Vegetation

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There continues to be evidence of widespread changes in vegetation in northern latitudes, primarily determined from trends in terrestrial greenness as detected by the Normalized Difference Vegetation Index (NDVI) derived from the NOAA AVHRR satellites (Myneni et al. 1997; Zhou et al. 2001; Lucht et al. 2002; Jia et al. 2003; Goetz et al. 2005; Bunn et al. 2007). Changes in land cover, vegetation density, and other factors are reflected in NDVI. Overall, increasing NDVI is consistent with warming soil and air temperatures, earlier snow melt, and the expansion of shrubs and tree line to the north.

In coastal regions, models have predicted that the retreating sea ice should affect the temperature and ecosystems of adjacent lands (e.g., Lawrence et al., 2008). Time series of sea-ice area, land temperatures, and an index of photosynthetic activity (the annual maximum NDVI or MaxNDVI) were investigated for trends and variability during the period 1982–2008 along the coastlines of 14 Arctic seas. Temporal analyses of these regional time series (not shown) consistently indicate that higher land-surface temperatures and higher NDVI values correspond to below-average sea-ice concentration (Bhatt et al., 2008, 2009).

The trend analysis shows that summer sea ice within 50 km of the coast declined in all regions, with a decrease of 25% for the northern hemisphere as a whole (Fig. 1, blue bars). The largest declines were along the northern Beringia region, including the E. Siberia (-47%), W. Chukchi (-46%), and E. Chukchi (-44%) seas. This portion of the Arctic saw large areas of summer ice retreat in 2005, 2007, and 2008.

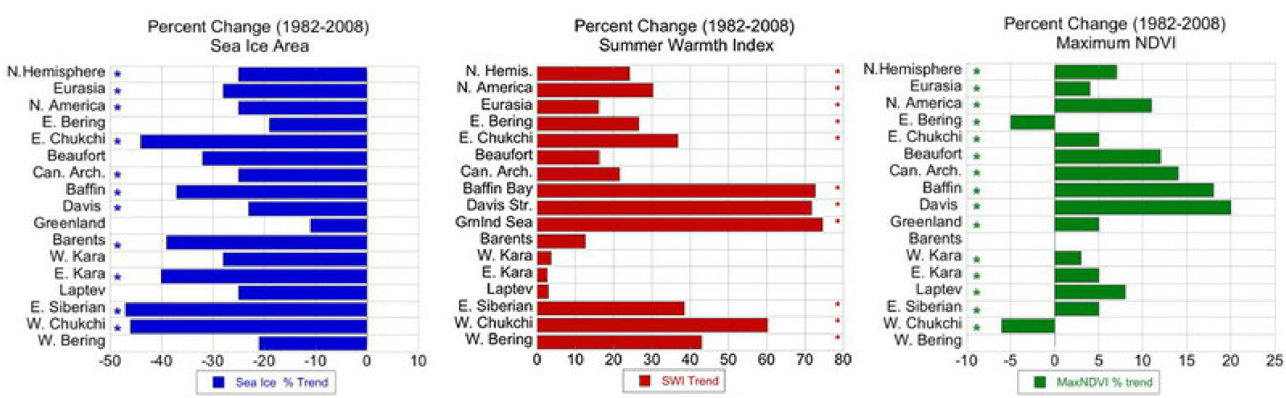

Figure 1. Blue bars: Percentage change in sea-ice area in late spring (when the long-term mean 50% concentration is reached) during 1982–2008 along the 50-km-seaward coastal margin in each of the major seas of the Arctic using 25-km resolution SSMI passive microwave Bootstrap sea-ice concentration data (Comiso and Nishio, 2008). Red bars: Percentage change in the summer land-

surface temperature landward of each sea for the entire tundra domain as measured by the summer warmth index (SWI = sum of the monthly mean temperatures above freezing, °C mo) based on AVHRR surface-temperature data (Comiso, 2003). Green bars: Percentage change in greenness for the full tundra area in the vicinity of each Arctic sea as measured by the annual maximum Normalized Difference Vegetation Index (MaxNDVI) based on revised biweekly GIMMS NDVI (Tucker et al., 2001). Asterisks denote significant trends at $p < 0.05$.

Summer tundra land temperatures as measured by the summer warmth index (sum of the monthly mean temperatures that are above freezing) increased 24% for the northern hemisphere as a whole (Fig. 1, red bars). The North America Arctic tundra experienced a 30% increase in summer land temperatures while Eurasia experienced a 16% increase. Large increases in summer warmth occurred in the vicinity of the W. Chukchi (60%) and W. Bering (43%) seas and near Davis Strait (72%), Greenland Sea (75%) and Baffin Bay (73%). Weak warming occurred along the northern coast of Russia (Laptev Sea, E. Kara Sea and W. Kara Sea).

Photosynthetic activity was determined using the MaxNDVI derived from Global Inventory Modeling and Mapping Studies (GIMMS) data set. The NDVI is an index of the photosynthetic activity that is derived from earth's reflectance in the visible and near infrared portions of the spectrum. MaxNDVI over the tundra region increased 7% for the Arctic as a whole (Fig. 1, green bars), but was variable. Larger percentage increases occurred in North America (11%) than in Eurasia (4%). The largest percentage increases were in the North American High Arctic in the vicinity of Davis Strait (20%), Baffin Bay (18%), and the Canadian Archipelago (14%) and in the Beaufort Sea (12%). Declines or no trend occurred in the Bering-Chukchi region (W. Chukchi -6%, E. Bering -5% and W. Bering 0%). The NDVI changes observed in coastal regions are in general agreement with strong increases in NDVI noted previously in the North American Arctic (Jia et al., 2003; Goetz et al., 2005; Verbyla, 2008; Raynolds et al., 2008) and with ground observations from the same regions (Tape et al., 2006; Walker et al., 2008; Epstein et al., 2008), but the new information from the High Arctic of Canada and Greenland points to previously overlooked major changes to plant productivity occurring in this region. Because of the currently low productivity in these coldest areas of the Arctic, small increases in photosynthetic activity are likely to lead to major changes in biodiversity and total plant biomass.

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