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PHOTOGRAMMETRY AND MORPHOMETRICS

Whisker spots on polar bears reveal increasing fluctuating asymmetry

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Abstract

Developmental instability resulting from environmental or genetic stress is often measured through fluctuating asymmetry, the minor, random deviations from symmetry in bilateral features. Polar bears (*Ursus maritimus*) in western Hudson Bay are under environmental stress from the effects of climate change, such as an increase in the length of the ice-free season, which could destabilize development and decrease symmetry. We examined fluctuating asymmetry in polar bear whisker spot patterns using an image-processing software that extracts whisker spot patterns and calculates their similarity to patterns saved in an image library of known bears. We obtained photographs of both sides of the face of polar bears near Churchill, Manitoba from 2003 to 2005 ($n = 24$) and 2013 to 2016 ($n = 21$). We calculated similarity scores for whisker spot patterns and compared them to other photos of the same side of the face of the same bear, to the other side of the face of the same bear, and to the face of another bear. Whisker spot patterns on opposite sides of the face exceeded the threshold similarity score indicating two different bears, and were no more similar than patterns on different bears. These similarity scores suggest fluctuating asymmetry between sides of the bears' faces. Average asymmetry was greater in 2013–2016 than 2003–2005, suggesting that the degree of fluctuating asymmetry increased between these periods. Using whisker spot analysis from photographs to measure fluctuating asymmetry in live bears experiencing environmental stress illustrates how non-invasive morphometric analysis can be used to address conservation issues in wildlife.

Keywords Climate change · Fluctuating asymmetry · Photographic monitoring · *Ursus maritimus* · Whisker spot pattern

Introduction

Fluctuating asymmetry, defined as random, minor deviations from perfect symmetry in corresponding features on either side of the body, reflects developmental stability in bilaterally symmetrical organisms (Van Valen 1962; Palmer and Strobeck 1986). Developmental stability is an organism's ability to buffer development against random perturbations, allowing the individual to achieve equal development and thus morphological symmetry (Waddington 1942). Organisms experiencing developmental instability are expected to exhibit variation among bilateral structures, and thus fluctuating asymmetry is suggested to reflect the environmental or genetic stress experienced by an organism during development (Palmer and Strobeck 1986). Fluctuating asymmetry occurs in traits that are normally expected to be bilaterally symmetrical (Palmer and Strobeck 1986). Fluctuating asymmetry has been demonstrated in both lab and natural settings in relation to various environmental stressors, such as nutritional stress, pollution, and high population density (e.g. Swaddle and Witter 1994; Zakharov et al. 1997, 2020), and genetic stressors, such as inbreeding (e.g. Wayne et al. 1986; Gomendio et al. 2000).

Some suggest that since maintaining homeostatic development is energetically expensive, the degree of buffering against perturbations may be greater in traits with high functional importance (Watson and Thornhill 1994; Clarke 1995; Van Dongen 2006). For example, symmetry in wing length is important for the normal functioning of flying organisms (Swaddle 1997), and thus would exhibit high symmetry even in stressful environments. In contrast, characters that do not

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require symmetry for functioning may exhibit asymmetry even when the organism is not subject to high levels of stress (Clarke 1995).

Populations under stress may exhibit higher levels of fluctuating asymmetry than populations not subject to stress (Leary and Allendorf 1989; Clarke 1995). For example, urban populations of the common wall lizard (*Podarcis muralis*) subject to anthropogenic disturbances such as pollution exhibited higher asymmetry compared to rural populations (Lazić et al. 2013). Two resident killer whale (*Orcinus orca*) populations in the eastern North Pacific, which may be under genetic stress from a small population size, had greater asymmetry in saddle patch shape than other killer whale populations with greater genetic diversity or larger population sizes (Mäkeläinen et al. 2013). Likewise, high fluctuating asymmetry levels in the tarsus bone of seven bird species (*Zosterops silvanus*, *Turdus helleri*, *Andropadus milanjensis*, *Phyllastrephus cabanisi*, *Pogonocichla stellate*, *Phylloscopus ruficapillus*, *Nectarinia olivacea*) in Kenya was attributed to recent fragmentation of the forest habitat (Lens et al. 1999). Therefore, fluctuating asymmetry may have applications in conservation biology as a method of actively monitoring the effects of stressors on populations (Leary and Allendorf 1989; Clarke 1995). Beasley et al. (2013) found environmental stress to have a large effect on fluctuating asymmetry in a meta-analysis of insects, suggesting that fluctuating asymmetry can serve as a sensitive biomarker. However, some literature questions whether fluctuating asymmetry is an effective and appropriate monitoring tool in all circumstances (e.g. Gilligan et al. 2000; Lens et al. 2002).

Increasing surface temperatures due to climate change have led to a multitude of changes in the Arctic and subarctic, including a decrease in the seasonal sea-ice extent, resulting in a series of ecological consequences for Arctic predators such as polar bears (*Ursus maritimus*; Post et al. 2009; Parkinson 2014). Polar bears evolved from brown bears to use sea ice as their primary grounds for mating and bearing young (Ramsay and Stirling 1988; Stirling and Derocher 1990; Talbot and Shields 1996), and depend on sea ice to hunt and gain mass in the spring to prepare to fast while on shore (Stirling and Archibald 1977). Polar bears meet the majority of their energetic requirements during this time (Stirling and Øritsland 1995), and thus are negatively affected by longer ice-free periods. Longer periods spent on land prevent polar bears from accessing their marine prey, extending the summer fasting period (Cherry et al. 2013). Impacts of reduced sea ice include reduced access to prey, declines in body condition, lower cub survival, and population decline (Regehr et al. 2007; Rode et al. 2010; Stirling and Derocher 2012; Hamilton et al. 2017; Lunn et al. 2016; Laidre et al. 2020).

In western Hudson Bay, which freezes completely each winter, sea ice is breaking up earlier and freezing later (Gagnon and Gough 2005). Stern and Laidre (2016) reported a trend of earlier spring sea-ice retreat of 5.1 days per decade, while fall sea-ice advance got later by 3.5 days per decade between 1979 and 2014. Lunn et al. (2016) reported similar results, with earlier spring breakup of 5.5 days per decade and later fall freeze-up of 4.1 days per decade. The ice-free season lengthened by approximately 3 weeks between 1979 and 2015, increasing polar bears' time onshore by the same amount (Castro de la Guardia et al. 2017). The Western Hudson Bay population of polar bears has declined from approximately 1185 individuals in 1987 to approximately 806 individuals in 2011, with decreased survival in juvenile, subadult and senescent-adult polar bears attributed to the earlier breakup of sea ice in the spring (Regehr et al. 2007; Lunn et al. 2016). Declining population energetics as well as increased variability in maximum corticosteroid binding capacity suggest that the Western Hudson Bay polar bear population is experiencing significant environmental stress from these changing conditions (Boonstra et al. 2020; Johnson et al. 2020).

Patterns of whisker spots, the small, dark circles around whisker follicles, have been used to identify individuals in several large mammals, such as lions (*Panthera leo*) and Australian sea lions (*Neophoca cinerea*; Pennycuick and Rudnai 1970; Osterrieder et al. 2015). These patterns have also been evaluated as a successful, non-invasive method of repeatedly identifying individual polar bears, since whisker spot patterns appear to be unchanging in an individual bear (in > 95% of polar bears examined, whisker spots were reliable over three years of analysis) (Anderson et al. 2007, 2010; Waterman Unpubl. data). Anderson et al. (2010) developed a computer system that extracts an individual's whisker spot pattern (i.e., whisker print) from a photograph, facilitating the use of digital whisker prints to identify individuals. The system calculates a similarity score between whisker prints extracted from different photographs, allowing the user to match patterns to known bears in the system and identify new bears. Other than the manual placement of three anchor points on the image of the bear's face, the system is fully automated, reducing user bias and measurement error (Anderson et al. 2010).

Grant and Goss (2022) suggest that environmental factors, such as diet and health, may affect variations in whisker position during development. When photographs are available for both sides of an individual's face, whisker spot patterns may be used to evaluate fluctuating asymmetry in that individual (Packer and Pusey 1993). Analyses of fluctuating asymmetry typically measure physical features, such as skull morphometrics or wing length, which requires the heavy sedation or death of the animal. For example, previous analyses of fluctuating asymmetry in polar bears used metric and meristic traits of skulls collected from museum samples and subsistence hunters to compare bears from different periods and subpopulations (Sonne et al. 2005; Bechshøft et al. 2008, 2009). Although this method allowed comparison of the subpopulations across an extensive period (1982–2004), it does not permit evaluation of fluctuating asymmetry in live animals. Using photographic methods to measure fluctuating asymmetry is non-invasive, and thus does not require any handling of the animal. Further, photographic methods provide real-time evaluation of the degree of fluctuating asymmetry in a population under stress (Mäkeläinen et al. 2013).

In this study, we used the Whisker Print software developed by Anderson et al. (2010) to evaluate the degree of fluctuating asymmetry in whisker spot patterns between sides of the face in polar bears. We used the same technique to determine whether fluctuating asymmetry increased over 10 years, from the period of 2003–2005 to 2013–2016. We hypothesized that the Western Hudson Bay polar bears, a population impacted by the effects of climate change, will exhibit developmental instability. We predicted that whisker spot patterns would exhibit significant fluctuating asymmetry between the right and left sides of the face, and that the level of asymmetry would be higher in bears photographed in the 2010s than in the 2000s.

Methods

Study area and photographs of bears

Polar bears in western Hudson Bay spend the ice-free season on land, and aggregate along the coast near Cape Churchill, Manitoba in October and November as they wait for the sea ice to return (Latour 1981; Derocher and Stirling 1990). The Western Hudson Bay polar bear population consists of approximately 800–900 bears (Regehr et al. 2007; Lunn et al. 2016). We have compiled a long-term database of digital photographs of bears in this region collected intermittently since 2001. Photographs were taken approximately 30 km east of the town of Churchill, Manitoba (58° 45′ N, 93° 45′ W; Fig. 1) from a tundra vehicle (Anderson et al. 2007), approximately 50–100 m from the individual. Several photographs were taken of each bear to obtain photographs from the best angle and sufficient quality (in terms of image sharpness) for whisker spot analysis (Anderson et al. 2010). Sex and age of individual bears was not recorded, since it was not possible to determine the sex or age consistently and reliably by visual assessment from the tundra vehicle or from the photographs.

We used photographs of bears taken from 2003 to 2005 ($n=24$ individuals) and 2013 to 2016 ($n=21$ individuals). In 2003–2005 we used Nikon D100 6.0 megapixel digital cameras and 70-300 mm and 80–400 mm lenses (Nikon, Melville, New York), and in 2013–2016 we used the same Nikon D100 cameras, in addition to two Nikon D300 13.0 megapixel digital cameras with the same zoom lenses. We selected individuals for which photographs were available of both sides of the face, and chose photographs of the best angle and quality (preferably directly perpendicular to the side of the bear's face, and close enough so the whisker spot pattern is clearly visible when the photo is cropped; Fig. 2). No individuals were photographed in both 2003–2005 and 2013–2016. For each bear, we selected three photographs: two of the primary side of the face (left or right) and one of the other side of the face. The primary side of the face was

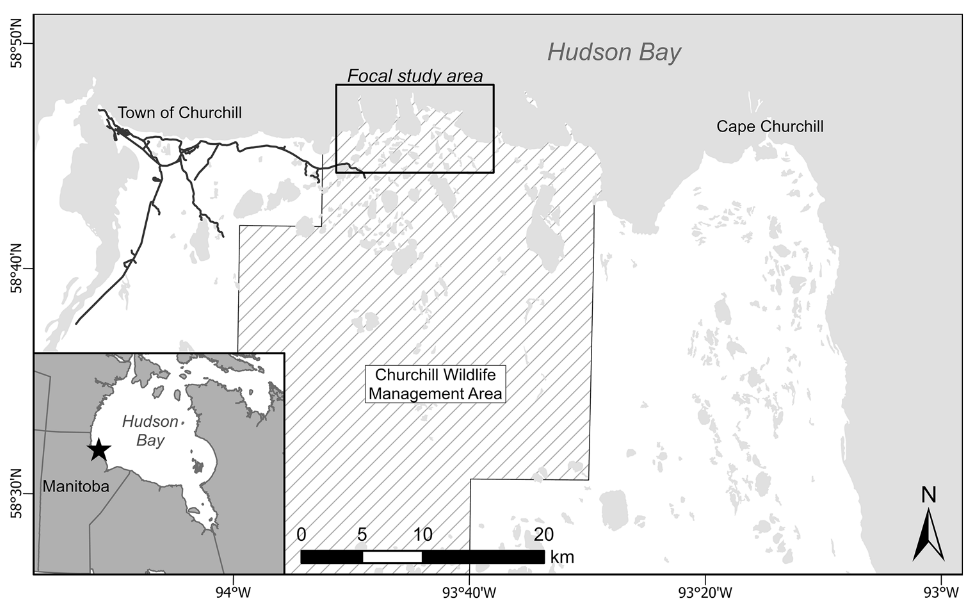

Fig. 1 Map of study area in the Churchill Wildlife Management Area (gray cross-hatched). Most photographs were taken in the focal study area (outlined in black), where tundra vehicle routes are concentrated

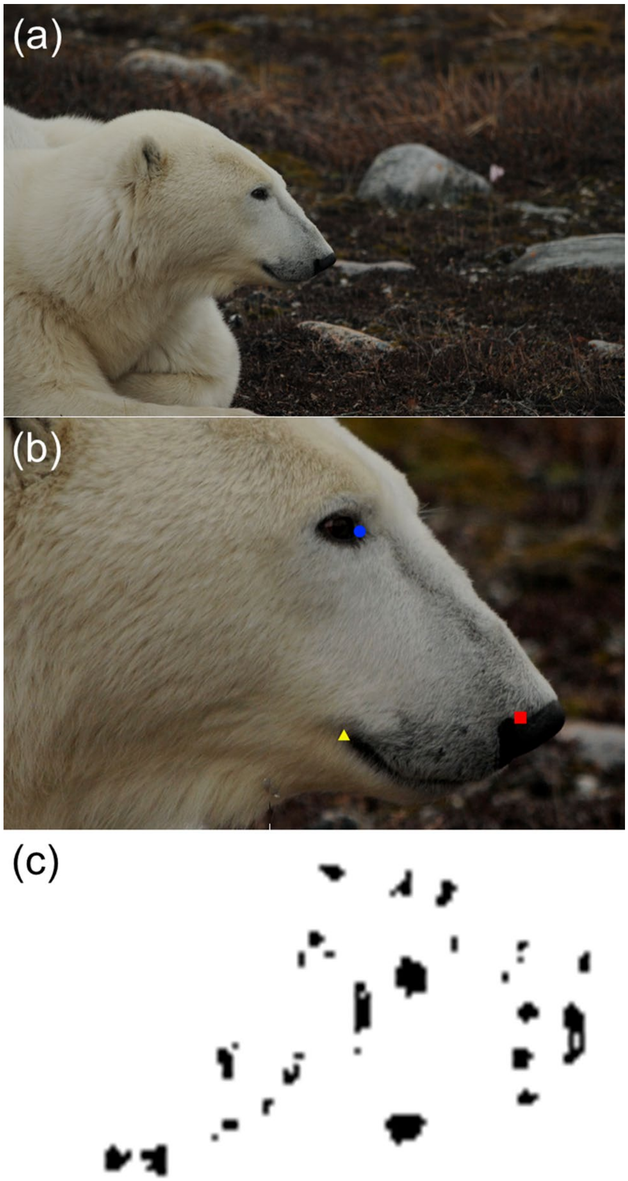

Fig. 2 Process of whisper spot pattern extraction from a photograph using the Whisker Print software (Anderson et al. 2010), starting with **a** the original photograph of the individual (Dill, 2014), then **b** the cropped and sharpened image with anchor points placed at the inside corner of the eye (blue circle), the inlet of the nose (red square), and the corner of the mouth (yellow triangle). Finally, **c** the black and white whisker print extracted from the image

determined by the side of the face with the greatest number of good-quality photographs.

Image processing and whisker spot analysis

All image processing and analyses were performed by the same person (CEK) to avoid user bias. We pre-processed images prior to analysis with the Whisker Print software by cropping photos to include just the face of the bear and sharpened photographs to increase clarity using Microsoft Photos (Fig. 2). In the Whisker Print software, photographs can be entered into a library and saved under an individual bear's identification code, or as a "candidate" where a photo can be compared to all bears saved in the library. The whisker print image processing and similarity score algorithm are described in detail by Anderson et al. (2010) and summarized here.

Whisker prints are extracted from the image by placing three anchor points on the bear's face: first on the inside corner of the eye, second on the inlet of the nose, and third on the corner of the mouth (Fig. 2). The software standardizes and enhances the image by converting it to grayscale, then transforming the image based on the anchor points so that each anchor is a standard number of pixels from the others. The image is then cropped, enhanced, smoothed, and finally each pixel is converted to black or white using adaptive thresholding (Anderson et al. 2010). This process produces a black and white whisker print for that side of the individual's face (Fig. 2). Once a whisker print has been produced and saved for an individual bear, the patterns produced from other images can be compared. Since the images are standardized, images of different quality can be easily compared. The software uses a Chamfer distance algorithm (Borgefors 1986) to calculate the similarity score between two processed whisker prints. These scores can be influenced by differences in the angle and quality of the images being compared (Anderson et al 2010). A similarity score of zero indicates an exact match, a score < 1.5 indicates a strong probability that the candidate is the same bear, a score < 2.0 indicates a possible match, and a score > 2.0 indicates a strong probability of a different bear. All matches were confirmed by visual assessment.

For each bear, we first entered a photograph of the primary side under the bear's identification code in the library, classified it as the left or right side, extracted the whisker print, and saved it to the library. We then entered the same photograph as a candidate and compared the extracted whisker print to the original photograph three times to obtain an exact match (similarity score $= 0$) to the original whisker print, to ensure the precision of the anchor placement on the primary photograph and thus minimize measurement error in future measurements. Next, we entered the second photograph of the primary side as a candidate, extracted the whisker print, and calculated the similarity score to the bear's original photo ("same-side" score). We then entered this photograph into the library under the bear's identification code. This score provides a baseline that accounts for the remaining measurement error due to angle or image sharpness. To compare the other side of the bear's face to the primary side, we flipped the photograph of the other side of the face along the vertical axis and entered the flipped photograph into the software as a candidate. We extracted the whisker print and calculated the similarity score to the primary side of the bear's face ("other-side" score), then entered the un-flipped photograph into the library under the bear's identification code.

Once all three photographs, and thus whisker prints for both sides of the face, were processed and saved in the library for all bears, we compared each bear's primary whisker print to one other randomly assigned individual to evaluate the similarity of patterns between sides of the face to other bears. We randomly assigned one other bear for comparison to each individual. We entered the first primary-side photograph of each bear as a candidate and calculated the similarity score to the same side of the face of the assigned bear ("other-bear" score). For each comparison (same side, other side, and other bear), we repeated the pattern extraction and similarity score calculation three times to account for measurement error (Palmer and Strobeck 1986).

Statistical analysis

We analyzed all data using RStudio version 1.1.463 with $p \leq 0.05$ considered statistically significant. Since we used similarity scores calculated by the Whisker Print software to assess differences in two whisker prints rather than geometric measurements of each pattern, we have only one measurement of the feature per comparison rather than a left and right measurement. Further, since we analyzed a difference in patterns rather than a metric or meristic trait, directional asymmetry is not applicable, and the traditional two-way, mixed-effect ANOVA advocated by Palmer and Strobeck (1986) is not suitable.

We calculated the coefficient of variation of the three scores per category per bear to assess measurement error. Since the variance was minimal relative to the average scores, we used the average of the three similarity scores per category per bear for further analysis. To analyze the degree of fluctuating asymmetry, we used a one-way ANOVA to compare the similarity scores among the three categories (same side, other side, and other bear; $n = 45$ bears) followed by a Tukey HSD post-hoc test. To examine if fluctuating asymmetry has increased over time, we compared our three scores (same side, other side, and other bear) between 2003 and 2005 and 2013–2016 using t-tests when the assumptions were met (other side) or when the log-transformed data met the assumptions (other bear). We used a Wilcoxon rank sum test on same-side scores because transformation did not improve normality.

Results

Standard deviation of the three repeated similarity scores averaged 0.128 ± 0.022 (SE) for same-side scores, 0.145 ± 0.017 for other-side scores, and 0.131 ± 0.015 for other-bear scores. The coefficients of variation were 13.6%, 5.7% and 4.6% for same side, other side, and other-bear scores, respectively. For other-side similarity, 86.7% of bears had scores above two, the threshold at which the patterns are considered to be from two different bears unless visually confirmed. Similarity scores differed among same side, other side, and other-bear comparisons (ANOVA: $F_{2,132} = 114.3$, $p < 0.001$). Same-side similarity scores

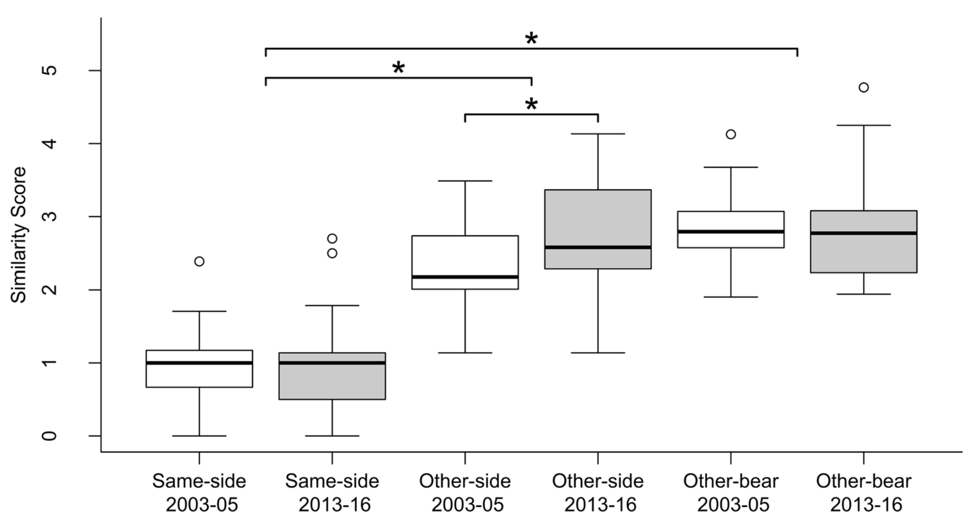

Fig. 3 Similarity scores (average of three measurements) for whisker spot patterns of polar bears (*Ursus maritimus*) near Churchill, Manitoba, calculated from photographs using the Whisker Print software (Anderson et al. 2010). Similarity scores were calculated for patterns of all individual bears using a different photograph of the same side of the face, a flipped photograph of the other side of the face, and a photograph of another randomly assigned bear. A score below two indicates a likelihood of the same bear. Boxes represent the median and quartiles, whiskers represent 1.5 times the interquartile range, and asterisks indicate significant differences ($p < 0.05$)

(mean ± SE = 0.94 ± 0.10) differed from other-side scores (2.55 ± 0.10; Tukey HSD: $p < 0.001$) and other-bear scores (2.87 ± 0.09; Tukey HSD: $p < 0.001$), and although other-side scores did not differ from other-bear scores, the difference approached significance (Tukey HSD: $p = 0.054$; Fig. 3). Same-side similarity scores in 2003–2005 (0.92 ± 0.11) and 2013–2016 (0.97 ± 0.16) did not differ (Wilcoxon rank sum test; $W = 253$, $p = 0.90$; Fig. 3). Likewise, other-bear similarity scores in 2003–05 (2.86 ± 0.10) and 2013–16 (2.87 ± 0.15) did not differ (Student's *t* test; $t_{43} = 0.15$, $p = 0.88$; Fig. 3). However, other-side similarity scores were greater in bears observed in 2013–2016 (2.79 ± 0.16) than bears observed in 2003–2005 (2.34 ± 0.12; Student's *t* test; $t_{43} = -2.25$, $p = 0.029$; Fig. 3).

Discussion

Our results suggest fluctuating asymmetry in whisker spot patterns between sides of the face in the Western Hudson Bay population, as the similarity scores between sides of the face exceeded the threshold that generally indicates two different bears (Anderson et al. 2010). The similarity scores suggest that on average, the two sides of a bears' face are no more similar than two different bears. This conclusion is further supported by the comparison among same-side scores, other-side scores, and other-bear scores, as same-side scores were significantly lower than other side and other-bear scores, while other side and other-bear scores did not differ significantly. This latter result was surprising, as we expected lower scores within a bear than among bears. However, our p-value was close to significance, suggesting that perhaps a larger sample size would support differences among bears.

Other-side similarity scores increased between 2003–2005 and 2013–2016 while same side and other-bear scores did not, suggesting that fluctuating asymmetry has become more pronounced over time. Polar bears are a long-lived mammal with a lifespan that may exceed 20 years, though bears in the study area are typically < 10 years of age (Stirling et al. 1977; Regehr et al. 2007), with an increase in older bears in the area after 2000 (Heemskerk et al. 2020). Therefore, it is reasonable to expect that we would observe a difference in fluctuating asymmetry over the study period if fluctuating asymmetry is increasing in new bears over time, since the bears sampled in the later time period should include bears born after 2005. However, without actual age or sex of the bears photographed we could not test for differences among generations or different demographic groups.

The ice-free period in the Hudson Bay has lengthened since the 1980s, which is negatively affecting Western Hudson Bay polar bears (Lunn et al. 2016; Castro de la Guardia et al. 2017; Johnson et al. 2020). Environmental stress caused by changing climatic conditions may possibly be contributing to developmental instability in this population. The rates of decline in body condition, survival, and energetics attributed to the changes in sea ice differ among the sex and age classes of polar bears (Stirling et al. 1999; Regehr et al. 2007; Johnson et al. 2020). Likewise, different groups may exhibit different levels of fluctuating asymmetry in response to environmental stress. Further investigation of the change in fluctuating asymmetry over a longer time and among different demographic groups, for example by determining sex and age class of the individuals photographed, may reveal additional patterns.

Whisker prints are expected to be bilaterally symmetrical since, as with other bilateral traits, they are assumed to be derived from the same genetic plan (Whitlock 1996). The stabilization of whisker spot patterns may be weak in comparison to other traits for which symmetry is important for function (Clark 1995). Therefore, it is unclear to what degree whisker prints are an appropriate predictor of population fitness for conservation purposes (Watson and Thornhill 1995; Clarke 1995). However, the Western Hudson Bay polar bear population is exhibiting other signs of decreased fitness, such as declines in body condition (Stirling and Derocher 2012; Boonstra et al. 2020; Johnson et al. 2020).

Although the increased length of the ice-free season is a considerable source of stress on the Western Hudson Bay polar bears, other stressors may be contributing to developmental instability in the population. Genetic stressors, such as inbreeding, can also lead to fluctuating asymmetry in populations (Wayne et al. 1986; Gomendio et al. 2000). Despite a declining population size, only low rates of inbreeding have been detected in the Western Hudson Bay bears (Malenfant et al. 2016; Viengkone et al. 2016). Therefore, it is unlikely that low population size or inbreeding is contributing to fluctuating asymmetry in these bears. However, environmental contaminants are present in Arctic regions (Hung et al. 2016) and have also been associated with developmental instability in some contexts. For example, blood organochlorine concentrations increased wing feather asymmetry in Glaucous Gulls (*Larus hyperboreus*) in the Barents Sea (Bustnes et al. 2002). Conversely, no link was found between fluctuating asymmetry and organohalogens in East Greenland and Svalbard polar bears (Bechshøft et al. 2008, 2009). The presence of both mercury and organochlorines have been detected in the hair and tissues of Western Hudson Bay polar bears (Polischuk et al. 2002; Bechshøft et al. 2016; Morris et al. 2019). Furthermore, some persistent organic pollutants, such as octachlorostyrene and Mirex, have increased in male Western Hudson Bay polar bears between 2007–2008 and 2013–2014 (Letcher et al. 2018). Exposure to these contaminants may also be contributing to the environmental stress and thus developmental instability endured by these bears. Future studies may wish to examine how fluctuating asymmetry of whisker spot patterns in the Western Hudson Bay bears compares to other polar bear populations.

Using fluctuating asymmetry in a single trait to infer developmental instability should be performed with caution since a single trait provides only one sample of the developmental noise in an individual (Whitlock 1996). For this reason, many studies of fluctuating asymmetry use several traits to measure the effects of environmental stress. Studies of fluctuating asymmetry in East Greenland and Svalbard polar bears using nine to 14 metric or meristic traits in the skull and jaw found evidence of fluctuating asymmetry in only a portion (Sonne et al. 2005; Bechshøft et al. 2008, 2009). However, it is challenging to obtain measures of fluctuating asymmetry in multiple traits through methods such as photography, and without the death of the animal. Photographic measures of a single trait have previously been used to measure fluctuating asymmetry in killer whales (Mäkeläinen et al. 2013). Therefore, measuring asymmetry in a single trait for polar bears, such as photographs of whisker spot patterns, may still provide a valid method of non-invasively measuring fluctuating asymmetry in live polar bears. Further, as mentioned previously, factors such as angle and image sharpness can affect similarity scores in the WhiskerPrint program. Although there remains some error associated with the score calculation, since the standard deviation of scores was < 0.15 and the coefficient of variation was < 14%, we do not believe this error is a significant source of bias in assessing fluctuating asymmetry in whisker prints.

Regardless of the source of environmental stress, photographic analysis of whisker spot patterns provides a promising method of monitoring the effects of environmental stress on developmental stability in polar bears. Our results suggest that fluctuating asymmetry is present in a population subject to environmental stress from climate change and other anthropogenic threats. Conditions in Hudson Bay are expected to worsen for polar bears (Castro de la Guardia et al. 2013). It will be critical to continue monitoring the fitness of this population as these changes progress. Although photographic monitoring has limitations, such as needing close access to the individual and high-quality photographs from a good angle, photographs can in some cases be more easily obtained when populations are easily accessible, such as in the western Hudson Bay. Higher quality cameras and lenses will hopefully widen the set of circumstances in which photographs can be safely obtained. Trail cameras have also been used to identify individual terrestrial mammals (McBride and Sensor 2015). As trail cameras improve in quality, there may be opportunity to identify individuals where groups of bears cluster (e.g. Laidre et al. 2018) or in high-density areas (Choo et al. 2020). Photographs collected from a tundra vehicle, trail camera, or a safe distance, may pose less risk to both the bear and the photographer than more traditional invasive methods of monitoring. Further, since photographs can also be used to measure body condition in bears (e.g. Shirane et al. 2020, who used photographs to measure body condition in brown bears, *Ursus arctos*), photographs may be used to assess changes in fitness by multiple measures. Here, we show that the WhiskerPrint software by Anderson et al. (2010) can be used not only to identify individual bears, but also provides a novel method of measuring fluctuating asymmetry in polar bears.

Appendix

See Fig. A1.

Fig. A1 Adult male polar bear (*Ursus maritimus*) photographed near Churchill, Manitoba, Canada in fall 2012 (photo: Jane M. Waterman). Polar bears are currently classified as "Vulnerable" by the International Union for Conservation of Nature (Wiig et al. 2015)

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Author contributions CEK processed the photographs, analyzed the data, and wrote the first draft. JMW and JDR led the collection of photographs and data. All three authors edited the manuscript.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states there is no conflict of interest.

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