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Drying drives decline in muskrat population in the Peace-Athabasca Delta, Canada

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Abstract

Empirical and anecdotal reports suggest that muskrat are in decline across North America, including in the Peace-Athabasca Delta ('Delta'), Canada, one of the largest inland deltas in the world and part of a World Heritage Site with 'in Danger' status pending. Muskrat are a key ecological indicator in the Delta. We investigate whether the large-scale loss of critical habitat over the past half-century could be driving a decline in muskrat abundance in the Delta. To do this, we use the Landsat record (1972–2017) to construct a 46 year record of inundation, and compare changes in the extent of critical habitat to the survey record for muskrat (1970–2016) over this 5500 km² region. Results show that the declines in critical habitat and muskrat numbers in the Delta are synchronous: ~1450 km² of temporarily inundated regions that support critical habitat have diminished by ~10 km² yr⁻¹ over the past 46 years, while the muskrat population density (houses/km²) has also declined and is significantly related to critical habitat area (km²) ($R^2 = 0.60$, $P = 0.0001$). These findings have implications for the Delta, a Ramsar Wetland of International Importance in part for its role as a habitat for nearly 200 species of birds, many of which rely on the aquatic habitat considered here. Our results further suggest that the loss of wetland habitat is a primary driver of the decline of muskrat across the species' native range.

Introduction

Canada's Peace-Athabasca Delta ('Delta'), the largest inland boreal delta in the world, is a Ramsar Wetland of International Importance and part of a UNESCO World Heritage Site with 'in Danger' status pending. Indigenous land users with decades of trapping experience in the Delta have reported 'dramatic decline in the relative abundance of muskrat' (*Ondatra zibethicus*), at least since ~1935 (Straka *et al* 2018). Recent work has shown that after years of known flooding (1972, 1974, 1996, 1997, and 2014), muskrat numbers recovered and then showed a short-term decline in subsequent years (up to 16 years since flooding) (Straka *et al* 2018), but does not evaluate drivers of the long-term trend reported by trappers. For the first time, we investigate how a long-term disappearance in critical habitat is associated with

long-term drying in the Delta that then drives the reported decline of the muskrat population.

Climate change and river regulation are driving drying in the Delta (Beltaos 2014). In the Delta, the paleolimnological record suggests drying has occurred since the late 1800s (Wolfe *et al* 2006), and analysis of the flood observational record since 1900 further indicates a 50% decline in flood frequency since 1968 (Beltaos 2018), when Peace River flows were altered for hydropower generation. Previous work has mapped Delta-wide drying for the brief episode 1996–2001, but does not address the long-term trend as we do here (Töyrä and Pietroniro 2005). The rate and spatial distribution of floodplain drying over the past half-century, which are crucial to muskrats, have not been quantified even though floodplain drying is often mentioned (Wolfe *et al* 2012, Beltaos 2014, 2018).

We quantify a severe long-term decline in abundance of the Delta's muskrat, a key ecological indicator in wetland regions, a change also noted empirically and anecdotally across North America (Roberts and Crimmins 2010, Brietzke 2015, Ahlers and Heske 2017, Straka *et al* 2018). The causal mechanisms underlying the widespread population decline of muskrat across its native range have not been identified (Ahlers and Heske 2017). Studies of muskrat ecology across its native North American range indicate that they are highly sensitive to changing hydrologic conditions (Bellrose and Low 1943, Proulx and Gilbert 1983, Toner *et al* 2010). Here we investigate drying and the ensuing decreases in critical habitat of the 5500 km² Delta as a likely mechanism driving the decline in muskrat.

'Critical habitat' for muskrat in the Delta is comprised of hundreds of ephemeral water bodies that provide environments necessary for their sustainability in the Delta. This is because muskrat are semi-aquatic. Muskrat inhabit lakes, small ponds, streams, rivers and wetlands (Soper 1942), and they rely on emergent vegetation for food and to build houses (Westworth 1974). Muskrat must over-winter in their houses that are primarily anchored to stable near-shore features and overlie water deep enough for foraging under the winter ice covering lakes and ponds (Straka *et al* 2018).

Methods

Open water persistence mapping

We use Landsat (60 and 30 m resolution) satellite imagery (1972–2017) to quantify the spatial dynamics of open water on the Delta floodplain. Annual cloud-free composite scenes of the Delta were generated for the period 1984–2017 (except 2012) using the Google Earth Engine Landsat Simple Composite algorithm on images taken during the ice-free period between 15 June and 15 September. This default date range was customized for images where the default date range yielded cloud contamination and to avoid smoke from a 2015 fire in the northwest portion of the site (supplementary data table 1 is available online at stacks.iop.org/ERL/13/124026/mmedia). For years 1972–1983 and in 2012, cloud-free scenes of the Delta were selected from the GEE Landsat collections (supplementary data table 2). To minimize the effect of time of year on the measure of open water, images from June, July, and August were given priority over images from April, May, September and October, and images from July were given priority over images from June and August. For years with no single cloud-free image of the Delta, portions of multiple images were mosaicked to yield as cloud-free a view of the Delta as possible.

Open water mapping was performed using the JavaScript API and the GEE Landsat collections (supplementary data table 1) (Gorelick *et al* 2017). For each

year, a water index was calculated for the TOA Reflectance image. For images with a shortwave infrared (SWIR) band, the modified normalized difference water index (NDWI) (Xu 2006) was calculated; for images without a SWIR band, the NDWI (McFeeters 1996) was calculated (supplementary data table 1). For 2012, the Landsat 5 Multispectral Scanner images' Band 3 (NIR) was used rather than Band 4 (NIR) to calculate NDWI, as Band 4 data were not available.

Dynamic thresholding for each water index image was performed on the bimodal water index histogram using Otsu's method, (GEE code developed by Nicholas Clinton), to yield a binary water/non-water image. Otsu's method was used as it maximizes the inter-class variance of a bimodal distribution and has been applied for open water detection in GEE (Donchyts *et al* 2016).

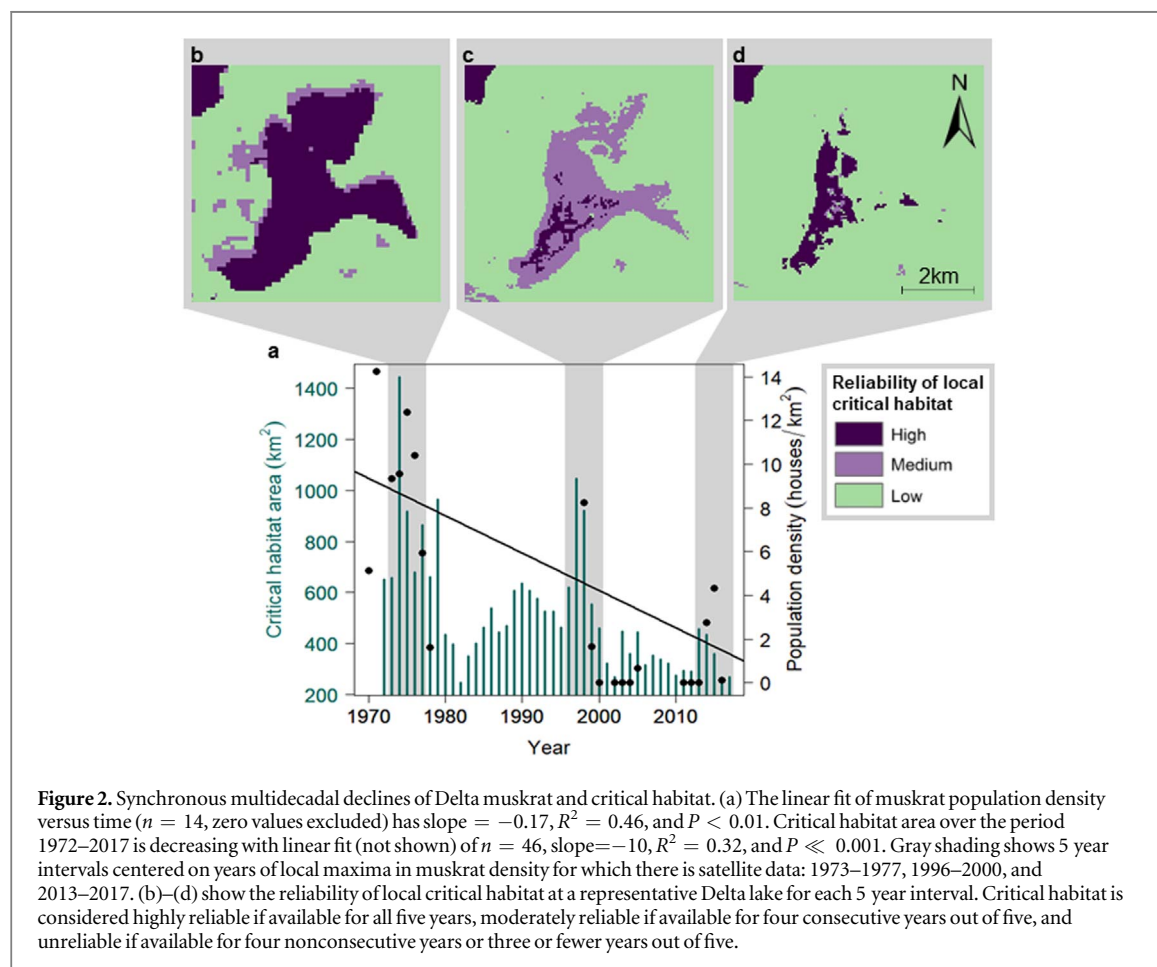
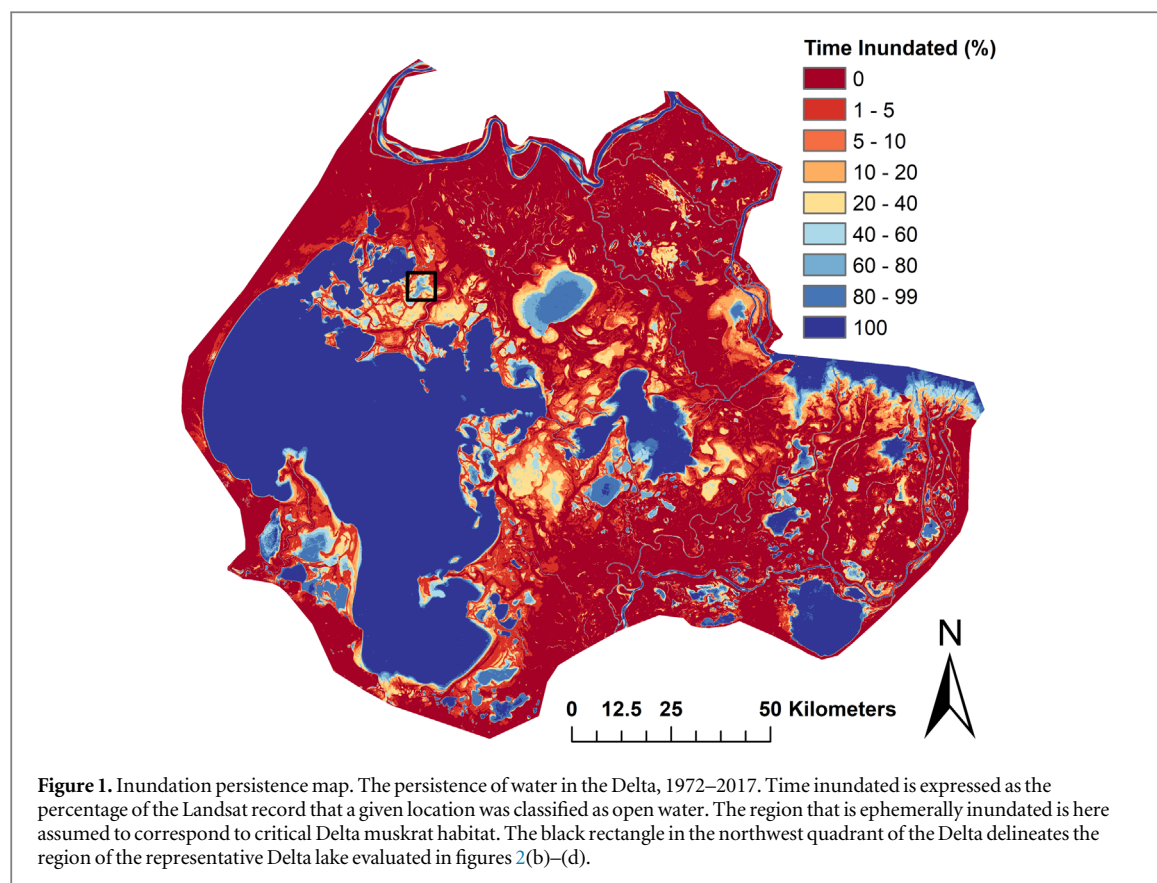
Pixels in the water class were assigned a value of 1, and pixels in the non-water class were assigned a value of 0. Binary images in GEE API at zoom level 12 were corrected for misclassification. Misclassification of pixels occurred rarely and was due to contamination from clouds, cloud shadows, detector image errors (e.g. transmission striping), or unambiguous misclassification of water and land pixels.

The persistence map for the 46 year record (figure 1) was generated by adding pixel values of the binary images. A value of '0' indicates continuously dry pixels, 46 indicates continuously inundated pixels, and intermediate values indicate an intermediate frequency of inundation. These values were converted to the percentages shown in the persistence map. The decadal inundation maps (supplementary data figure 1) were generated by adding pixel values of the binary images, with the pixel value indicating the number of years in the period that the pixel was inundated. Data to generate figure 2 employed GEE Image Pixel Area and Reducer Sum methods applied in succession to each binary map to calculate the total area of open water. The maximum region of critical habitat in at least one year was 1798 km².

Muskrat counts

We analyzed 21 years of muskrat count records since they were first collected in 1970 in the Delta. As mounds on ice-covered lakes, muskrat houses are counted during snowmobile ground surveys in winter and used as an index of population size, based on an average of five muskrat per house in the Delta (Ambrock and Allison 1972).

Muskrat house count data were from five survey reports during 1970–2005 and from the Peace-Athabasca Delta Ecological Monitoring Program during 2011–2016 (Surrendi and Jorgensen 1971, Ambrock and Allison 1972, Poll 1980, Westworth and Wiacek 2002, Westworth Associates Environmental Ltd 2006, Straka *et al* 2018). Data in hard copy were digitized. Each data point was manually verified to fix rare



misreads. Survey areas for each count site were digitized in GIS using maps and GPS coordinates (supplementary data figure 2). Individual points were excluded if not associated with a verified survey site, or outside the Delta. Each count was normalized by its respective survey area, to obtain population density (houses/km²) (supplementary data table 3). Median densities observed in any given year served as our best estimate.

Ground survey muskrat count data provide a more accurate measure of house abundance than aerial surveys in the Delta (Poll 1980). In the absence of ground counts, we used aerial estimates for 1971, and converted values to ground count estimates using an empirical 1.9:1 ground to fixed-wing aircraft conversion ratio for the Delta (Ambrock and Allison 1972). The open water map for a given year was compared to the house count for the ensuing ice-bound period.

Given potential detection bias of years in which the median observed value of population density was zero, particularly since 2000, we excluded all years with zero median population densities from the linear fit of median population density versus time (figure 2(a)). Therefore, our estimate of declining population density over time is likely conservative.

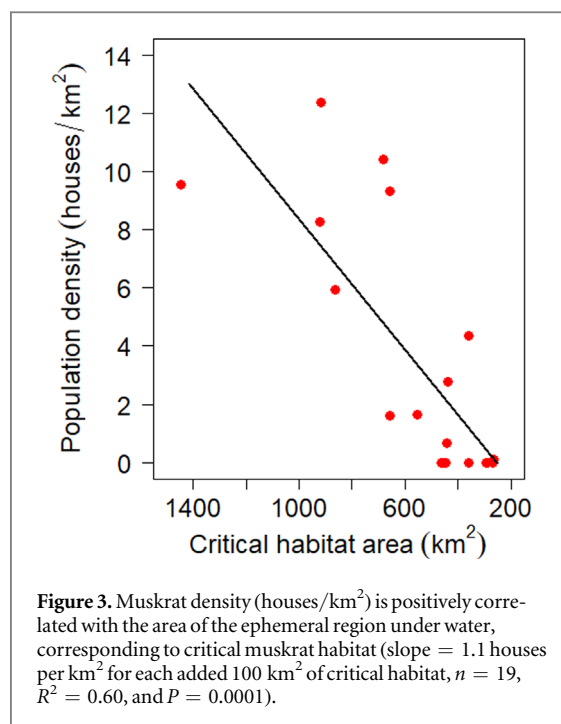
Habitat reliability

The hydrologic landscape changes on a multi-annual basis during periods of flooding and drying (Peters *et al* 2006). Here we suggest that populations thrive when there is reliable local critical habitat for muskrat to establish their home range. We indicate critical habitat reliability as the number of years that a location is consistently suitable for muskrat occupation. We evaluate reliability at a representative Delta lake for three five-year periods centered around years of peak muskrat population density (figures 2(b)–(d)). The areas that are suitable during five consecutive years (high reliability) and 4 consecutive years (medium reliability) provide the most temporally reliable habitat (figures 2(b)–(d), dark and light purple). Fewer consecutive years of critical habitat area are mapped as low temporal reliability.

We focus on a representative lake in the north-western quadrant of the Delta with a maximum reliable critical habitat area of 16 km² (figure 1). We examine the relation between critical habitat reliability and three sequentially lower local maxima in muskrat population density (1975, 1998, and 2015) (figure 2(a)). During these years, we inspected satellite images in a five-year window about each population density peak year.

Results

Inundation persistence, defined as the percent of the 46 years of record that any location appears as open water, is a simple measure of habitat viability (figure 1).



The hydrologic landscape falls into three categories: regions that remain continuously dry, regions comprised mostly of the largest continuously inundated lakes, and periodically inundated or dry regions. The former two categories are either too dry or inhospitable, providing unsuitable habitat for muskrat. The latter ephemerally inundated region consists of hundreds of water bodies ranging in size from 100 to 0.1 km². For muskrat this set of ephemeral water bodies serves as ‘critical habitat’ that provides environments necessary for their sustainability in the Delta.

The critical habitat area has changed over time, exhibiting a decline over the past half-century and showing multi-annual wet and dry periods (supplementary data figure 1). The maximum area of critical habitat was 1445 km² (in 1974). Analysis of annual changes in critical habitat from the satellite record shows an overall decline from 913 km² (63% of the maximum) for the earliest period 1973–1977 down to 357 km² (25% of the maximum) for the period 2013–2017. Although there is tremendous temporal variation in critical habitat area, there is a general pattern of lower highs and lower lows, suggesting a decline over the entire period of 32% (a loss of 10 km² per year over the 46 year period 1972–2017; $R^2 = 0.32$, $P \ll 0.001$, figure 2(a)). While larger water bodies remain static features of the landscape, smaller hydrologic features comprising critical habitat are drying out (figure 1, figure 2(a)).

Since 1970, there has been a significant decline in muskrat population density ($n = 14$, zero values excluded, $R^2 = 0.46$, $P < 0.01$). There were 19 years of survey records that overlapped with the satellite-derived critical habitat record (figure 3). On an annual basis, there is a positive correlation between muskrat

population density and critical habitat area (slope = 1.1 houses per km² for each added 100 km² of critical habitat, $n = 19$, $R^2 = 0.60$, and $P = 0.0001$, figure 3).

Considering five-year-long time windows during which critical habitat persisted, we see a decline in reliable critical habitat at the representative Delta lake (figures 2(b)–(d)). This decline in critical habitat corresponds to a decrease in muskrat population density. It is noteworthy that muskrat population density drops more precipitously from its peak value to low levels as the extent of reliable critical habitat diminishes; the drop taking >3 years after 1975, ~2 years after 1998, and just 1 year after 2015 (figures 2(a)–(d)).

Discussion and conclusions

Satellite imagery analysis of the Delta shows ~1450 km² of temporarily inundated regions that support critical habitat have diminished by ~10 km² yr⁻¹ over the past 46 years; a decline of ~32% over the last half-century. This environmental change corresponds to the severe decline of the muskrat population, a semi-aquatic mammal with cultural and economic importance for Indigenous communities in the Delta region, Canada and Alaska (Wilson 2014, Brietzke 2015, Straka *et al* 2018). The long-term loss of wetland habitat has implications for the ecological significance of the Delta landscape. There, hundreds of lakes and wetlands serve as habitat for nearly 200 species of birds, many migrating from across North America (Timoney 2013). With accelerating impacts of climate change at high latitudes and additional hydropower development underway on the Peace River, a continued decline in the Delta's critical habitat is anticipated. In this case, the impacts of hydrologic change on Delta muskrat demonstrated here will likely worsen. Taken together with our findings, concurrent observations of widespread loss of wetland and aquatic habitat at sites across North America (Riordan *et al* 2006, McMenamin *et al* 2008, Davidson 2014) suggest that critical habitat loss is a likely causal mechanism responsible for the ongoing decline of muskrat across its native range.

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