviour quickly returns to normal (avg. 40 min; Jay et al. 1998), suggesting that walruses are quite robust to infrequent disturbances of short duration. It is possible that walruses in Svalbard are relatively accepting of the presence of humans compared to areas where they are currently still hunted (e.g. Greenland, Eastern Canadian Archipelago, Alaska). Studies have showed that there were less than 100 animals left in Svalbard, prior to their protection from hunting in 1952 (Born 1984). In subsequent years, animals have migrated from Franz Josef Land where little hunting took place (Wiig et al. 1996). Given that the Svalbard population has been protected for over 50 years, walruses in the region have no experience with threats from human hunters.

Approximately half of the tourist landings reported in government post-visit reports were not detected in the photographic records at the study sites. Some landings may not have been caught on camera because the tourists landed for reasons other than visiting the walrus haul-outs (f. inst. cultural sites at Andréetangen and Kapp Lee or rare bird nesting sites at Lågøya; Pedersen et al. 2015). Tourist groups might also have been missed because of the low temporal resolution of the sampling; coming and leaving again within a time interval in which no images were taken. However, considering the large number of observed visits, and their lack of detectable impacts on the walruses, these undetected landings were unlikely to have caused disturbance to the walrus herds. Many visitations to the walrus haul-out sites observed in this study were not reported to the Governor's office by tourist operators, suggesting that the majority of landings are conducted by people that are not associated with registered cruise-ship operators.

Walruses remained undisturbed during most polar bear visits in the current study. Previous observers have reported aggressive behaviours by adult walruses towards approaching bears, such as threatening roars and swinging tusks (Popov 1958, translated in Fay 1982; Ovsyanikov 1996). The majority of walruses summering in Svalbard are adult males, as most females and calves remain in Franz Josef Land during this period (Wiig et al. 1996; Andersen et al. 1998). Given their large bodies, long tusks and aggressive behavior, it is likely that large male walruses have the capacity to fatally wound a polar bear. There is no scientific documentation of such an event, though it is speculated to occur (Kiliaan and Stirling 1978). The behavioural responses of all-male groups of walruses to the presence of bears suggests that polar bears do not represent a risk to them, thus the bears are usually ignored. However, in some years at Andréetangen and Storøya, the presence of polar bears was found to disturb the walrus herds significantly. The frequency of these disturbance events was likely underestimated, because bears were in some cases only observed before or after the walruses had retreated into the water, and not at the exact time of the disturbance (time=t), so the effect of their presence could not be detected in the statistical analysis. According to a recent population survey of walruses in Svalbard, Andréetangen and Storøya were the only two haul-out sites, out of the five included in the current study, where mother-calf pairs are observed (Kovacs et al. 2014). Close inspections of images from these two sites, especially Storøya, show that many individuals located on the lower part of the beach and in the shallows are small individuals, including calves. This spatial structuring by age and sex has also been documented at walrus haul-out sites elsewhere in the species range (e.g. Miller 1976, Miller and Boness 1983). Additionally, the groups containing young animals at Andréetangen and Storøya were more easily scared into the water when bears were present compared to larger walruses hauled out further up on the beach. Thus, it seems like the disturbing effect of polar bears at walrus haul-out sites depends on the age-sex composition of the group, suggesting that some bears attempt to predate on walrus calves in some years at these sites.

Polar bear attacks and predation attempts on walruses have been documented in many previous observational studies (Popov 1958, translated in Fay 1982; Calvert and Stirling 1990; Rugh 1993; Ovsyanikov 1996). Although most of these attacks were unsuccessful, polar bears do occasionally capture and kill walruses. Detailed descriptions of a polar bear killing a walrus calf in the Chukchi Sea have been documented by Rugh (1993). Over a four year period, Ovsyanikov (1996) reported 35 predation attempts by polar bears on walruses hauled out on shore. Two of the observed attacks were successful, and in both cases, it was calves that were killed. Although it appears that polar bears rarely pose a serious threat to adult walruses, bears have been observed successfully capturing and killing adults (e.g. Calvert and Stirling 1990). Moreover, indirect walrus mortality can be induced by polar bears when attempted hunts cause alarm responses in walrus herds and induce rapid retreats into the water (Ovsyanikov 1996). Such disturbances can result in stampedes of calves located on the lower parts of the beach, and there has been speculation that some bears use this strategy to get access to walrus calf carcasses (Popov 1958, translated in Fay 1982). Dietary studies have confirmed that polar bears occasionally feed on walruses in some areas in the Canadian Arctic (Iverson et al. 2006; Galicia et al. 2016). Although dietary studies are unable to distinguish between polar bears scavenging or actively preying on walruses, they provide indications of ecological interactions. For example, Galicia et al. (2016) found that walrus consumption was higher and more frequent in adult male polar bears compared to females. Based on these findings they argued that walruses were actively hunted rather than scavenged, considering that adult male bears may be twice the size of females (Derocher et al. 2005, 2010), and thus more capable of attacking large prey such as walruses. Previous studies on polar bear diet in

Svalbard have not found traces of walruses (Derocher et al. 2002; Iversen et al. 2013), suggesting that walruses are not common prey for bears in this area.

Occasionally, rapid decreases in the number of walruses hauled out on shore occurred without the presence of any apparent disturbing factors. Similar observations were made by Calvert and Stirling (1990), who reported that walruses sometimes rushed into the water when no obvious source of disturbance was present. On some rare occasions, rapid increases in walrus numbers were detected, with the most extreme cases being recorded at Andréetangen and Storøya. These extreme increases in the number of animals on shore sometimes occurred shortly after events with large reductions in numbers, some of which were polar bear related. Popov (1960, translated by Fay 1982) reported similar patterns, where adult male walruses abandoned haul-outs due to polar bear disturbances, but quickly returned to the same place after the bears left. Some rapid increases were detected in this study in connection with establishment of a haul-out at a previously empty beach. In these cases, the site was often visited repeatedly by one or a few individuals who remained in the water and left the beach empty. Eventually, when an individual came ashore, it induced a rapid build-up of numbers resulting in a large group. These observed patterns suggest that many individuals were present in the water close-by, and all that was needed was one or a few individuals to initiate the haul-out.

The Barents Sea region, where the Svalbard-Franz Josef Land population of walruses occur, has experienced the most extreme losses of summer sea ice in the entire Arctic (Laidre et al. 2015). The duration of the ice-free period has increased with more than 20 weeks between 1979-2013 (Laidre et al. 2015). It has been shown in other Arctic regions that space use and foraging patterns in walruses is strongly dependent on sea ice (Beatty et al. 2016), and that animals are forced to spend more time feeding in nearshore areas in years with little sea ice over the continental shelf (Jay et al. 2012). As sea ice continues to retreat, similar changes are expected for walruses in Svalbard. Additionally, recent studies have shown that polar bears in Svalbard are forced to search for food on shore as their access to sea ice and ice-associated prey are reduced (Prop et al. 2015, Hamilton et al. 2017). The increasing association of both walruses and polar bears with land is almost certainly causing greater temporal and spatial overlap the two species in Svalbard. This overlap is creating a situation with increasing potential for polar bear predation on walruses in the future.

Conclusions

Human visitation at walrus sites in Svalbard did not cause disturbance effects. However, polar bears did occasionally induce large disturbances of walrus herds at terrestrial haul-out sites. These disturbances are likely associated with predation attempts on younger animals, although no kills were documented in this study. Increasing number of walrus calves at terrestrial haul-out sites in Svalbard, and increasing presence of bears on shore during the ice free season are likely to result in increased walrus – polar bear confrontations in the future. Despite the fact that no disturbance effects were documented as a result of visiting tourists, it is important to maintain the current recommendations for how tourists should behave near walrus haul-out sites. It is especially important to keep a safe distance away from haul-out groups containing females and calves, in order to minimize the risk of disturbance. Walruses across the Arctic are facing a variety of climate-related challenges (Kovacs et al. 2011); so tourist-associated disturbances should be avoided to minimize cumulative impacts on these animals.

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References

Andersen LW, Born EW, Gjertz I, Wiig Ø, Holm LE, Bendixen C (1998) Population structure and gene flow of the Atlantic walrus (*Odobenus rosmarus rosmarus*) in the eastern Atlantic Arctic based on mitochondrial DNA and microsatellite variation. Mol Ecol 7:1323-1336

Association of Arctic Expedition Cruise Operators (AECO) (2017) Walrus. Retrieved from: https://www.aeco.no/guidelines/wildlife-guidelines/ Accessed 7 April 2017

Beatty WS, Jay CV, Fischbach AS, Grebmeier JM, Taylor RL, Blanchard AL, Jewett SC (2016) Space use of a dominant arctic vertebrate: Effects of prey, sea ice, and land on pacific walrus resource selection. Biol Conserv 203:25-32

Born EW (1984) Status of the Atlantic walrus *Odobenus rosmarus rosmarus* in the Svalbard area. Polar Res 2:27-45

Born EW, Knutsen LØ (1997) Haul-out and diving activity of male Atlantic walruses (*Odobenus rosmarus rosmarus*) in NE Greenland. J Zool, Lond 243:381-396

Calvert W, Stirling I (1990) Interactions between polar bears and overwintering walruses in the Central Canadian High Arctic. Bears: Their Biology and Management 8:351-356

Carlens H, Lydersen C, Krafft BA, Kovacs KM (2006) Spring haul-out behavior of ringed seals (*Pusa hispida*) in Kongsfjorden, Svalbard. Mar Mamm Sci 22:379-393

Derocher AE, Andersen M, Wiig Ø (2005) Sexual dimorphism of polar bears. J Mammal 86:895-901

Derocher AE, Andersen M, Wiig Ø, Aars J (2010) Sexual dimorphism and the mating ecology of polar bears (*Ursus maritimus*) at Svalbard. Behav Ecol Sociobiol 64:939-946

Derocher AE, Wiig Ø, Andersen M (2002) Diet composition of polar bears in Svalbard and the western Barents Sea. Polar Biol 25:448-452

Efroymson RA, Suter II (2001) Ecological risk assessment framework for low-altitude aircraft overflights: II. Estimating effects on wildlife. Risk Anal 21:263-274

Fay FH (1982) Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. N Am Fauna 74:1-279

Galicia MP, Thiemann GW, Dyck MG, Ferguson SH, Higdon JW (2016) Dietary habits of polar bears in Foxe Basin, Canada: possible evidence of a trophic regime shift mediated by a new top predator. Ecol Evol 6:6005-6018

Gjertz I, Griffiths D, Krafft BA, Lydersen C, Wiig Ø (2001) Diving and haul-out patterns of walruses *Odobenus rosmarus* on Svalbard. Polar Biol 24:314-319

Gilg O, Kovacs KM, Aars J, Fort J, Gauthier G, Grémillet D, Ims RA, Meltofte H, Moreau J, Post E, Schmidt NM, Yannic G, Bollache L (2012) Climate change and the ecology and evolution of Arctic vertebrates. Ann N Y Acad Sci 1249:166-190

Hagen D, Vistad OI, Eide NE, Flyen AC, Fangel K (2012) Managing visitor sites in Svalbard: from a precautionary approach towards knowledge-based management. Polar Res 31, 18432, doi:10.3402/polar.v31i0.18432

Hamilton CD, Kovacs KM, Ims RA, Aars J, Lydersen C (2017) An Arctic predator-prey system in flux: climate change impacts on coastal space use by polar bears and ringed seals. J Anim Ecol in press

Hamilton CD, Kovacs KM, Lydersen C (2015) Year-round haul-out behaviour of male walruses *Odobenus rosmarus* in the northern Barents Sea. Mar Ecol Prog Ser 519:251-263

Hamilton CD, Lydersen C, Ims RA, Kovacs KM (2014) Haul-out behaviour of the world's northernmost population of harbour seals (*Phoca vitulina*) throughout the year. PLoS ONE 9, e86055. doi:/10.1371/journal.pone.0086055

Iversen M, Aars J, Haug T, Alsos IG, Lydersen C, Bachmann L, Kovacs KM (2013) The diet of polar bears (*Ursus maritimus*) from Svalbard, Norway, inferred from scat analysis. Polar Biol 36:561-571

Iverson SJ, Stirling I, Lang SLC (2006) Spatial and temporal variation in the diets of polar bears across the Canadian Arctic: indicators of changes in prey populations and environment. In: Wanless S, Boyd IL, Camphuysen CJ (eds) Top predators in marine ecosystems. Their role in monitoring and management. Cambridge Univ Press, pp 98-117

Jay CV, Fischbach AS, Kochnev AA (2012) Walrus areas of use in the Chukchi Sea during sparse sea ice cover. Mar Ecol Prog Ser 468:1-13

Jay CV, Olson TL, Garner GW, Ballachey BE (1998) Response of Pacific walruses to disturbances from capture and handling activities at a haul-out in Bristol Bay, Alaska. Mar Mamm Sci 14:819-828

Jay CV, Taylor RL, Fischbach AS, Udevitz MS, Beatty WS (2017) Walrus haul-out and in water activity levels relative to sea ice availability in the Chukchi Sea. J Mammal 98:386-396

Kiliaan HPL, Stirling I (1978) Observations on overwintering walruses in the eastern Canadian High Arctic. J Mammal 59:197-200

Kovacs KM, Aars J, Lydersen C (2014) Walruses recovering after 60+ years of protection in Svalbard, Norway. Polar Res 33, 26034, doi: 10.3402/polar.v33.26034

Kovacs KM, Moore S, Overland JE, Lydersen C (2011) Impacts of changing sea-ice conditions on Arctic marine mammals. Mar Biodiv 41:181-194. -0061-0

Laidre KL, Stern H, Kovacs, KM, Lowry L, Moore SE, Regehr EV, Ferguson SH, Wiig Ø, Boveng P, Angliss RP, Born EW, Litovka D, Quakenbush L, Lydersen C, Vongraven D, Ugarte F (2015) Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conserv Biol 29:724-737

Lydersen C, Aars J, Kovacs KM (2008) Estimating the number of walruses in Svalbard from aerial surveys and behavioural data from satellite telemetry. Arctic 61:119-128

Miller EH (1982) Herd organisation and female threat behaviour in Atlantic walruses *Odobenus rosmarus rosmarus* (L.). Mammalia 46:29-34

Miller EH (1976) Walrus ethology. II. Herd structure and activity budgets of summering males. Can J Zool 54:704-715

Miller EH, Boness DJ (1983) Summer behavior of Atlantic walruses *Odobenus rosmarus rosmarus* (L.) at Coats Island, NWT (Canada). Z Säugetierkd 48:298-313

Ovsyanikov NG (1996) Interactions of polar bears with other large mammals, including man. J Wildl Res 1:254-259

Pedersen HR, Lien EM, Yri HAT, Pedersen ST, Stokke E, Lutnæs G (2015) Management Plan for Nordaust-Svalbard and Søraust-Svalbard nature reserves, 2015–2023. pp 35-120. Retrieved from: http://www.sysselmannen.no/Documents/Sysselmannen_dok/English/Regulations/Management%20Plan%20for%20Nordaust-Svalbard%20and%20S%C3%B8raust-Svalbard%20Nature%20Reserves.pdf Accessed 17 April 2017

Popov LA (1958) Herd of walruses on Peschan Island. Priroda (Moscow) 9:102-103

Popov LA (1960) The status of coastal herds of walruses in the Laptev Sea. Okhr Prirody Oze (Moscow) 3:95-104

Prop J, Aars J, Bårdsen BJ, Hanssen SA, Bech C, Bourgeon S, de Fouw J, Gabrielsen GW, Lang J, Noreen E, Oudman T, Sittler B, Stempniewicz L, Tombre I, Wolters E, Moe B (2015) Climate change and the increasing impact of polar bears on bird populations. Front Ecol Evol 3, 33, doi: 10.3389/fevo.2015.00033

R Core Team (2016) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rugh DJ (1993) A polar bear kills a walrus calf. Northwest Natural 74:23-24

Salter RE (1979) Site utilization, activity budgets, and disturbance responses of Atlantic walruses during terrestrial haul-out. Can J Zool 57:1169-1180

Udevitz MS, Jay CV, Fischbach AS, Garlich-Miller JL (2009) Modeling haul-out behavior of walruses in Bering Sea ice. Can J Zool 87:1111-1128

Udevitz MS, Taylor RL, Garlich-Miller JL, Quakenbush LT, Snyder JA (2013) Potential population-level effects of increased haul-out-related mortality of Pacific walrus calves. Polar Biol 36:291-298

Wiig Ø, Born EW, Gjertz I, Lydersen C, Stewart REA (2007) Historical sex-specific distribution of Atlantic walrus (*Odobenus rosmarus rosmarus*) in Svalbard assessed by mandible measurements. Polar Biol 31:69-75

Wiig Ø, Gjertz I, Griffiths D (1996) Migration of walruses (*Odobenus rosmarus*) in the Svalbard and Franz Josef Land area. J Zool, Lond 238:769-784

Fig. 1 Map of Svalbard showing the location of the five automated walrus monitoring camera stations; Andréetangen, Havmerra, Kapp Lee, Lågøya and Storøya. Tourist traffic at each site is quantitatively represented by the size of the blue circles, based on the average number of people on shore from 2007-2015

Fig. 2 **a** Distribution of residuals (as log proportions) calculated from the ARIMA model fitted to each walrus count time series collected at Andréetangen, Havmerra, Kapp Lee, Lågøya and Storøya from 2007-2015. The vertical lines are labelled with percentages (converted from log proportions); -1=-63% (dashed blue), -0.25=-22% (solid blue), 0.25=28% (solid red) and 1=172% (dashed red). **b** Residual size associated with the observed magnitude and direction of the change in absolute walrus numbers (Δ Walrus count) between two time steps. Each vertical line corresponds to the lines and the associated residual sizes in **a**

Fig. 3 Estimated number of walruses hauled out (black) at Andréetangen (2007-2015), from June to November. Note the sporadically occurring peaks, and the gradual increases and decreases in number of animals on shore. Missing values spanning over 12 time steps or less (i.e. ≤ ½ day), are replaced by a mean value (grey). This mean is calculated as $N[t_1-1]+N[t_i+1]/2$, where 1 is the first missing value and *i* is the number of consecutive, missing values. Missing values spanning > 12 time steps are plotted as NA (orange). The occurrences of people (blue) and polar bears (red) are illustrated by coloured circles on top of the bars

Fig. 4 Estimated number of walruses hauled out (black) at Havmerra (2007-2015), from June to November. Note the sporadically occurring peaks, and the gradual increases and decreases in number of animals on shore. Missing values spanning over 12 time steps or less (i.e. ≤ ½ day), are replaced by a mean value (grey). This mean is calculated as $N[t_1-1]+N[t_i+1]/2$, where 1 is the first missing value and *i* is the number of consecutive, missing values. Missing values spanning > 12 time steps are plotted as NA (orange). The occurrences of polar bears is illustrated by the red circles on top of the bars

Fig. 5 Estimated number of walruses hauled out (black) at Kapp Lee (2011-2014), from June to November. Note the sporadically occurring peaks, and the gradual increases and decreases in number of animals on shore. Missing values spanning over 12 time steps or less (i.e. ≤ ½ day), are replaced by a mean value (grey). This mean is calculated as $N[t_1-1]+N[t_i+1]/2$, where 1 is the first missing value and *i* is the number of consecutive, missing values. Missing values spanning > 12 time steps are plotted as NA (orange). The occurrences of people (blue) and polar bears (red) are illustrated by coloured circles on top of the bars

Fig. 6 Estimated number of walruses hauled out (black) at Lågøya in (2007-2014), from June to November. Note the sporadically occurring peaks, and the gradual increases and decreases in number of animals on shore. Missing values spanning over 12 time steps or less (i.e. ≤ ½ day), are replaced by a mean value (grey). This mean is calculated as $N[t_1-1]+N[t_i+1]/2$, where 1 is the first missing value and *i* is the number of consecutive, missing values. Missing values spanning > 12 time steps are plotted as NA (orange). The occurrences of people (blue) and polar bears (red) are illustrated by coloured circles on top of the bars

Fig. 7 Estimated number of walruses hauled out (black) at Storøya in (2010-2014), from July to October. Note the sporadically occurring peaks, and the gradual increases and decreases in number of animals on shore. Missing values spanning over 12 time steps or less (i.e. ≤ ½ day), are replaced by a mean value (grey). This mean is calculated as $N[t_1-1]+N[t_i+1]/2$, where 1 is the first missing value and *i* is the number of consecutive, missing values. Missing values spanning > 12 time steps are plotted as NA (orange). The occurrences of people (blue) and polar bears (red) are illustrated by coloured circles on top of the bars

Fig. 8 Estimated number of walruses (left) hauled out from June to November at various walrus haul-out sites in Svalbard (Storøya=S, Lågøya=L, Kapp Lee=K, Havmerra=H and Andréetangen=A) compared to percentage ice cover (right) of the shoreline. The two-digit number after each letter represents the year that the time series was collected. Walrus numbers were estimated from images collected by camera stations placed at the haul-out sites, from 2007 to 2015.

Fig. 9 a Tourist group visiting Lågøya (18/10/2010) while remaining at a fixed distance to the hauled out walruses. **b** Group of people in close contact with the walrus colony at Lågøya (13/07/2011). **c** Polar bears present at Kapp Lee (06/07/2013) without causing any apparent disturbance, and **d** Polar bear chasing entire walrus colony (>100 animals) into the water at Storøya (23/07/2012). **e** Polar bear approaching the walruses at Storøya (24/07/2010) with calves clearly visible within the herd, identified by their small heads and bodies combined with short tusks. Some small animals can also be seen trapped between adults facing the water. **f** Polar bears apparently only disturbing walruses located on lower part of the beach at Storøya (13/08/2010), with calves present in the disturbed group. **g** Adult walruses at Storøya remaining on land despite the presence of a bear and zodiacs (12/08/2010), and **h** despite windy and snowy weather conditions (27/09/12)

Fig. 10 Frequency distributions (on the log scale) of residuals associated with absence (grey) and presence (red) of polar bears at **a** Andréetangen 2013, **b** Storøya 2012 and **c** Storøya 2010, with the residuals grouped into three categories; ≤-1 (-), -1 to 1 (0) and ≥1 (+). The distributions show that polar bear presence was generally associated with small residuals (0), i.e. little influence on the change in walrus numbers between two time steps. However, there is a shift from equally frequent negative and positive residuals when bears are absent, to relatively more frequent negative residuals when bears are present in these three time series

Fig. 11 Residuals plotted against time, calculated from the ARIMA model fitted to the time series collected at **a** Andréetangen 2013, **b** Storøya 2012 and **c** Storøya 2010. The coloured circles illustrate the absence of polar bears (grey), presence at time t (red), presence at time t-1 (blue) and presence at time t+1 (green). The horizontal dashed lines illustrate limits used to group residuals into three numerical categories, where residuals ≤-1 and ≥1 are defined as rare and representative of potential disturbance events

Table 1 Overview of the total number of images collected by camera stations placed at five different walrus haul-out sites in Svalbard (Andréetangen, Havmerra, Kapp Lee, Lågøya and Storøya). Twenty-eight sets of images (of a possible 39) were collected from 2007 to 2015. Images were missing from some years because the camera station was not operative (-) or due to technical camera failures (F)

Location	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Andréetangen	1380	2865	F	2806	2373	1424	1614	2746	3632	18840
Havmerra	1207	3027	3194	2994	F	2157	2086	F	3192	17857
Kapp Lee	-	-	-	F	2373	F	2443	1708	F	6524
Lågøya	2335	2613	1206	2933	2607	F	2642	935	F	15271
Storøya	-	-	-	1985	F	2997	F	2891	F	7873

Table 2 Total number of images people, boats and polar bears were observed. The images were collected by automated camera stations placed at walrus haul-out sites at Andréetangen, Havmerra, Kapp Lee, Lågøya and Storøya in the period 2007 to 2015

Location	Year	People	Polar bears	Boats
Andréetangen	2007	4	0	1
	2008	12	8	8
	2010	12	0	4
	2011	4	7	16
	2012	15	1	13
	2013	22	20	1
	2014	4	0	72
	2015	6	2	21
Havmerra	2007	0	0	0
	2008	0	2	0
	2009	0	0	0
	2010	0	0	0
	2012	0	0	0
	2013	0	3	0
	2015	0	0	0
Kapp Lee	2011	34	0	21
	2013	46	2	11
	2014	49	1	12
Lågøya	2007	1	22	4
	2008	0	0	0
	2010	12	2	1
	2011	30	8	1
	2013	15	0	2
	2014	1	1	0
Storøya	2010	6	130	4
	2012	0	272	3
	2014	0	0	0

Table 3 Comparisons between dates when people were observed in images (P) collected by camera stations placed at walrus haul-out sites (Andréetangen, Kapp Lee, Lågøya and Storøya) and tourist landing dates reported in post-visit reports (R) from 2008 to 2015. The % of tourist landing dates that corresponded with dates when people were observed in images were calculated (%P/R), and vice versa (%R/P)

Location	Year	P	R	%P/R	%R/P
Andréetangen	2008	7	1	100	14
	2010	2	3	33	50
	2011	5	0	-	0
	2012	4	1	0	0
	2013	1	2	0	0
	2014	5	3	100	60
	2015	5	0	-	0
Kapp Lee	2011	11	3	100	27
	2013	20	17	88	75
	2014	14	20	60	86
Lågøya	2009	0	1	0	-
	2010	8	21	38	100
	2011	13	11	82	69
	2013	8	15	40	75
	2014	1	0	-	0
Storøya	2010	5	5	0	0
	2012	0	1	0	-
	2014	0	0	-	-
Average				46	35

Table 4 Results from a log-linear regression model (Poisson distribution with a log-link) implemented on residuals from the ARIMA model fitted to time series of walrus counts. The time series were collected at walrus haul-out sites (Andréetangen, Kapp Lee, Lågøya and Storøya) from 2007 to 2015. The intercept represents residual probability under average conditions (Avg) when people were absent (A). There were no significant interactions between residual size (Neg=negative and Pos=positive) and the presence (P) of people. Interactions with year included in the model are not shown here

Location		Estimate	± SE	z value	p-value
Andréetangen	A:Avg (Intercept)	7.00	± 0.0301	233	< 2e-16***
	P: Neg	0.628	± 1.01	-0.621	0.535
	P: Pos	-15.5	± 1835	-0.008	0.993
Kapp Lee	(Intercept)	7.59	± 0.0223	340	< 2e-16***
	P: Neg	0.390	± 0.725	0.536	0.592
	P: Pos	-0.322	± 1.01	-0.318	0.751
Lågøya	A:Avg (Intercept)	7.52	± 0.0232	324	< 2e-16***
	P: Neg	-17.2	± 5037	-0.003	0.997
	P: Pos	-17.2	± 5037	-0.003	0.997
Storøya	A:Avg (Intercept)	7.19	± 2.75e-02	262	< 2e-16***
	P: Neg	-21	± 6.97e+04	0	1
	P: Pos	-21	± 6.97e+04	0	1

Table 5 Results from a log-linear regression model (Poisson distribution with a log-link) implemented on residuals from the ARIMA model fitted to time series of walrus counts. The time series were collected at walrus haul-out sites (Andréetangen, Kapp Lee, Lågøya and Storøya) from 2007 to 2015. The intercept represents residual probability under average conditions (Avg) when boats were absent (A). There were no significant interactions between residual size (Neg=negative and Pos=positive) and the presence (P) of boats. Interactions with year included in the model are not shown here

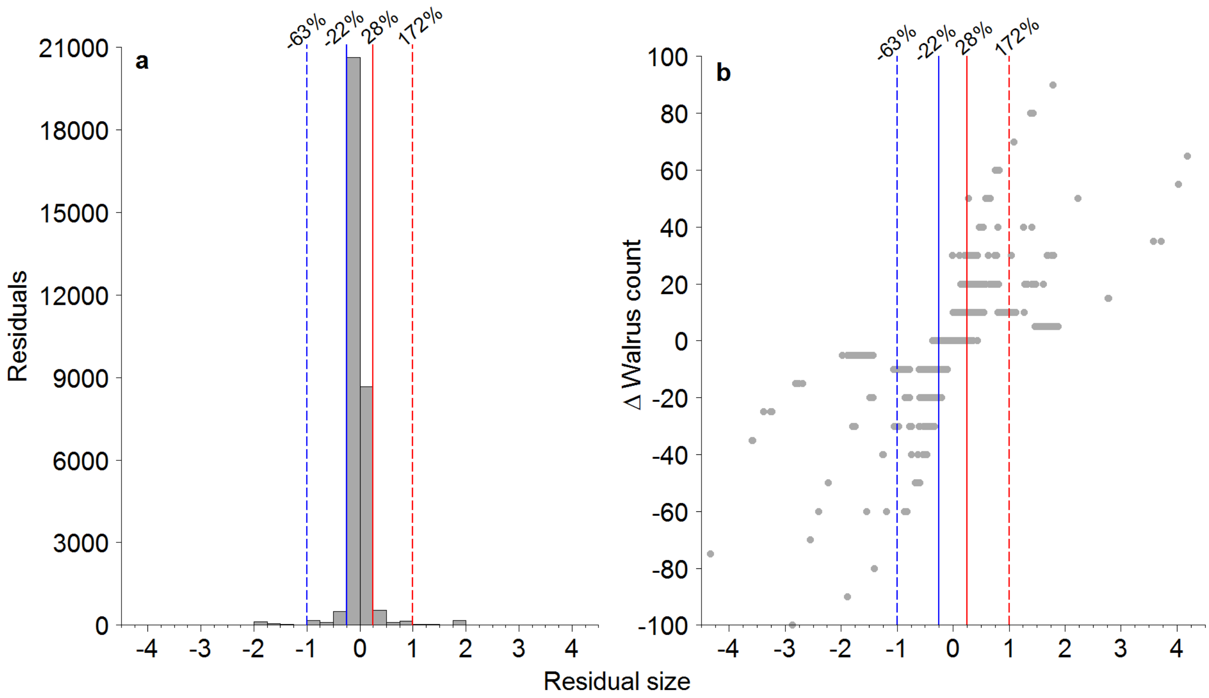
Location		Estimate	± SE	z value	p-value
Andréetangen	A:Avg (Intercept)	7.00	± 0.03	233	< 2e-16***
	P: Neg	-17.5	± 3801	-0.005	0.996
	P: Pos	-17.6	± 3801	-0.005	0.996
Kapp Lee	A:Avg (Intercept)	7.60	± 0.0222	342	< 2e-16***
	P: Neg	-16.4	± 3228	-0.005	0.996
	P: Pos	0.768	± 1.02	0.753	0.451
Lågøya	A:Avg (Intercept)	7.51	± 0.0232	324	< 2e-16***
	P: Neg	-16.0	± 7231	-0.002	0.998
	P: Pos	-16.0	± 7231	-0.002	0.998
Storøya	A:Avg (Intercept)	7.18	± 0.0273	263	< 2e-16***
	P: Neg	1.94	± 1.09	1.78	0.0744
	P: Pos	-15.7	± 3993	-0.004	0.997

Table 6 Results from a log-linear regression model (Poisson distribution with a log-link) implemented on residuals from the ARIMA model fitted to time series of walrus counts. The time series were collected at walrus haul-out sites (Andréetangen, Havmerra, Kapp Lee, Lågøya and Storøya) from 2007 to 2015. The intercept represents residual probability under average conditions (Avg) when polar bears were absent (A). There were no significant interactions between residual size (Neg=negative and Pos=positive) and polar bear absence (A). Significant interactions between residual size and the presence (P) of bears are shown in bold. Interactions with year included in the model are not shown here

Location		Estimate	± SE	z value	p-value
Andréetangen	A:Avg (Intercept)	7.82	± 0.0199	393	< 2e-16***
	P: Neg	2.54	± 0.614	4.14	**3.47e-5*** **
	P: Pos	1.32	± 1.02	1.30	0.195
Havmerra	A:Avg (Intercept)	7.75	± 2.08e-02	373	< 2e-16***
	P: Neg	-15.0	± 1.09e+04	-0.001	0.999
	P: Pos	-14.6	± 1.09e+04	-0.001	0.999
Kapp Lee	A:Avg (Intercept)	7.65	± 2.18e-02	352	< 2e-16***
	P: Neg	-18.4	± 2.92e+04	-0.001	0.999
	P: Pos	-18.4	± 2.92e+04	-0.001	0.999
Lågøya	A:Avg (Intercept)	7.51	± 0.0233	322	< 2e-16***
	P: Neg	-17.0	± 5832	-0.003	0.998
	P: Pos	-17.0	± 5832	-0.003	0.998
Storøya	A:Avg (Intercept)	7.10	± 0.0286	248	< 2e-16***
	P: Neg	1.12	± 0.258	4.33	**1.52e-05** **
	P: Pos	0.360	± 0.319	1.13	0.26


10°E
15°E
79°N
77°N
Lågøya
Storøya
Kapp Lee
Andréetangen
Havmerra
Haul out sites
Land
Number of tourists on shore each year (average 2007-15):
1-100
100-500
500-1000
>1000
Data: Governor of Svalbard
0
50
100
150
200 km
N

Fig. 1


a
b
21000
18000
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12000
9000
6000
3000
0
Residuals
-4
-3
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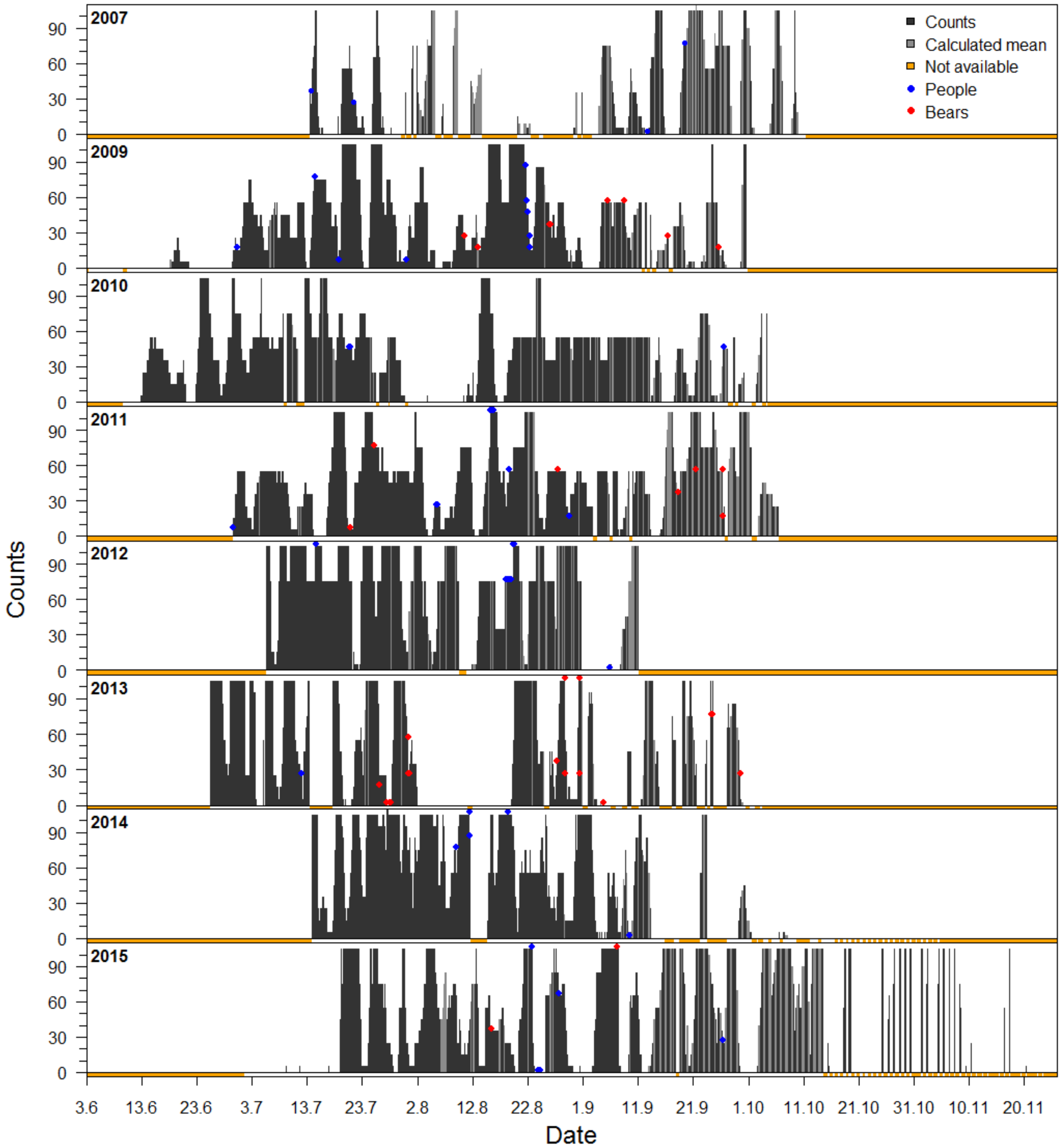
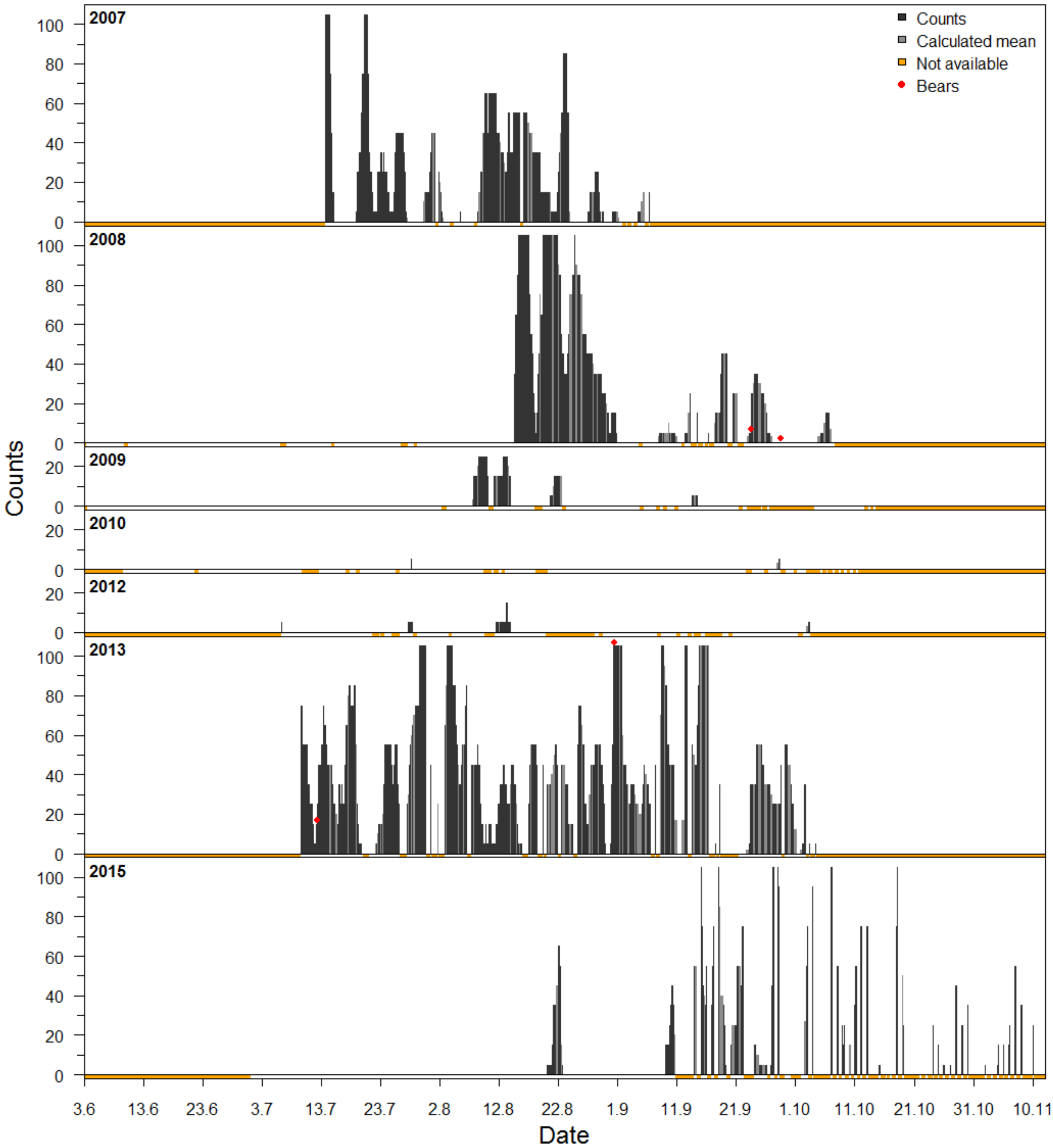
0
1
2
3
4
-63%
-22%
28%
172%
100
80
60
40
20
0
-20
-40
-60
-80
-100
Δ Walrus count
Residual size

Fig. 2



Counts
Calculated mean
Not available
People
Bears
2007
2009
2010
2011
2012
2013
2014
2015
Counts
Date
3.6
13.6
23.6
3.7
13.7
23.7
2.8
12.8
22.8
1.9
11.9
21.9
1.10
11.10
21.10
31.10
10.11
20.11

Fig. 3



Counts
Calculated mean
Not available
Bears
2007
2008
2009
2010
2012
2013
2015
Counts
Date
3.6
13.6
23.6
3.7
13.7
23.7
2.8
12.8
22.8
1.9
11.9
21.9
1.10
11.10
21.10
31.10
10.11

Fig. 4

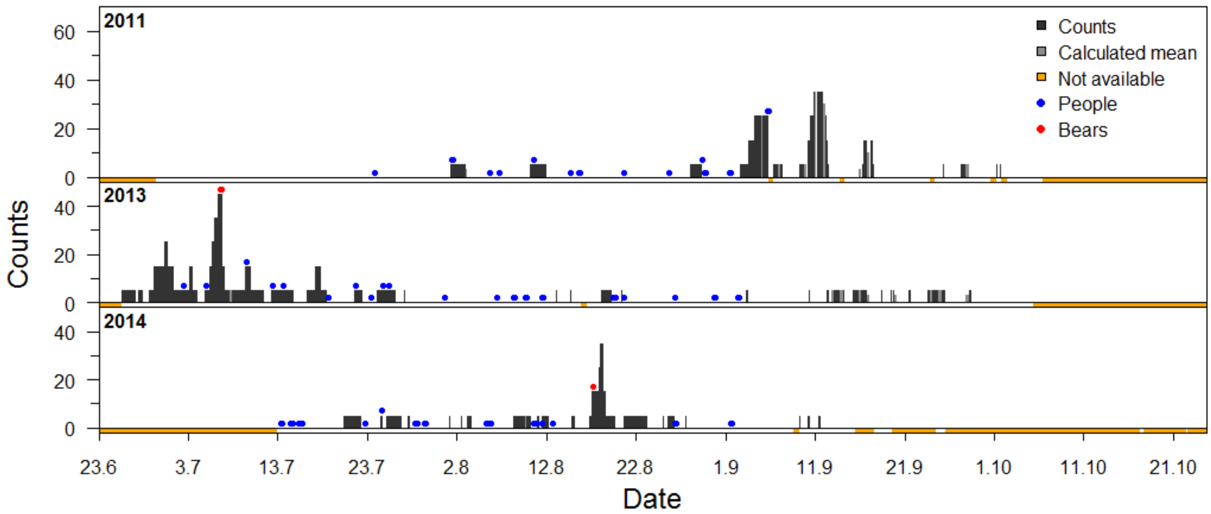
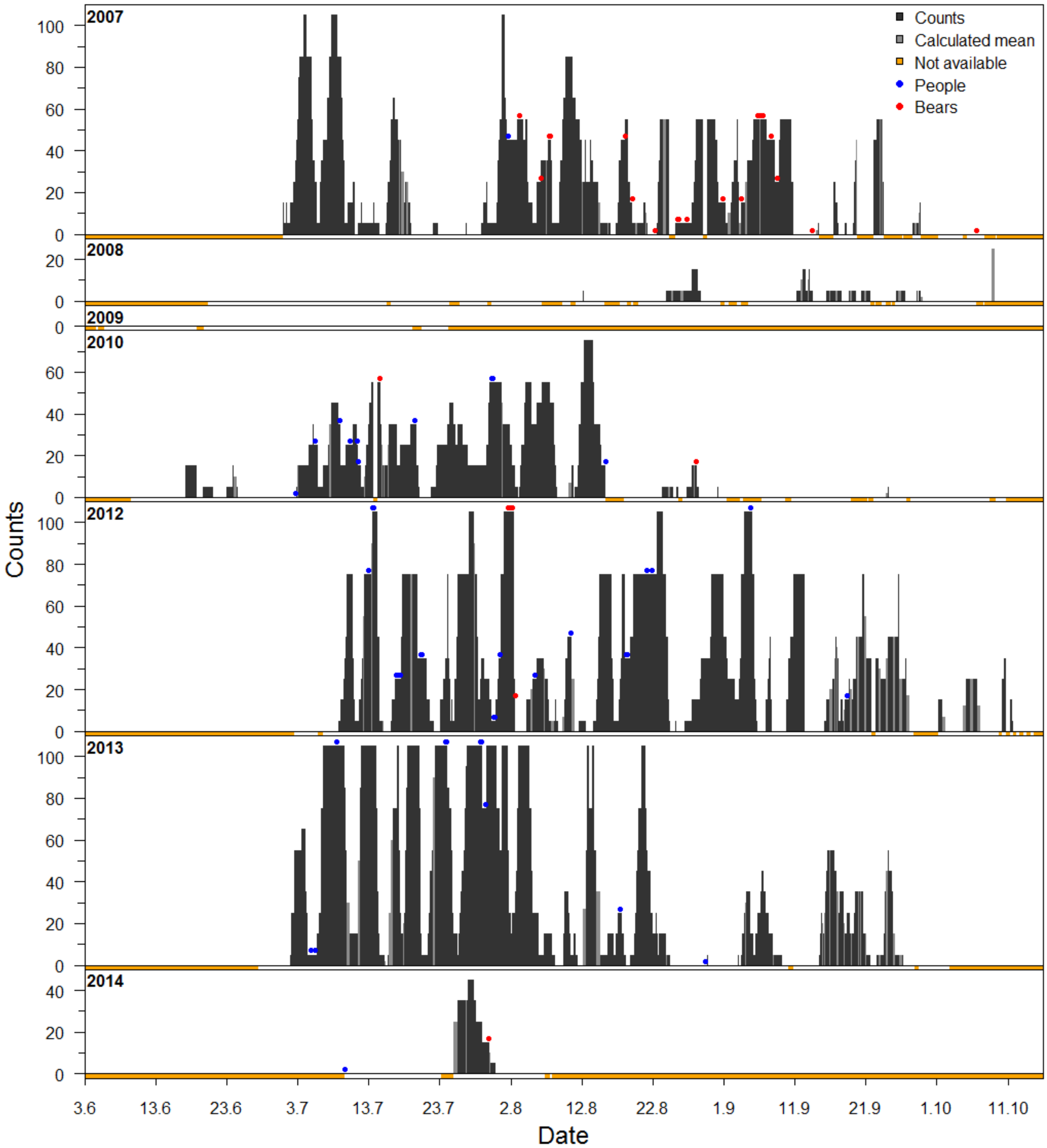

2011
2013
2014
Counts
Calculated mean
Not available
People
Bears
Counts
Date
60
40
20
0
23.6
3.7
13.7
23.7
2.8
12.8
22.8
1.9
11.9
21.9
1.10
11.10
21.10

Fig. 5



Counts
Calculated mean
Not available
People
Bears
2007
2008
2009
2010
2012
2013
2014
Counts
Date
3.6
13.6
23.6
3.7
13.7
23.7
2.8
12.8
22.8
1.9
11.9
21.9
1.10
11.10

Fig. 6

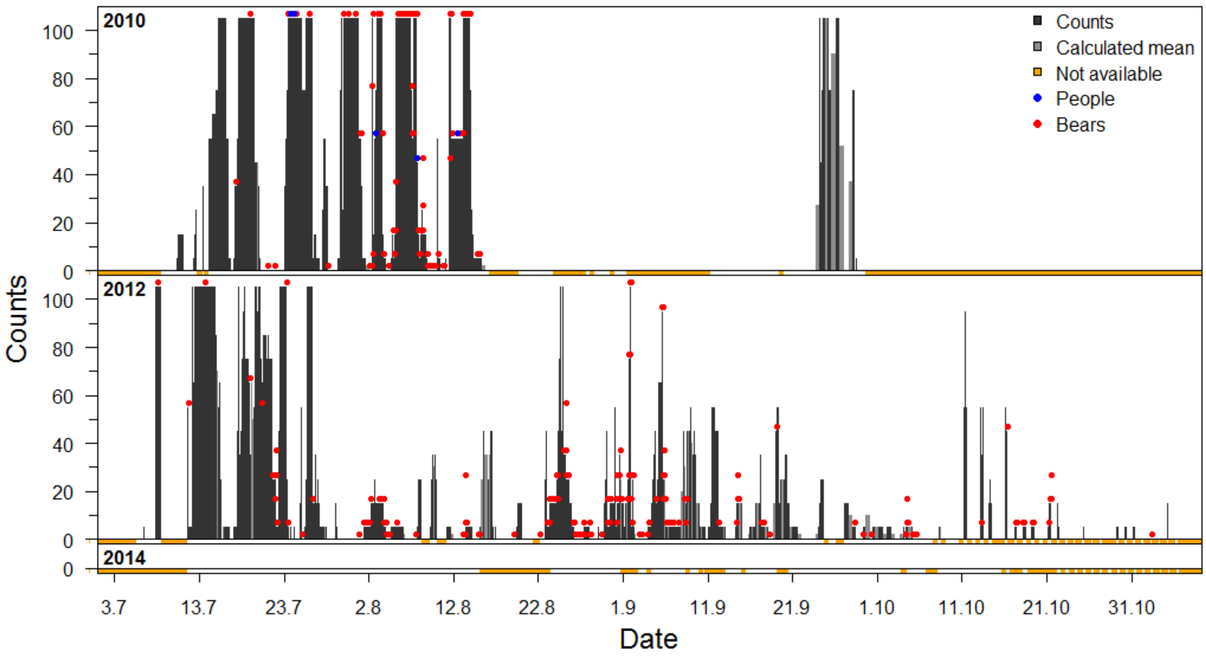

2010
2012
2014
Counts
Calculated mean
Not available
People
Bears
100
80
60
40
20
0
Counts
3.7
13.7
23.7
2.8
12.8
22.8
1.9
11.9
21.9
1.10
11.10
21.10
31.10
Date

Fig.7

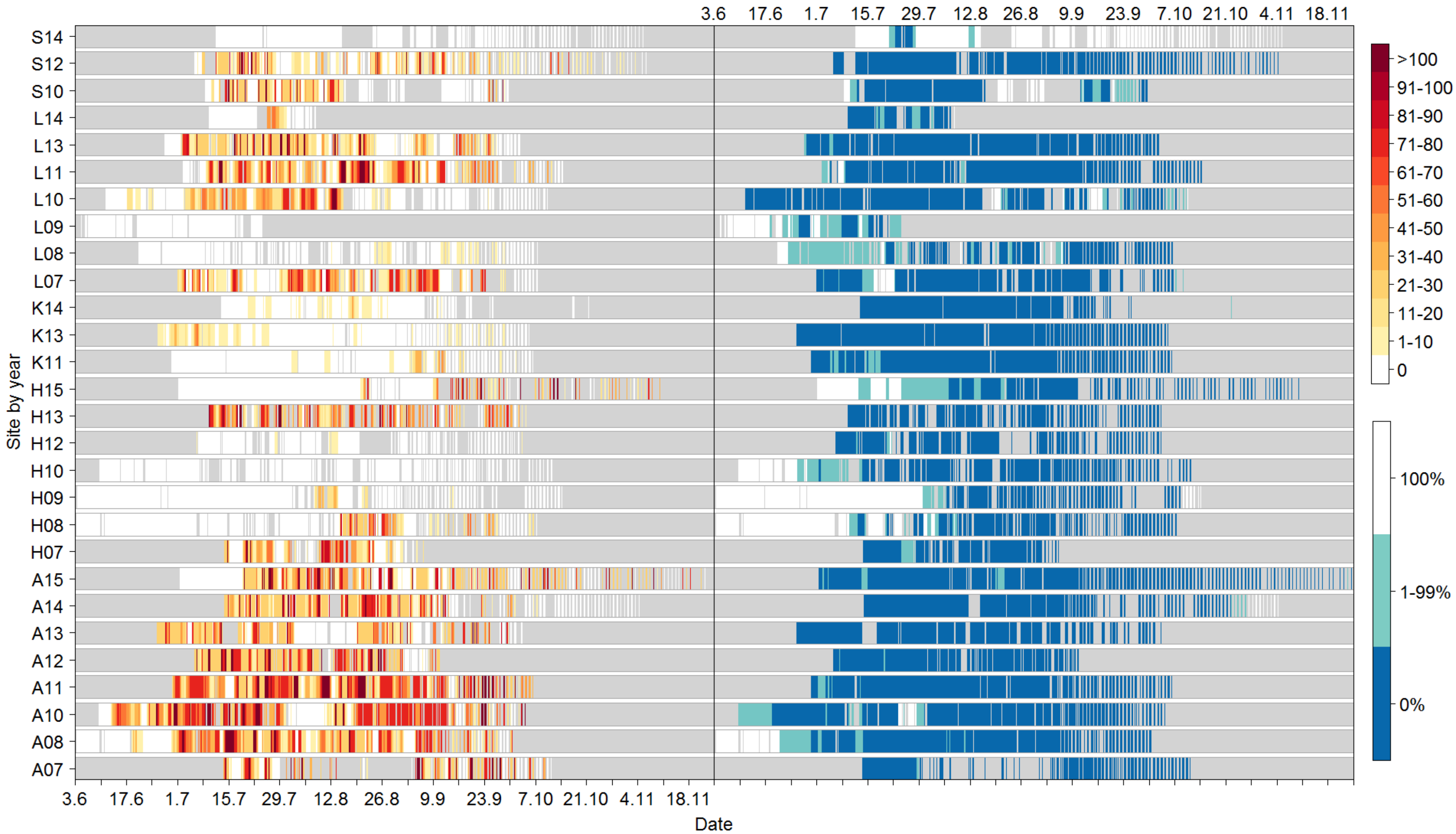

Site by year
S14
S12
S10
L14
L13
L11
L10
L09
L08
L07
K14
K13
K11
H15
H13
H12
H10
H09
H08
H07
A15
A14
A13
A12
A11
A10
A08
A07
3.6 17.6 1.7 15.7 29.7 12.8 26.8 9.9 23.9 7.10 21.10 4.11 18.11
3.6 17.6 1.7 15.7 29.7 12.8 26.8 9.9 23.9 7.10 21.10 4.11 18.11
Date
>100
91-100
81-90
71-80
61-70
51-60
41-50
31-40
21-30
11-20
1-10
0
100%
1-99%
0%

Fig. 8

Fig. 9

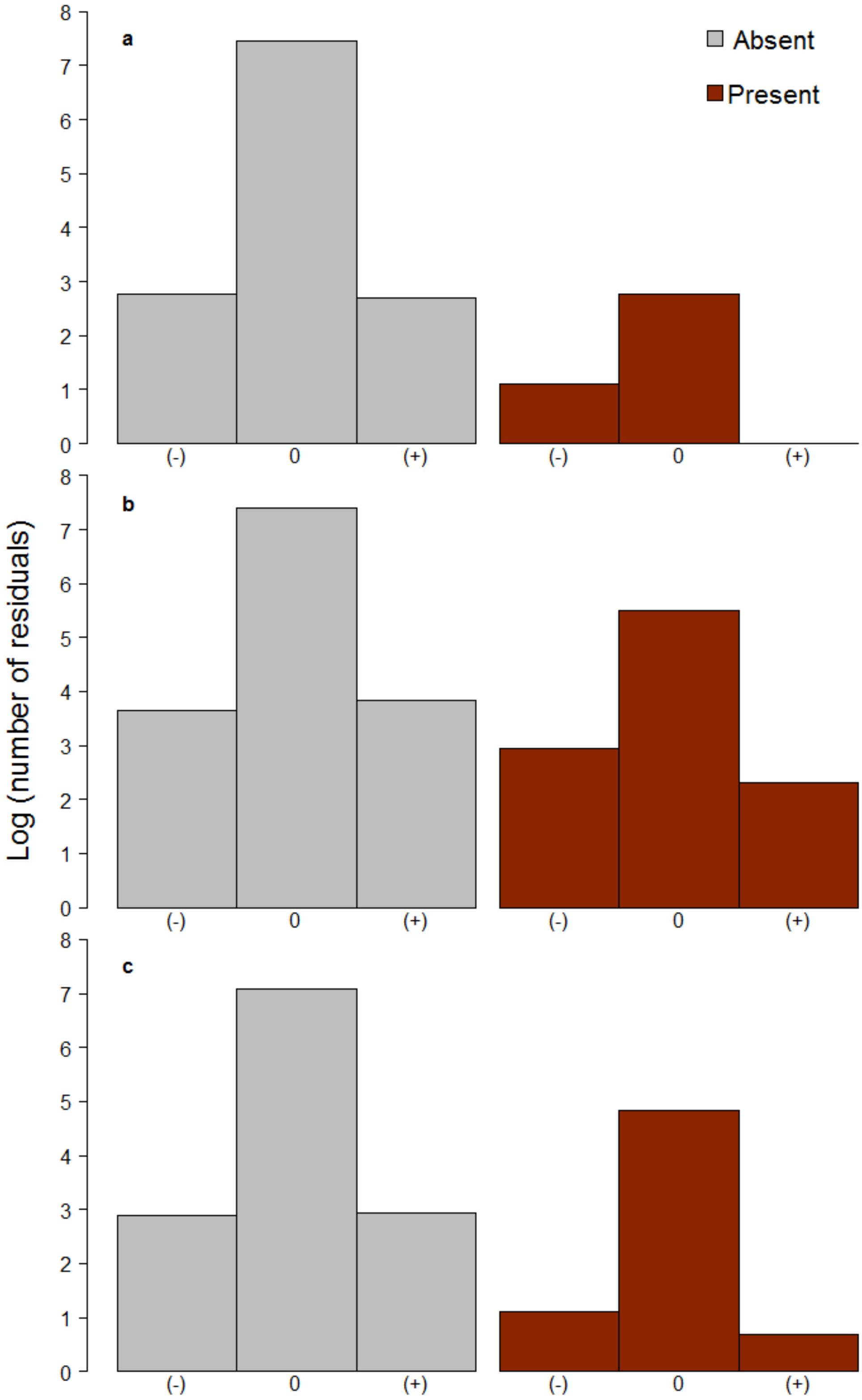


Fig. 10

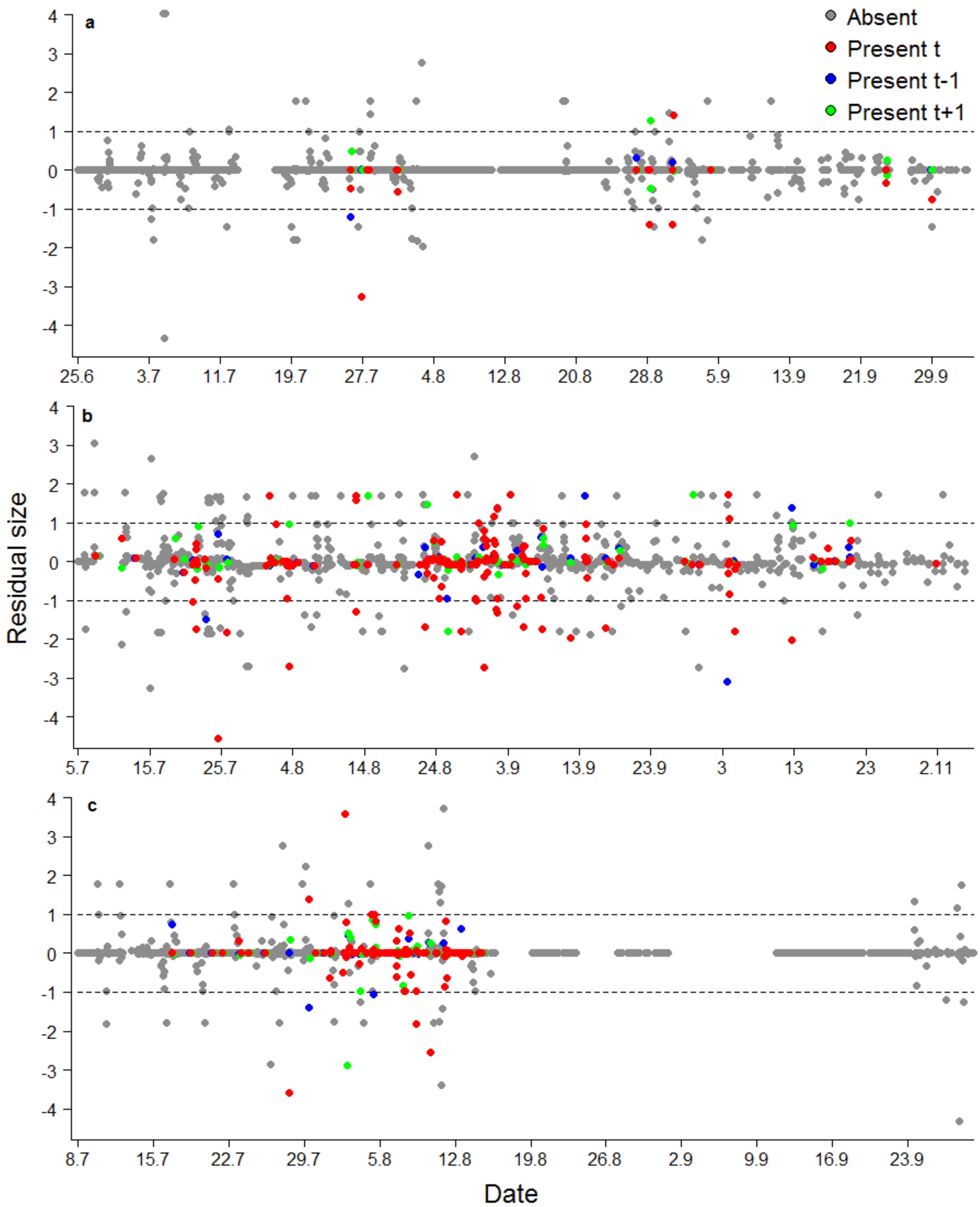

a
b
c
Absent
Present t
Present t-1
Present t+1
Residual size
Date
25.6
3.7
11.7
19.7
27.7
4.8
12.8
20.8
28.8
5.9
13.9
21.9
29.9
5.7
15.7
25.7
4.8
14.8
24.8
3.9
13.9
23.9
3
13
23
2.11
8.7
15.7
22.7
29.7
5.8
12.8
19.8
26.8
2.9
9.9
16.9
23.9

Fig. 11