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Monitoring sea ice habitat fragmentation for polar bear conservation

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Abstract

Polar bears are a sea ice-dependent carnivore, sensitive to sea ice habitat loss. Climate change has negatively affected sea ice habitat through much of this species' range. We applied landscape fragmentation analysis to quantify polar bear sea ice habitat loss and fragmentation trends (1979–2008) in Foxe Basin, Hudson Strait and Hudson Bay, Canada. Microwave satellite derived monthly mean sea ice concentration maps were classified into four habitat quality categories, and the trends in fragmentation metrics were analyzed. In all regions where preferred habitat declined, sea ice season length decreased and habitat fragmentation increased. The observed trends may affect polar bear movement patterns, energetics and ultimately population trends. Monitoring of sea ice habitat condition in combination with harvest data can provide a dynamic approach to population management and conservation.

Introduction

Habitat loss and fragmentation have been identified as the greatest conservation threats to carnivores (Sunquist & Sunquist, 2001; Crooks, 2002) particularly for habitat specialists (Fischer & Lindenmayer, 2007) such as the polar bear (*Ursus maritimus* Phipps, 1774). Anthropogenic land use activities such as forestry, agriculture and urbanization have been the primary causes of habitat destruction (Schipper *et al*., 2008), but climate change is emerging as an equally important driver of habitat change in terrestrial and marine ecosystems (Grebmeier *et al*., 2006; Parmesan, 2006). Sea ice provides a spatially and temporally dynamic habitat for a diversity of species and is integral to Arctic marine food webs (Bluhm & Gradinger, 2008). Life history patterns of Arctic marine species are tied to sea ice phenology and structural characteristics (Gaston, Gilchrist & Hipfner, 2005; Moore & Huntington, 2008). Polar amplification of climate change in the Arctic continues to cause rapid modification and loss of sea ice (Markus, Stroeve & Miller, 2009) and is considered a threat to polar bears and their prey (Derocher, Lunn & Stirling, 2004; Laidre *et al*., 2008).

Polar bear demographic and habitat research has focused on the effects of changing spring sea ice break-up patterns (Stirling, Lunn & Iacozza, 1999; Stirling & Parkinson, 2006; Regehr *et al*., 2007) as well as habitat selection and loss in higher latitude regions (Ferguson, Taylor & Messier, 2000; Mauritzen *et al*., 2003a; Durner *et al*., 2009). Sea ice at lower latitudes (< 70° N), however, is changing faster than higher latitudes (Markus *et al*., 2009) and may have greater negative effects on polar bear populations in southern regions (Amstrup, Marcot & Douglas, 2008). Climate change projections show disproportionate impacts on polar bear sea ice habitat in the seasonal ice regions of the lower latitudes (Amstrup *et al*., 2008); thus, we anticipate increasing habitat fragmentation and declining habitat quality; changes that accompany habitat loss (Andren, 1994; Lindenmayer & Fischer, 2006; Mortelliti, Amori & Boitani, 2010). Sea ice habitat fragmentation is expected to affect polar bear life history by altering movement patterns, mating ecology, and prey availability (Derocher *et al*., 2004; Molnár *et al*., 2007) yet no studies have addressed fragmentation.

Landscape and habitat fragmentation analyses have been used to monitor and quantify habitat conversion, degradation and loss (Coops *et al*., 2010; Mizerek, Regan & Hovel, 2011),to select wildlife movement corridors, species reintroduction sites and protected areas (Hostetler *et al*., 2009), and to identify important regions for protecting biodiversity (Crooks *et al*., 2011). Fragmentation metrics describe the composition and configuration of habitat patches within a landscape (McGarigal & Marks, 1995). Habitat patch quality is important in determining species occupancy and persistence (Visconti & Elkin, 2009; Schooley & Branch, 2011). Habitat fragmentation influences the habitat loss thresholds for species survival (Hanski & Ovaskainen, 2002; Swift & Hannon, 2010). Polar bear sea ice habitat is changing quickly (Stirling & Parkinson, 2006) making it important to introduce rapid assessment tools for monitoring habitat change.

Polar bear conservation efforts have emphasized hunting bans and harvest management (Peacock *et al*., 2011).

Regulated polar bear hunting is permitted in Canada, Greenland and Alaska, with the majority of the bears being taken in Canada (Obbard *et al*., 2010). Canadian polar bear harvest management is based on a precautionary approach that relies on the best available information on population size and trend (Peacock *et al*., 2011), yet habitat monitoring is not being used in harvest management. A total allowable harvest is calculated for each population, male-biased hunting is encouraged, and the harvest is monitored by collecting biological and morphometric data on killed bears (Taylor, McLoughlin & Messier, 2008). Harvest quotas do not include the influence of changing sea ice habitat conditions on polar bear populations, even though population level changes in reproduction, survival and population size related to sea ice conditions have been documented (Stirling *et al*., 1999; Regehr *et al*., 2007, 2010; Rode, Amstrup & Regehr, 2010). However, region- and population-specific sea ice habitat monitoring is possible, and habitat metrics can be included in polar bear harvest plans to augment precautionary measures associated with setting harvest levels.

In this study, we quantify temporal and spatial trends in polar bear sea ice habitat in three lower latitude Arctic regions of Canada using habitat fragmentation metrics. Further, we propose a new approach that uses contemporary estimates of sea ice habitat for input into harvest management.

Methods

The study area covers 1 241 250 km^2 of ocean surface and includes three marine regions: Foxe Basin (203 750 km^2), Hudson Strait (196 875 km^2) and Hudson Bay (840 625 km^2) (Fig. 1). We delineated each region

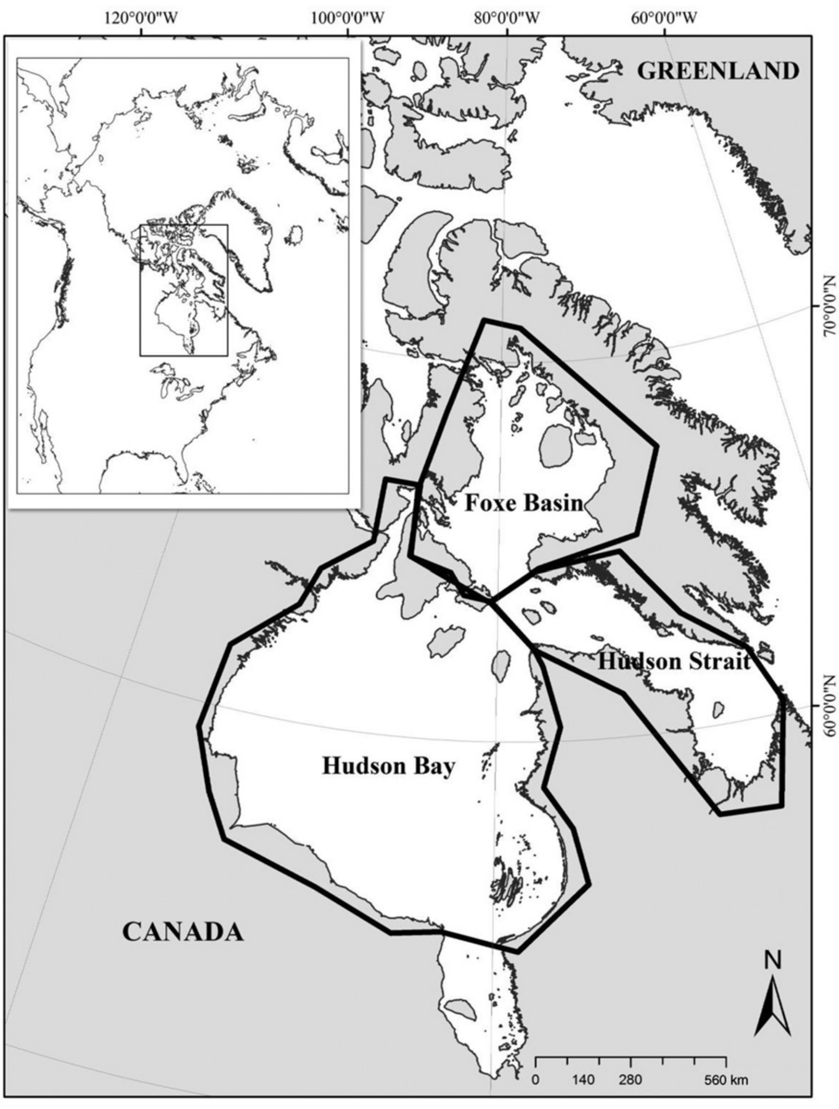

Figure 1 Study area map showing the marine regions of Foxe Basin, Hudson Strait and Hudson Bay, Canada.

using physical (coastline, bathymetry) and oceanographic (circulation, currents) characteristics. These are shallow (predominantly less than 200 m deep), productive mid- to low-latitude Arctic seas that undergo an annual sea ice phenological cycle from ice-free to almost total ice cover. Overall, duration of ice cover in the area has been declining, with delayed freeze-up and earlier break-up dates correlated with increasing surface air temperatures (Moore, 2006; Stirling & Parkinson, 2006; Hochheim & Barber, 2010; Galbraith & Larouche, 2011).

Monthly mean sea ice concentration (percent areal coverage of sea ice) data for 1979–2008 were obtained from the National Snow and Ice Data Center website (http://nsidc.org/). The data were collected by the Nimbus-7 Scanning Multi-channel Microwave Radiometer and Defense Meteorological Satellite Program-F8, -F11 and -F13 Special Sensor Microwave/Imager and processed at a grid cell of 25×25 km (Cavalieri *et al*., 1996 updated 2008). Each grid cell was attributed percent ice concentration between 0 and 100%. The temporal and spatial scales of the data are appropriate for quantifying regional trends in polar bear habitat because satellite-collared polar bears can move 25 km in a day and in a year traverse the extent of the study area (Amstrup *et al*., 2000; Parks, Derocher & Lunn, 2006).

Ice concentration data were imported into ArcMap 9.3 (ESRI, Redlands, CA, USA) as raster layers. Each monthly layer was classified into four categories reflecting a habitat type and relative quality: non-habitat (< 30% ice), poor (31–60% ice or very open ice), good (61–85% ice or open ice) and best (> 85% ice or closed ice) (Fig. 2). Our sea ice habitat classes were adapted from known polar bear habitat selection and preferences (Ferguson *et al*., 2000; Mauritzen *et al*., 2003a; Durner *et al*., 2009), the sea ice habitat used by Foxe Basin polar bears, and the threshold value of 50% sea ice concentration used in population trend research (Stirling *et al*., 1999; Regehr *et al*., 2010). We acknowledge that using habitat structure as a proxy of habitat quality is not ideal (Johnson, 2007) but proxies can work if there are no available species-specific habitat fitness measures (e.g. survival, reproduction) (Crooks *et al*., 2011; Mortelliti *et al*., 2011), as is the

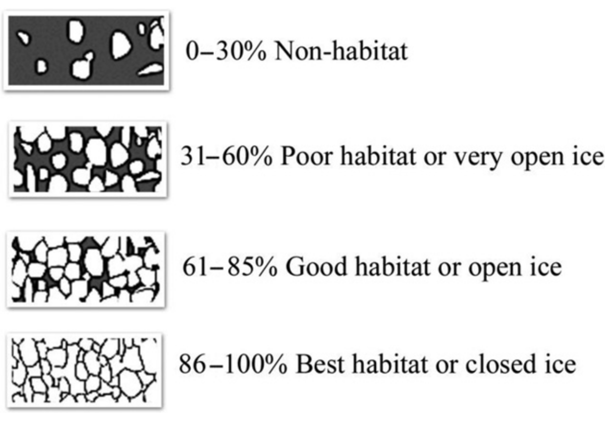

Figure 2 Polar bear sea ice habitat classes (adapted with permission from Canadian Ice Service).

case for polar bears. The classified sea ice habitat maps were exported as ASCII grid files for fragmentation analysis.

We used landscape fragmentation analysis to examine polar bear habitat trends over 30 years (1979–2008). FRAGSTATS v3.3 (McGarigal *et al*., 2002) was used to compute habitat patch-based fragmentation metrics for each month. Patches were identified as adjacent grid cells of the same habitat class, where, the smallest patch size is one grid cell and largest patch composed of all grid cells in the region. Fragmentation metrics describe the composition and configuration of habitat patches within a landscape or, in our case, a sea icescape. We used three habitat metrics to explore changes in icescape composition: PLAND, the proportional (%) area of each habitat class within each region; AREA_AM, the area weighted mean habitat patch size (km^2) to provide insight into how habitat loss is fracturing the icescape; and NP, the summed number of habitat patches as a measure of changing icescape habitat heterogeneity. Sea ice freeze-up and break-up patterns precluded use of FRAGSTATS configuration metrics such as proximity and contagion because habitat patches are spatially correlated: during freeze-up ice grows from the coastlines to the centre of each water body then reversing direction during the melt period and break-up.

The timing of sea ice phenological events was determined by binning good and best habitat PLAND into a new category called preferred habitat (i.e. ice cover > 60%). Freeze-up month was identified when there was > 30% PLAND of preferred habitat and break-up month when the PLAND of preferred habitat < 30%, for 7 years within a 10-year moving window. SPSS Statistics 18 (IBM, Somers, NY, USA) was used to evaluate the fragmentation metric trends (least-squares linear regression).

Results

From 1979 to 2008, the Foxe Basin ice season declined from 9 to 7 months. Before 1994, break-up occurred in August as the preferred habitat PLAND in July was generally higher than our defined 30% threshold (Fig. 3a). After 1994, preferred habitat was usually < 30%, with a low of 6% in 2005. Freeze-up was delayed from November to December with the amount of preferred habitat in November becoming less than 30% during most years after 1994 (Fig. 3b). The rate of change of best and good habitat during July and November was negative, ranging from –0.5% per year to –1.3% per year (Table 1). Best habitat also declined in April to July, November and December, with the greatest loss in June (–1.2% per year; Table 1). Best habitat was replaced by good habitat in April and December but in May–July and November best habitat was also replaced by poor and non-habitat (Table 1). Poor habitat began to appear in December as of 1998 (Fig. 3b).

The Hudson Strait ice season decreased from 7 to 5 months with break-up advancing into June as of 1998 and freeze-up delayed to January after 1995 (Fig. 3c,d). Hudson Strait is the only region that showed loss of best habitat during the winter period, January to March, and loss of

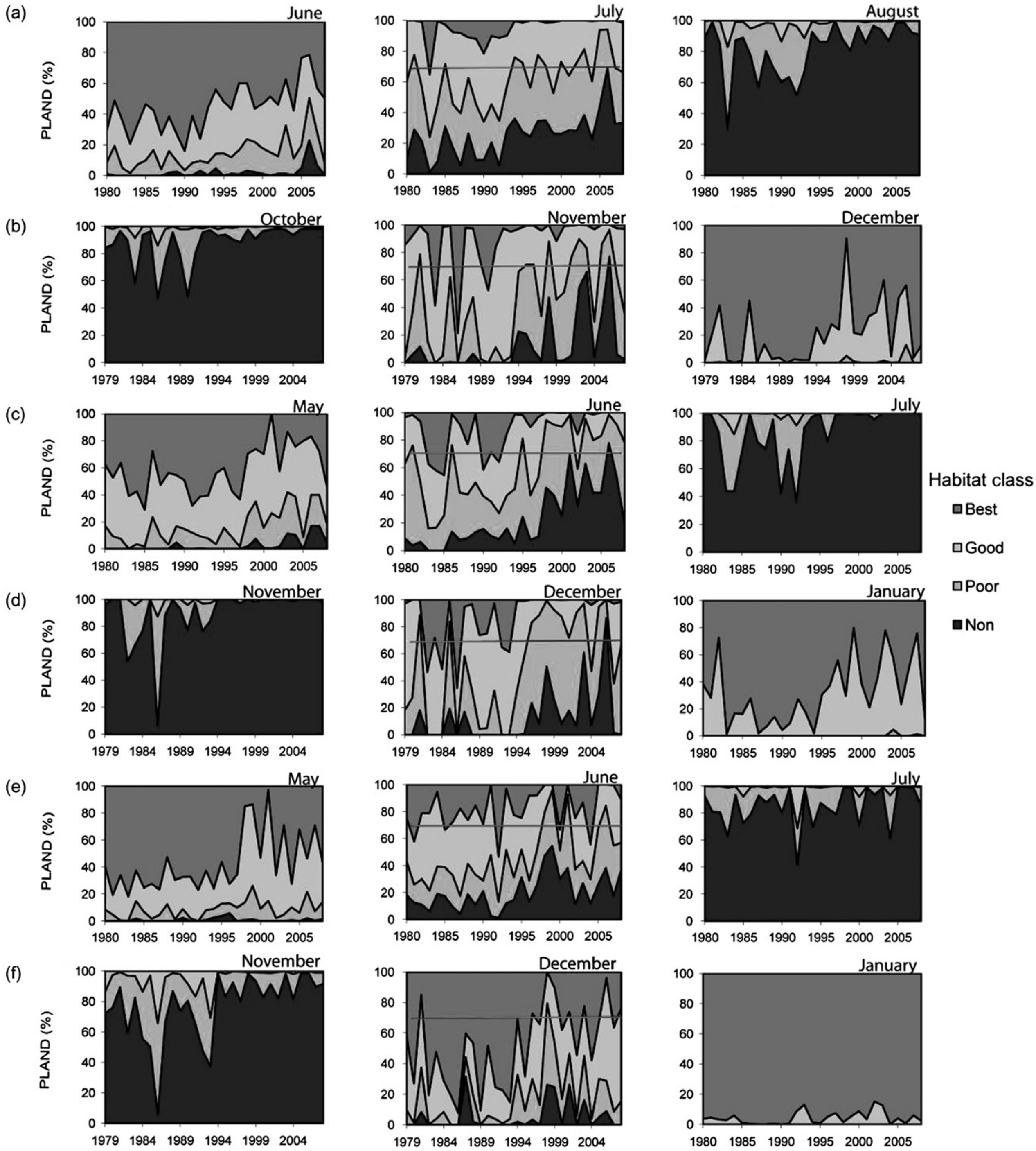

Figure 3 Polar bear sea ice habitat month of break-up and freeze-up (1979–2008): (a) Foxe Basin break-up; (b) Foxe Basin freeze-up; (c) Hudson Strait break-up; (d) Hudson Strait freeze-up; (e) Hudson Bay break-up; (f) Hudson Bay freeze-up. The horizontal red line shows the 30% threshold of preferred (best and good) habitat that identifies break-up and freezeup month.

good habitat in December (Table 1). Best habitat also declined in April (–1.4% per year) and May (–0.9% per year) (Table 1) and was greatly reduced after 1994 in June and December (Fig. 3c,d). In May, best habitat was replaced by poor and non-habitat (Table 1). Good sea ice habitat declined at high rates in June (–1.4% per year) and December (–1.5% per year). Good habitat was no longer present in July after 2003 and in November after 1993 (Fig. 3c,d). In

Table 1 Polar bear sea ice habitat class area as proportion of icescape (PLAND) slope (% per year) of linear regression trends over time, Foxe Basin, Hudson Strait and Hudson Bay, Canada (1979–2008)

	Foxe Basin PLAND (% per year)				Hudson Strait PLAND (% per year)				Hudson Bay PLAND (% per year)			
	Non[a]	Poor	Good	Best	Non	Poor	Good	Best	Non	Poor	Good	Best
January	~	~	nt	nt	~	nt	1.1	–1.1	~	~	nt	nt
February	~	~	nt	nt	~	nt	0.6*	–0.6*	~	~	nt	nt
March	~	~	nt	nt	~	nt	0.9*	–0.9*	~	~	nt	nt
April	~	~	0.4*	–0.4*	~	0.2*	1.2*	–1.4*	~	nt	1.0	–1.0
May	~	0.2	0.4*	–0.6*	0.4*	0.5*	nt	–0.9	nt	0.3	1.1	–1.4*
June	0.2	0.4*	0.5	–1.2*	2.0*	nt	–1.4*	nt	0.8	nt	–1.0	–0.8
July	1.1*	nt	–0.7	–0.5	1.1	–1.0	nt	~	nt	nt	nt	~
August	0.9	–0.7	nt	~	nt	~	~	~	nt	~	~	~
September	nt	nt	~	~	nt	~	~	~	nt	~	~	~
October	0.7	–0.6	nt	~	nt	nt	~	~	nt	nt	~	~
November	1.0	nt	–1.3	–0.8	0.9	–0.8	nt	~	1.2*	–0.9*	–0.3	~
December	~	nt	0.7	–1.0	1.0	1.4	–1.5*	–1.8	nt	0.5	0.8	–1.5*

*$P < 0.005$ otherwise $P < 0.05$; ~ habitat class not observed or trace; nt, no trend.

[a]Sea ice habitat classes: Non (0–30% ice cover); Poor (31–60% ice cover); Good (61–85% ice cover); Best (>85% ice cover).

January, the first observation of poor habitat occurred in 2004 (Fig. 3d).

The Hudson Bay ice season remained at 7 months with break-up in July and freeze-up occurring in December (Fig. 3e,f). But break-up showed signs of advancing to June with the preferred habitat break-up threshold of 30% exceeded five times in June between 1997 and 2008 (Fig. 3e). In addition, June-preferred habitat trends were negative (best, –0.8% per year and good, –1.0% per year) and non-habitat increased (0.8% per year) (Table 1). Hudson Bay showed high rates of best habitat loss in April (–1.0% per year), May (–1.4% per year) and December (–1.5% per year) (Table 1). In November, good and poor habitats were replaced by non-habitat and poor habitat (Table 1, Fig. 3f).

In all regions from 1997 to 2008, there were generally negative trends in best habitat patch size (AREA_AM) in spring, and, positive trends in non-habitat patch size during break-up and autumn months; patch size trends were similar to the habitat loss (PLAND) trends. Foxe Basin best patch size trends were negative from April to July (–540 to –2867 km^2 per year), and in July (–1236 km^2 per year) and November (–3112 km^2 per year) good habitat patches size also declined (Table 2). Non-habitat patch size increased during June to August (239–2169 km^2 per year), October (1495 km^2 per year) and November (2439 km^2 per year). Hudson Strait showed the most widespread declines in best habitat patch size: February to June (–1571 to –3239 km^2 per year) and December (–1173 km^2 per year). Good habitat patch size declined in June (–1656 km^2 per year) and December (–2610 km^2 per year) and increased in February to April (858 to 1978 km^2 per year). Hudson Bay best patch size declined in April (–9381 km^2 per year), May (–11 727 km^2 per year) and December (–12 883 km^2 per year); good patch size declined in June (–7776 km^2 per year) and increased in April (5891 km^2 per year), May (9626 km^2 per year) and December (6615 km^2 per year) (Table 2).

Number of patches (NP) trend from 1979 to 2008 was positive during winter and spring, negative during break-up and autumn, and Hudson Bay showed the highest rates of patch size change (Table 2). In all regions, most increases in number of patches occurred during months when best habitat patch size declined: in Foxe Basin from April to June (0.1–0.2 patch per year), in Hudson Strait from February to April (0.1 patch per year), and in Hudson Bay in April (0.2 patch per year) and May (0.3 patch per year) (Table 2). Increase in the number of patches is an indicator of increasing icescape heterogeneity, as large habitat patches break into smaller patches and become interspersed with other patch types. Conversely, as the number of patches decreases, the icescape becomes more homogeneous, with fewer but larger patches of a single habitat type. Negative trends in a number of patches occurred when non-habitat patch size grew and increased in dominance: in Foxe Basin from June to October (–0.1 to –0.2 patch per year), in Hudson Strait in July (–0.2 patch per year) and November (–0.1 patch per year), and in Hudson Bay, with the exception of September, from June to November (–0.1 to –0.5 patch per year).

Discussion

Three sea ice habitat trends were found that may affect polar bear populations by altering movement patterns and affecting energetics: (1) changing sea ice phenology with earlier break-up and later freeze-up; (2) loss of preferred sea ice habitat in April to May (spring); (3) increasing habitat fragmentation.

Net habitat loss, as expressed by the decline in the proportion of preferred (best and good) habitat and changes in sea ice phenology potentially reduce the on-ice foraging time and efficiency for polar bears. The spring to break-up period is critical for polar bears (Watts & Hansen, 1987) because the bears are hyperphagic, feeding on vulnerable seal pups

Table 2 Polar bear sea ice habitat class area weighted mean habitat patch size (AREA_AM) slope (km^2 per year) of linear regression trends over time and region total number of habitat patches (NP) slope (patch per year) of linear regression trends over time, Foxe Basin, Hudson Strait and Hudson Bay, Canada (1979–2008)

	Foxe Basin					Hudson Strait					Hudson Bay				
	AREA_AM (km^2 per year)				NP per year	AREA_AM (km^2 per year)				NP	AREA_AM (km^2 per year)				NP per year
	Non[a]	Poor	Good	Best		Non	Poor	Good	Best		Non	Poor	Good	Best	
January	~	~	nt	nt	nt	~	nt	nt	nt	0.1	~	~	nt	nt	0.2
February	~	~	nt	nt	nt	~	nt	858	−1934*	0.1	~	~	nt	nt	nt
March	~	~	nt	nt	nt	~	nt	1140	−2355*	0.1	~	~	nt	nt	0.2
April	~	~	393*	−910*	0.1	~	314*	1978	−3239*	0.1	~	nt	5891	−9381	0.2*
May	~	223	455	−1314*	0.2*	562*	991*	nt	−1795	nt	nt	nt	9626	−11727*	0.3*
June	239	nt	1125	−2867*	0.2*	3522*	nt	−1656	−1571	nt	nt	nt	−7776	nt	−0.5
July	1898*	nt	−1236	−540	nt	2611	−1464	nt	~	−0.2*	nt	nt	nt	~	−0.3*
August	2169	nt	nt	~	−0.2	nt	~	~	~	~	nt	~	~	~	−0.1
September	nt	nt	~	~	−0.1	nt	~	~	~	nt	nt	~	~	~	nt
October	1495	−684	nt	~	−0.1*	nt	nt	~	~	nt	188*	nt	~	~	−0.1
November	2439*	nt	−3112	nt	nt	2002	−2670	nt	~	−0.1	3510*	−7461*	nt	~	−0.2
December	~	nt	nt	nt	nt	1921	2233	−2610	−1173*	nt	nt	4204	6615	−12883*	nt

* $P < 0.005$ otherwise $P < 0.05$; ~ habitat class not observed or trace; nt, no trend.

[a]Sea ice habitat classes: Non (0–30% ice cover); Poor (31–60% ice cover); Good (61–85% ice cover); Best (>85% ice cover).

and molting adult seals to recover the fat stores lost over winter in preparation for the ice-free summer months and when prey is usually inaccessible (Stirling & Øritsland, 1995; Derocher *et al*., 2004). The hyperphagic period is especially important for lactating females with high energy demands and pregnant females that need to store fat for over-winter maternal denning (Ramsay & Stirling, 1988). Earlier break-up date has caused reduced caloric intake resulting in lower body condition, cub litter size, and cub survivorship in the Western Hudson Bay and Southern Beaufort Sea populations (Stirling *et al*., 1999; Regehr *et al*., 2007, 2010; Rode *et al*., 2010; Molnár *et al*., 2011). These effects have resulted in a measurable decline in the size of the Western Hudson Bay polar bear population (Regehr *et al*., 2007). Although a numerical response in the Southern Beaufort Sea population has not been demonstrated, changes in sea ice composition will likely produce a negative population trend (Hunter *et al*., 2010; Regehr *et al*., 2010; Rode *et al*., 2010).

Regional icescape connectivity is important for polar bear populations because the bears move extensively on sea ice in search of prey and in spring during mating; female home ranges are large, up to 964 264 km^2 in high arctic, perennial sea ice regions (Mauritzen *et al*., 2002), and in our study area range from 8470–311 646 km^2 (Parks *et al*., 2006). Female polar bears show fidelity to summer retreat and denning areas (Ramsay & Stirling, 1990; Stirling *et al*., 1999) and to sea ice habitats (Mauritzen, Derocher & Wiig, 2001). Greater habitat fragmentation and longer ice-free seasons may disrupt their annual return and could alter population boundaries and gene flow (Derocher *et al*., 2004). Another more subtle affect resulting from greater habitat heterogeneity is reduced efficiency of male bears locating estrous female bears during the spring mating season resulting in reduced mating success (Molnár *et al*., 2007).

At the daily temporal scale, foraging energy costs for inter- and intra-habitat patch movements may add to the affects of prolonged fasting caused by shorter ice seasons. Our observations of declining best habitat patch size and rising icescape heterogeneity will increase inter-patch movements, and the frequency and distance of swimming events. Polar bears readily swim and are able to swim long distances between habitat patches but swimming has higher energetic costs than walking (Durner *et al*., 2011), and, can cause adult and cub mortality (Monnett & Gleason, 2006; Durner *et al*., 2011). Cubs are particularly vulnerable to hypothermia (Blix & Lentfer, 1979). Within days after den emergence, in March or April, cubs are exposed to variable sea ice habitat conditions as they begin their 2–3-year period of following their mother throughout her home range. The energy costs of intra-patch movement may increase as open ice habitats impose higher energetic costs and greater risks for polar bears than areas with higher ice concentrations (Mauritzen *et al*., 2003*a*,*b*). Intra-patch movements entail more and longer swimming events where lower quality habitat patches can consist of many small ice floes interspersed with open water (Fig. 2). Our results indicate that available habitat is composed of a greater proportion of lower quality sea ice for longer periods of each ice season since the mid-1990s.

Polar bear populations in the Canadian Arctic face the stresses of habitat loss and fragmentation as well as harvest. Sea ice habitat conditions are predicted to deteriorate throughout the range of polar bears (Durner *et al*., 2009; Amstrup *et al*., 2010) and the Canadian harvest, an integral part of arctic community culture and economy, will also continue (Peacock *et al*., 2011). With the habitat degradation and fragmentation that we observed in Foxe Basin, Hudson Strait and Hudson Bay, it should no longer be assumed that polar bear population parameters remain static among population inventories. We hypothesize that the polar bears of Foxe Basin and Hudson Strait regions, which are predominantly included in the Foxe Basin population, will show future reduced body condition and cub production in response to the documented changes in sea ice habitat, as have been observed in the Western Hudson Bay and Southern Hudson Bay populations (Stirling *et al*., 1999; Obbard *et al*., 2006; Regehr *et al*., 2007).

The polar bear is a candidate species to exhibit population lag effects and extinction debt. Highly mobile species, like polar bears, can show lag effects up to habitat loss thresholds of 70–80% (Andren, 1994). Slow-reproducing habitat specialists, like polar bears, are particularly prone to extinction debt (Lindenmayer & Fischer, 2006). Harvest, monitoring is unlikely to reveal population lag effects or extinction debt because polar bear harvest is adult- and male-biased (Derocher, Stirling & Calvert, 1997). The current polar bear population estimate interval of 15 years for most populations (Peacock *et al*., 2011) is inadequate to provide early detection of population decline. Habitat metric trend analyses have shown that habitat loss and fragmentation precede and are correlated with changes in species occurrence and abundance (Gu, Heikkila & Hanski, 2002; Metzger *et al*., 2009). The effectiveness of this approach is increased if habitat fragmentation metrics are linked to biological attributes such as body condition, reproduction and prey abundance (Mortelliti *et al*., 2010). Trends in polar bear biological attributes have been correlated with sea ice phenology (break-up date) (Regehr *et al*., 2007; Rode *et al*., 2010), but research is needed to link biological attributes and habitat fragmentation metrics. For our study area, this means combining the polar bear telemetry and capture datasets with sea ice habitat metrics. Ongoing monitoring of habitat loss and fragmentation can provide an early warning indicator for polar bear managers about vulnerable populations.

Microwave satellite earth observation data collection began in 1979, allowing sea ice habitat trends to be examined. Microwave imagery is available year round and its resolution is appropriate for monitoring polar bear sea ice habitat at regional or larger geographic scales. Finer scale resolution satellite imagery (e.g. AMSR-E, MODIS, SAR) is available but is limited in temporal and spatial coverage because of the timing of launch and decommission of satellites, satellite orbital path and use of optical sensors that require sunlit, cloud-free conditions, which are limited in Arctic regions. Our freeze-up and break-up trends are similar to those noted by others (Stirling & Parkinson, 2006; Hochheim & Barber, 2010; Galbraith & Larouche, 2011) but extending the analyses to trends in habitat provides new insights into ongoing ecosystem dynamics. Our application of habitat fragmentation analysis using FRAGSTATS is robust, cost effective, and has the potential to improve polar bear management and conservation.

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