Drivers and impacts of ecological change on the Yukon-Kuskokwim Delta, Alaska

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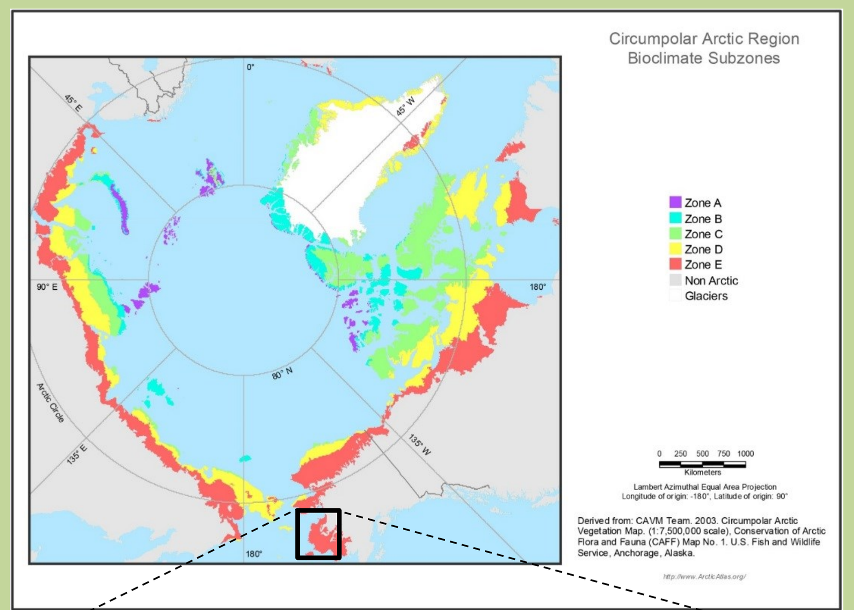
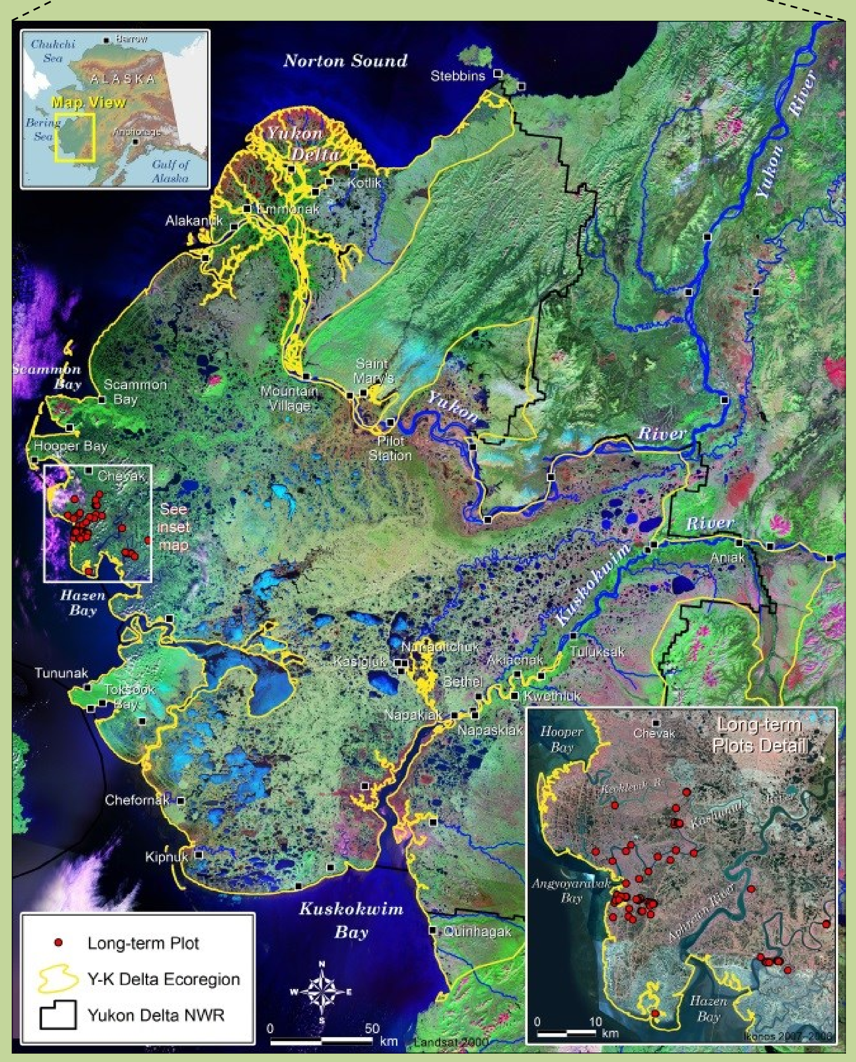
Abstract

The Yukon-Kuskokwim Delta (YKD) region is one of the most biologically productive areas of the tundra biome and supports one of the largest indigenous human populations in the Arctic. Much of the YKD lies near sea-level, and the region's warm, thin permafrost is highly susceptible to thaw as temperatures warm. Sea-level rise, sea-ice loss, and changes in the frequency and intensity of storms make coastal ecosystems and infrastructure especially vulnerable. Multi-scale satellite records, coupled with a network of long-term monitoring plots, offer a means of characterizing disturbance processes, the scales at which they operate, and how they manifest in changes to vegetation and habitat. At the regional scale, Normalized Difference Vegetation Index (NDVI) trends have been idiosyncratic relative to circumpolar trends, with coarse-scale (12.5 km) AVHRR time-series indicating strong declines in NDVI that contrast starkly with increases elsewhere in the Arctic. There is evidence that this "browning" is linked to regional climate drivers, including an increase in summer cloudiness; however, interpretation of NDVI trends are complicated by the large extent of surface water on the YKD. Also, the region's wide coastal zone is subject to abrupt, nonlinear dynamics after episodic storms, flooding, and salt-kill of vegetation. The Landsat record offers a means to corroborate trends observed by AVHRR, and to link them with underlying landscape-scale drivers. Landsat excels at pinpointing disturbance "hotspots," as well as directional changes in vegetation at 30 m resolution. Long-term field plots in YKD coastal areas (1994–present) are ideal for characterizing changes to the region's most biologically productive habitats and subsistence areas. These plots indicate a range of vegetation responses across gradients of landscape age; salt-tolerant vegetation has been resilient on younger delta deposits, whereas changes are accelerating on older deposits underlain by permafrost. The Landsat record generally corroborates the browning observed by AVHRR in the YKD coastal zone, but some obvious increases in vegetation productivity (e.g., tall shrub increase) elsewhere in the region are not evident in the AVHRR record.

Background

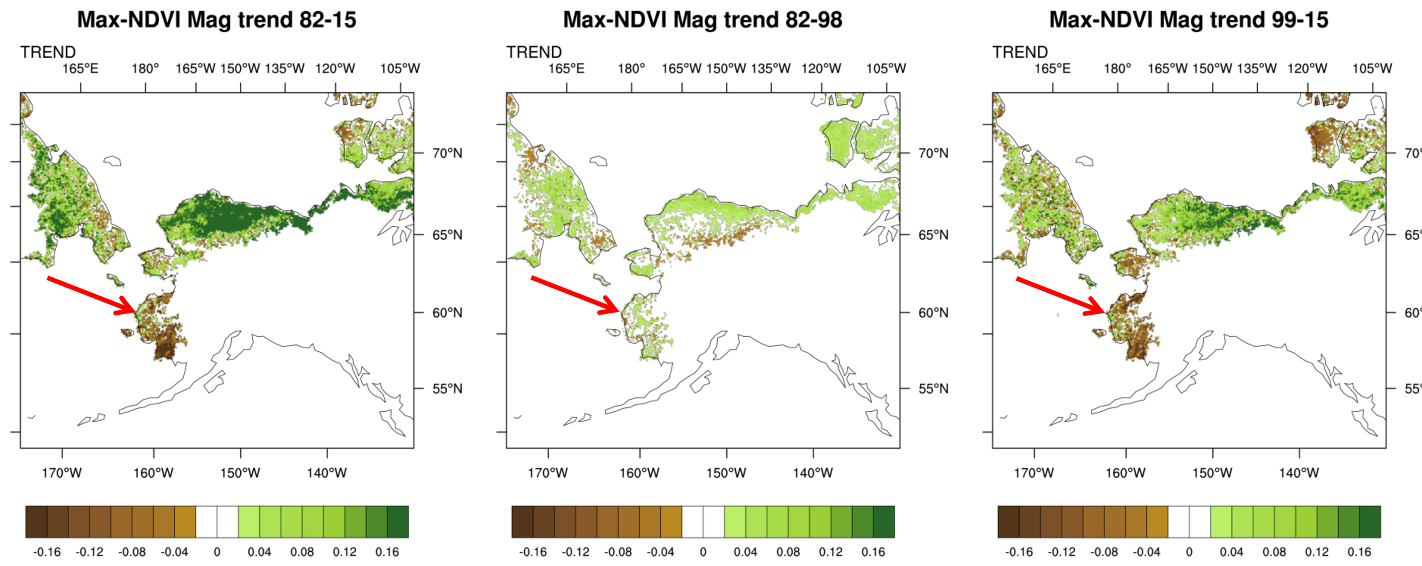




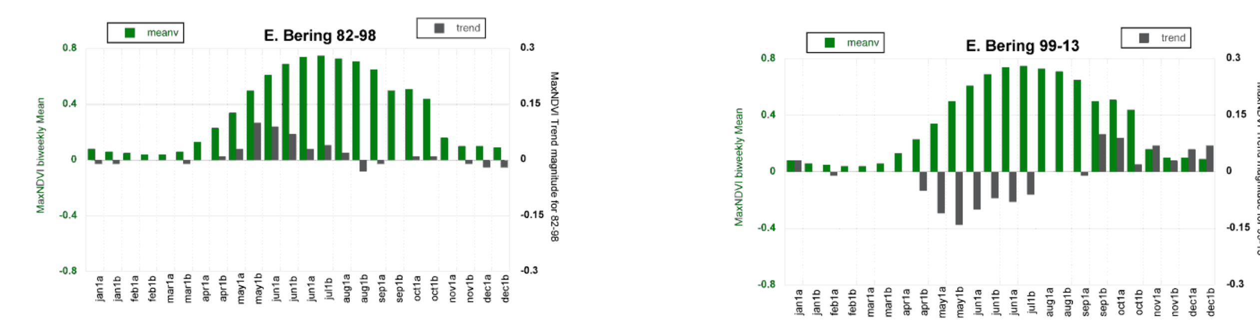
- southernmost part of tundra biome
- MAAT -2° C
- 70% below 30 m elevation
- 35 villages
- ~30,000 Yup'ik people
- exceptional breeding habitat for waterbirds

- **Y-K Delta has been underrepresented in studies of arctic environmental change despite high societal value**
- **vulnerable because of proximity to basic environmental thresholds: sea-level elevation and freezing point (permafrost thaw)**

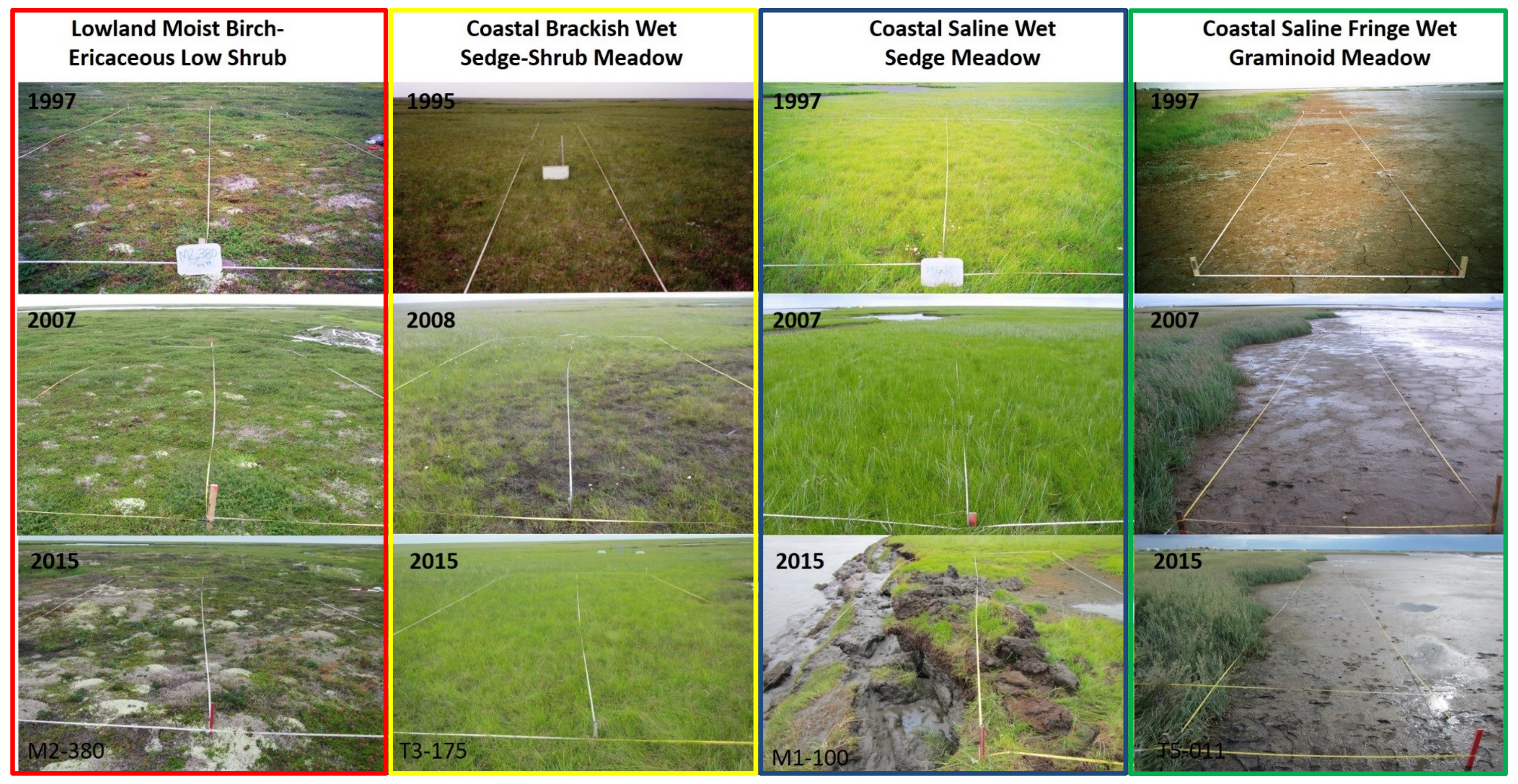
AVHRR time-series



Coarse-scale (12.5 km) AVHRR time-series indicate widespread NDVI decline on the YKD since 1982, especially over the period since 1999 (above). "Browning" is most pronounced in the early summer (below) There is evidence that this browning is linked to regional climate drivers, such as an increase in summer cloudiness, but interpretation of NDVI trends is complicated by abundant surface water on the YKD. Also, the region's wide coastal zone is subject to abrupt, nonlinear dynamics after episodic storms, flooding, and salt-kill of vegetation, while interior uplands have one of the most active fire regimes anywhere in the Arctic.



Field monitoring



Salt-killed dwarf birch after 2005 storm, later lichen expansion

Salt-killed meadow after 2005 storm, later *Carex ramenskii* sedge expansion

Bank erosion along the Manokinak tidal river

Smothering of halophytic sedges after 2005 storm, no recovery

Long-term field plots in YKD central coast (1994–present) are ideal for characterizing changes to the region's most biologically productive habitats and subsistence areas, and are well suited for analysis with Landsat time-series. These plots indicate a range of vegetation responses across gradients of landscape age; in general, salt-tolerant vegetation has been resilient on younger delta deposits, whereas changes are accelerating on older deposits underlain by permafrost.

Lowland Moist Birch-Ericaceous Low Shrub (M2-380)

Taxa or Cover	1997	2007	2015
Aulacomnium acuminatum			0.1
Aulacomnium palustre	8	10	15
Betula nana	30	33	0.1
Biatora vernalis			1
Carex rariflora	2	1	0.1
Cetraria islandica	2	3	7
Cladina arbuscula	4	3	9
Cladina rangiferina			0.1
Cladina stygia	9	16	24
Cladonia bellidiflora			0.1
Cladonia sp.		6	8
Cladonia uncialis			0.1
Dicranum laevidens			0.1
Dicranum sp.	25	15	21
Empetrum nigrum	50	83	31
Eriophorum angustifolium		1	2.1
Flavocetraria cucullata		1	2
Ledum decumbens		1	
Litter alone	3	3	3
Nephroma arcticum	4	2	2
Ochrolechia frigida			0.1
Orthocaulis binsteadii			7
Peltigera scabrosa	6	1	2
Petasites frigidus		5	1.1
Polytrichum strictum	3	1	3
Ptilidium ciliare			0.1
Rubus chamaemorus		3	9
Salix fuscescens	1	1	1
Sanionia uncinata	1	1	3
Sphaerophorus globosus			0.1
Sphagnum lenense			0.1
Sphagnum sp.	1		
Thamnolia vermicularis			0.1
Unknown moss	22	7	
Grand Total	171	197	152.4

Coastal Brackish Wet Sedge-Shrub Meadow (T3-100)

Taxa or Cover	1995	2008	2015
Calamagrostis deschampsioides	2	25	4
Cardamine umbellata		0.1	
Carex aquatilis aquatilis			1
Carex glareosa			2
Carex mackenziei		2	
Carex ramenskii	14	19	30
Carex rariflora	30	27	14
Chrysanthemum arcticum	14	9	8
Conioselinum chinense			0.1
Dupontia fischeri	2		
Elymus arenarius mollis			0.1
Empetrum nigrum		0.1	1
Festuca rubra		0.1	11
Parnassia palustris			1
Potentilla egedii			1.1
Primula borealis			0.1
Rumex arcticus		1	1
Salix fuscescens	10	5	14
Salix ovalifolia	2		
Sanionia uncinata	4		4
Sedum rosea integrifolium		3.1	1
Stellaria humifusa		1	0.1
Triglochin palustris			3
Unknown moss			3
Litter alone	48	32	39
Grand Total	126	124.4	138.5

Coastal Saline Wet Sedge Meadow (M1-100)

Taxa or Cover	1997	2007	2015
Aulacomnium palustre		1	
Calamagrostis deschampsioides	8	3	0.1
Carex glareosa	1	1	0.1
Carex ramenskii	71	92	53
Carex subspathacea			8
Chrysanthemum arcticum	2	1	0.1
Conioselinum chinense			0.1
Elymus arenarius mollis			0.1
Festuca rubra	1	1	
Poa eminens	1	8	1
Potentilla egedii	21	33	4
Primula borealis			0.1
Puccinellia phryganodes		1	0.1
Stellaria humifusa	6	1	0.1
Unknown algae			3
Litter alone	30	28	2
Bare Soil	5		47
Water			9
Grand Total	146	170	127.8

Coastal Saline Fringe Wet Gram. Mead. (T5-011)

Taxa or Cover	1997	2007	2015
Carex subspathacea	49	0.1	0.1
Poa eminens		0.1	1
Bare Soil	51	100	99
Grand Total	100	100.2	100.1

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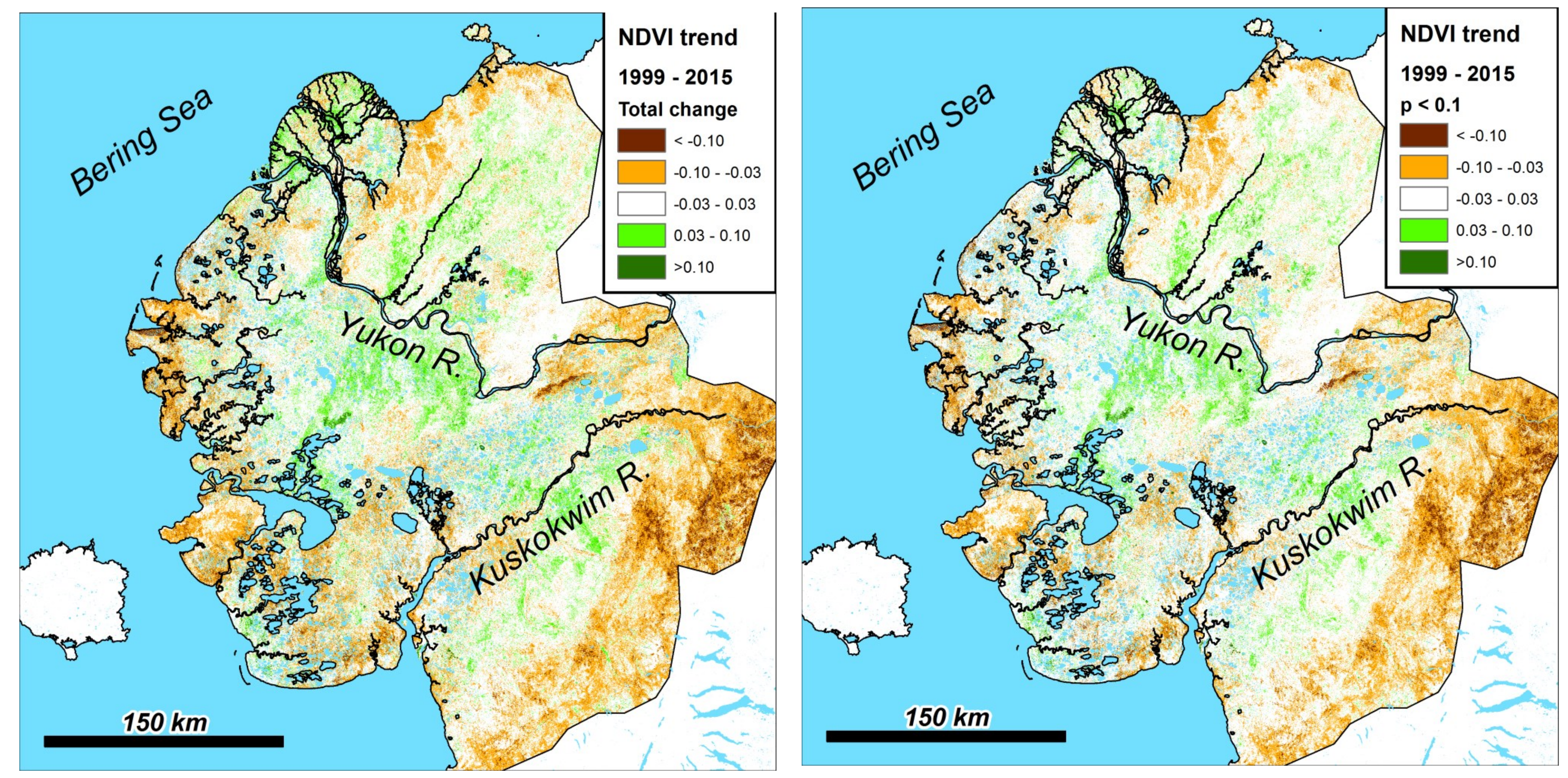
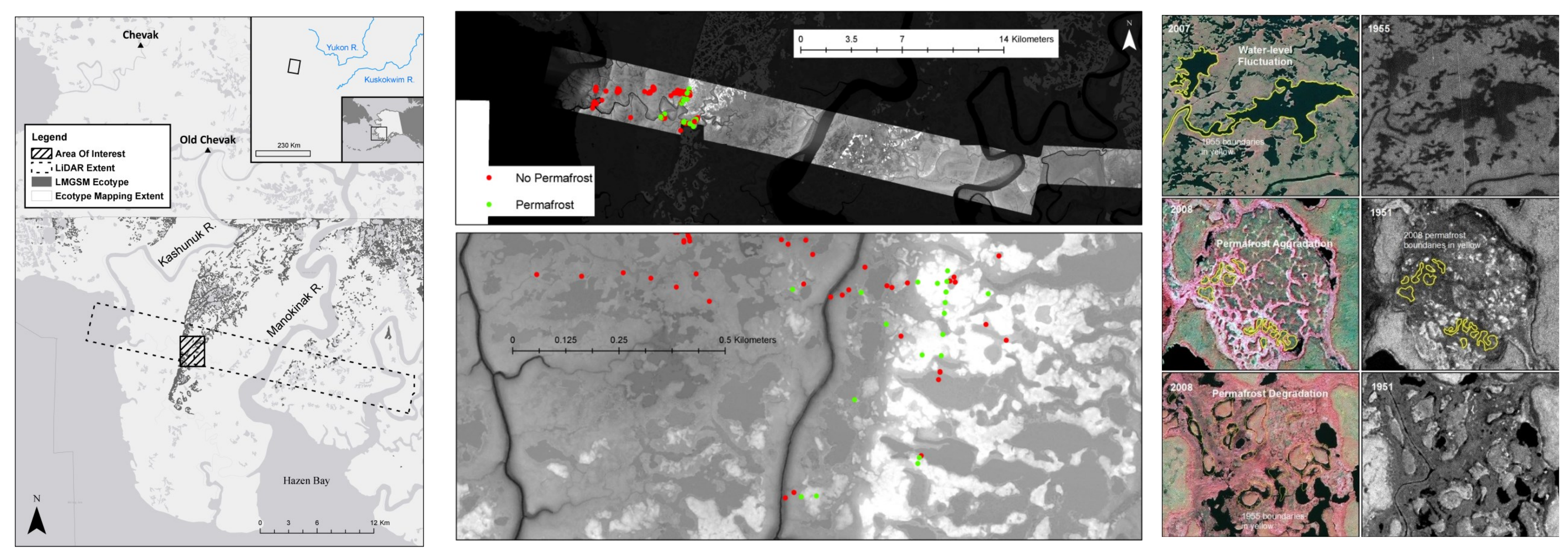
Landsat



The Landsat record can be used to corroborate trends observed by AVHRR, and link them with underlying landscape-scale drivers. Landsat excels at pinpointing disturbance "hotspots," as well as directional changes in vegetation at 30 m resolution. The Landsat TM/ETM+ record generally corroborates the browning observed by AVHRR in the YKD coastal zone; plausible mechanisms include regional climate trends such as increased summer cloudiness and winter plant mortality due to thinner snowpacks. Landsat-scale drivers include coastal flooding, salt-kill of vegetation, and permafrost degradation. However, greening is evident in upland areas (Nulato Hills, Izaviknek Hills) and on the modern Yukon Delta. Independent lines of evidence indicate that these areas are experiencing very rapid shrub expansion.

Ecosystem dynamics near the village of Newtok are influenced by coastal, fluvial, and permafrost processes. "Hotspots" of Landsat spectral trend (1999–2015; far right) include cutbank erosion and point bar accretion along rivers; lake drainage and plant colonization; and succession in older drained basins.

Permafrost Mapping with LiDAR



Topography on the outer delta is extremely flat, but the development of permafrost beneath older sediments generates 1–2 m of heave and creates extensive permafrost plateaus that rise abruptly above younger deposits. The flat topography, and fairly uniform ground-ice conditions make it possible to map permafrost extent using LiDAR (white areas, center). A LiDAR flight-line collected in 2009 provides baseline data for permafrost extent, which can be updated following future collections.

Key Points

1. The Y-K Delta is poised for rapid change due to its proximity to basic environmental thresholds: sea-level elevation (sea-level rise) and the freezing point (permafrost degradation).
2. In contrast to greening trends seen across much of the arctic, AVHRR time-series indicates strong declines in vegetation productivity on the Y-K Delta.
3. Landsat time-series for 1999–2015 generally support the AVHRR record.
4. Browning is most pronounced on outer delta, suggesting influence of Bering Sea; greening in interior uplands and the modern Yukon Delta are consistent with observed shrub expansion
5. Long-term field data are rare in the Arctic but offer a means to validate and interpret these spectral trends
6. Multi-scale approaches are needed to move from DESCRIPTION of "big picture" spatial patterns, to UNDERSTANDING of underlying drivers and impacts to ecosystem services.

Acknowledgments

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