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1 **Title**

2 A 2000-year sediment record reveals rapidly changing sedimentation and land use since the
3 1960s in the Upper Mara-Serengeti Ecosystem

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1 **1.0 Introduction**

2 Sustainable development in Africa relies upon using natural resources to promote socioeconomic
3 development while simultaneously protecting the ecosystem services relied upon by a large
4 proportion of the population (McClain, 2013). Water has been identified as playing a central role
5 in both areas (UN-Water, 2003). Water resource planning can increase human access to
6 improved domestic water sources and improved sanitation, ensure food security through irrigated
7 agriculture, and contribute to energy security via hydropower, while also conserving and
8 restoring biodiversity and ecosystem services (McClain, 2013; Sharma et al., 1996; Vörösmarty
9 et al., 2000). However, water resources are often negatively impacted by land use change
10 associated with development patterns (Foley et al., 2005). Understanding the impacts of land use
11 change on river basins and how they relate to historical dynamics is critically important to
12 making informed decisions about sustainable development and to interpreting present-day
13 patterns in quantity and quality of water resources (Kundzewicz, 1997; McClain, 2013).

14 The Mara River basin in East Africa is a trans-boundary river basin that highlights many of the
15 development and conservation challenges in the region. The Mara River flows from its
16 headwaters in the Mau Forest of Kenya through the northern portion of the Serengeti-Mara
17 Ecosystem and into Lake Victoria in Tanzania, where it forms part of the headwaters of the Nile
18 River basin. It is a river basin of international conservation significance, as it is the only
19 perennial water source in the Serengeti-Mara Ecosystem, and it sustains the largest remaining
20 overland migration of 1.4 million wildebeest that cross into this basin from the southern
21 Serengeti during the dry season (Holdo et al., 2009). The Mara River basin also supports an
22 estimated 1.1 million people, with over 60% of the human population directly reliant upon the

23 river for their domestic water needs (Hoffman, 2007; LVBC and WWF-ESARPO, 2010). The
24 basin has experienced considerable development in the past few decades, including a 27%
25 reduction in rangelands, a 32% reduction in forest cover, and a 203% increase in agriculture
26 between 1973-2003 (Mati et al., 2008).

27 Patterns of increasing development in the Mara River basin are similar to trends throughout East
28 Africa. Human populations have risen steadily in Kenya and Tanzania since the 1950s (FAO,
29 2018). Domestic animal populations have also increased since the eradication of rinderpest in the
30 1960s (Raikes, 1981; Talbot and Talbot, 1963). Some wildlife populations also increased after
31 rinderpest eradication, while multiple others began declining in the 1970s, partially due to land
32 use changes and further increases in domestic animal populations (Ogutu et al., 2011; Ogutu et
33 al., 2016). In the Mara River basin, these land use and land cover changes have likely altered the
34 hydrology and water quality in the Mara River, leading to increased peak flows, increased
35 erosion rates, and increased suspended sediments and nutrients in the river (Dutton et al., 2018;
36 LVBC and WWF-ESARPO, 2010; Mango et al., 2011; Mati et al., 2008; McClain et al., 2014).

37 Increasing suspended sediment loads are a major concern in the Mara River basin; sediment
38 loads are associated with increases in contaminant loads, and have direct potential consequences
39 for domestic water users (Hoffman, 2007; LVBC and WWF-ESARPO, 2010). There is also
40 widespread concern about anthropogenic contaminants in the river due to nutrient runoff from
41 agricultural fields, human waste from urban settlements and tourism establishments, and mercury
42 from artisanal gold mining in the basin, among other factors. Mercury contamination is a
43 particular concern in the lower portion of the Mara River basin, because widespread artisanal
44 gold mining commonly uses mercury in one of the processing steps (Saldarriaga-Isaza et al.,
45 2015).

46 Changing populations of wildlife and domestic animals in the Mara River basin may also impact
47 the long-term sediment and nutrient dynamics in the river. After the eradication of rinderpest, the
48 Serengeti blue wildebeest (*Connochaetes taurinus*) herd grew from <200,000 to approximately
49 1.4 million by the late 1970's (Hopcraft et al., 2013), and they contribute 1,100 tons of carcass
50 biomass per year to the river through mass drownings (Subalusky et al., 2017). The Mara River
51 also supports a large population of hippopotami (*Hippopotamus amphibius*, hippos), which has
52 grown by 1500% from the 1950s to over 4,000 individuals (Kanga et al., 2011), and they
53 contribute 13,200 tons of biomass as feces and urine per year to the river (Subalusky et al.,
54 2015). As wildebeest and hippo populations have recovered in the Mara, human and livestock
55 populations also have increased (Ogutu et al., 2016).

56 Here, we have used sediment cores from the Mara Wetland (near its outlet into Lake Victoria) to
57 evaluate how sedimentation rates and sources have changed historically, through a period
58 marked by major changes in human and livestock population densities, land use, and disease
59 epidemics (rinderpest). To do this, we evaluated sediment sources, nitrogen and carbon isotope
60 signatures, and mercury along a transect of age-calibrated sediment cores in the Mara Wetland,
61 from the upstream reaches to Lake Victoria. We hypothesized that sediment deposition has
62 increased overall as human and livestock populations increased through time in the river basin.
63 Furthermore, we hypothesized that sediment deposition would also increase as a result of land
64 use change, including deforestation in the Upper Mara sub-catchment and increased livestock
65 populations in the grazing lands of the Talek, Middle Mara, and Lower Mara sub-catchments,
66 resulting in changes in sediment provenance in cores. We also hypothesized that both mercury
67 and nutrient concentrations in the wetland would increase, and that carbon and nitrogen stable
68 isotope ratios would shift over time to reflect changes from natural to anthropogenic sources.

69 **2.0 Materials and Methods**

70 *2.1 Study Site*

71 The Mara River is a trans-boundary river shared between Kenya and Tanzania (Fig. 1), and one
72 of the more pristine basins within the greater Nile Basin of Africa (Mati et al., 2008). The Mara
73 River basin is approximately 13,500 km² and ranges in elevation from 2900 m in the headwaters
74 to 1130 m at the mouth in Lake Victoria. The Mau Forest Complex forms the headwaters of the
75 basin and has undergone major changes since the 1970s due to legal and illegal settlements and
76 deforestation (Olang and Kundu, 2011). The basin also hosts two conservation areas of
77 international significance: the Maasai Mara National Reserve in Kenya and the Serengeti
78 National Park in Tanzania.

79 We delineated the Mara River basin into four major sub-catchment areas (Upper Mara, Middle
80 Mara, Lower Mara, and Talek) based upon drainage patterns from the 15m ASTER Global DEM
81 dataset, Version 2. The Upper Mara (2450 km², 18% of the basin) accounts for everything
82 upstream of the Emarti Bridge, including the two main tributaries that form the Mara, the
83 Nyangores and Amala rivers. This sub-catchment has small-scale settlements, small-scale
84 agriculture and forested regions that are remnants of the largest indigenous montane forest in
85 East Africa. The Middle Mara (3010 km², 22% of the basin) includes the main Mara River
86 channel from the Emarti Bridge to the Purungat (New Mara) Bridge, which is on the border
87 between Kenya and Tanzania. This sub-catchment primarily consists of wildlife conservancies,
88 including portions of the Maasai Mara National Reserve, grazing land for domestic livestock
89 (cattle, goats, and sheep), and tourism facilities. The Lower Mara (5380 km², 40% of the basin)
90 includes everything downstream of the Purungat Bridge, as well as drainage from land in Kenya

91 near the Lamai Wedge on the west and the Sand River catchment on the east. This region
92 includes portions of both the conservation areas of the Maasai Mara and Serengeti, and
93 agricultural areas in Tanzania. The Talek region (2660 km², 20% of the basin) includes the entire
94 catchment of the Talek River, which is a seasonal and flashy tributary draining semi-arid wildlife
95 conservancies and grazing lands for domestic livestock. The Upper Mara receives approximately
96 1400mm per year of rainfall, the Middle and Lower Mara receive approximately 1100mm per
97 year, and Talek receives approximately 600mm per year (Mati et al., 2008; Mduma et al., 1999).

98 The Mara River flows into Lake Victoria after flowing through the Mara Wetland (also known as
99 the Masirori swamp) near Musoma, Tanzania (Kassenga, 1997). The Mara Wetland is
100 approximately 45 km long and up to 14 km wide. Some research suggests the Mara Wetland has
101 expanded in size by over 300% since the 1970s, which has been hypothesized to be due to
102 increasing sediment loads and rising lake levels (Mati et al., 2008). The Mara Wetland may play
103 an important role in buffering the effects of land use changes in the Mara River basin on Lake
104 Victoria (O'Sullivan et al., 2016). For example, an estimated 75 tons of nitrogen are removed
105 yearly by the Mara Wetland (Mayo et al., 2013). Lake Victoria is the second largest freshwater
106 body in the world and of tremendous socioeconomic importance to the region, but its ecosystem
107 services are at risk due to deteriorating water quality, primarily caused by rivers discharging into
108 the lake (Odada et al., 2004; Scheren et al., 2000).

109 We delineated the Mara Wetland into four regions (Seasonal Wetland, Upper Wetland, Middle
110 Wetland, and Lower Wetland) based on evaluations of satellite imagery and field surveys of
111 changes in vegetation and flow patterns conducted in August, 2015. The Seasonal Wetland
112 region is the most upstream portion of the Mara Wetland, where the river is still primarily
113 confined to one incised channel. Small-scale agriculture takes place on the fringes of the

114 Seasonal Wetland and, in some instances, within it. Papyrus and other common wetland plants
115 primarily begin in the Upper Wetland section and the channel begins to bifurcate multiple times.
116 Most of the Middle Wetland is not navigable due to dense, floating papyrus mats that impede
117 travel. The Lower Wetland is deeper (up to 25 meters) and directly tied to the hydrology of Lake
118 Victoria. The boundaries between these regions are somewhat arbitrary and likely dynamic
119 depending on recent precipitation. Low-impact artisanal fishing involving nets occurs within all
120 navigable portions of the wetland.

121 *2.2 Sediment Core Collection and Processing*

122 Four sets of cores were taken from the four distinct areas of the Mara Wetland. The Seasonal
123 Wetland set of cores were taken just downstream of the Seasonal Wetland area within a
124 constrained channel just prior to a bifurcation in the channel. The Upper Wetland core set was
125 taken within a shallow lake (approximately 0.5 km²) in the middle of the Upper Wetland section.
126 The Middle Wetland core was taken in the middle portion of the wetland that was cut off from
127 navigation from the other portions of the wetland. The Lower Wetland core was taken near the
128 entry point into Lake Victoria (Fig. 1).

129 Sediments were cored from a stable, floating platform built at the site that consisted of several
130 sheets of wood placed on two inflatable air mattresses. We collected sediment cores in August,
131 2015, at the sediment-water interface using a Universal Corer (Aquatic Research Instruments,
132 Hope, Idaho, USA) at four sites in distinct portions of the wetland (Fig. 1). Each Universal core
133 (UC) included approximately 0.5 to 1 m in depth below the sediment-water interface. At two of
134 those sites, we also collected deeper cores using a Russian Peat Borer (Aquatic Research
135 Instruments, Hope, Idaho, USA), each segment of which was 50 cm in depth. These Russian
136 cores (RCs) were collected at an approximately 1-meter offset from the location of the Universal

137 cores, starting at the deepest point collected with the previous core with a 10 cm vertical overlap
138 between each 50 cm depth intervals. Russian cores were collected to the maximum depth we
139 were able to access by manually pushing and retrieving the corer through the wetland sediments.
140 Universal cores were immediately extruded and sectioned in the field into 1 cm intervals and
141 sealed in air-tight Ziploc polyethylene bags. Entire Russian cores were sealed in the field with
142 saran wrap to prevent desiccation and taped into PVC tubes to prevent shrinking or damage
143 during transport. All samples were shipped wet from Tanzania to Yale University and arrived
144 within several days.

145 In the lab, we processed the top core sections from all four cores (Seasonal Wetland, Upper
146 Wetland, Middle Wetland, and Lower Wetland) for ^{210}Pb dating. We processed additional deeper
147 cores for radiocarbon dating from the Seasonal Wetland (consisting of UC7, RC9, RC10, RC11,
148 and RC12) and the Upper Wetland (consisting of UC11, RC21, and RC23). All Russian cores
149 from those two sites were sectioned into 1 cm intervals. Portions of the 1 cm sections from the
150 universal cores and Russian cores were then dried at 60° C and re-weighed to obtain bulk mass
151 density estimates. The dried portions were then gently disaggregated with a mortar and pestle to
152 obtain a homogenous sample and apportioned to dating, sediment fingerprinting, carbon and
153 nitrogen isotopic analysis, and mercury analysis.

154 *2.3 Dating and Age-Depth Model*

155 We used lead-210 (^{210}Pb ; 22.3 yr half-life) to assign ages to sediment deposited during the past
156 110 years (five half-lives). Geochemical measurements were made on subsamples dried to 60°C.
157 Dried, ground samples were sealed in 10 mL scintillation vials, and equilibrated for at least 21
158 days before analysis. This equilibration period allowed supported ^{210}Pb (^{210}Pb produced by in-

159 situ decay of ^{226}Ra , measured indirectly as ^{214}Pb) to be distinguished from unsupported or excess
160 ^{210}Pb ($^{210}\text{Pb}_{\text{xs}}$). Activities of ^{210}Pb and ^{214}Pb were measured by gamma ray spectrometry using a
161 low-background Ge detector. ^{210}Pb and ^{214}Pb activities were measured at energies of 46.5 and
162 352.7 keV, respectively, and were corrected for detector efficiency and self-absorption (Cutshall
163 et al., 1983).

164 We also measured ^{137}Cs in the upper portions of the Seasonal Wetland, Upper Wetland, Middle
165 Wetland and Lower Wetland cores. ^{137}Cs was distributed globally during atmospheric nuclear
166 testing in the 1950s and 1960s and can be used as an independent time marker for the age-depth
167 model (Ritchie and McHenry, 1990).

168 We created age-depth models using the Plum model for the Bayesian analysis of ^{210}Pb dating for
169 the upper portions of the Upper Wetland, Middle Wetland, and Lower Wetland cores (Aquino-
170 López et al., 2018). We did not create an age-depth model for the Seasonal Wetland core due to
171 mixing throughout the depth of the core (see results and discussion below). The Plum model is
172 loosely based on the CRS model, which allows sedimentation rates to vary (Aquino-López et al.,
173 2018; Oldfield and Appleby, 1984; Robbins, 1978). The Plum model retains two of the basic
174 assumptions of the CRS model, including (1) that supply of ^{210}Pb is constant, and (2) that there is
175 no vertical displacement of radionuclides (i.e., no mixing or post-depositional diagenesis).
176 However, a continuous inventory of ^{210}Pb from the entire core is not required and it is not
177 necessary to achieve background in order to formulate the model.

178 The Plum model is formulated within a robust statistical framework to natively quantify any
179 uncertainty within the modelled dates (Aquino-López et al., 2018). Plum uses a self-adjusting
180 Markov Chain Monte Carlo (MCMC) algorithm known as the *t*-walk (Christen and Fox, 2010).

181 Use of the t -walk requires very little customization in setting the default model parameters.
182 Changes in sedimentation accumulation are calculated through millions of iterations of the
183 MCMC using the same gamma autoregressive semiparametric age-depth function contained
184 within *Bacon*, a popular age-depth model for paleoclimate reconstructions (Blaauw and Christen,
185 2011). Full details of the Plum model formulation can be found in Aquino-López et al. (2018).

186 We used radiocarbon dating to date samples at longer time scales than ^{210}Pb dating. We dried
187 samples at 45°C and then submitted bulk sediments to the Lawrence Livermore National
188 Laboratories (LLNL, Livermore, California, USA) for radiocarbon dating. Samples appeared
189 homogeneous with no obvious evidence of macrofossils. All samples were subjected to the
190 standard pretreatment steps at LLNL, including the acid-base-acid chemical pretreatment, in
191 order to remove carbonates. Radiocarbon dating was thus performed in the total organic carbon
192 (TOC) of the bulk sediments, preventing any potential aging effects of the carbonates (Bronk
193 Ramsey, 2008). Five radiocarbon dates were measured for the Seasonal Wetland core set (UC7,
194 RC9, RC10, RC11, and RC12) and four radiocarbon dates were measured for the Upper Wetland
195 core set (UC11, RC21, and RC23) (Fig. S1). The dates were calibrated using the IntCal13 curve
196 implemented in *Bchron* in R (Parnell, 2016; Reimer et al., 2013).

197 We built a Bayesian age-depth model using *Bchron* in R for the Upper Wetland core (Haslett and
198 Parnell, 2008; Parnell, 2016). In the age-depth model, we used all of the radiocarbon dates (4
199 total) and a subset of the ^{210}Pb -modelled dates (7 total) to prevent the age-depth model from
200 being unfairly biased towards the ^{210}Pb -modelled dates (Fig. 4) (Kemp et al., 2013). We used the
201 standard program settings for creation of the age-depth model (Parnell, 2016).

202 Sediment accretion and mass accumulation rates were calculated from $^{210}\text{Pb}_{\text{xs}}$ data for the top
203 sections of the Upper Wetland (UC11), Middle Wetland (UC15), and Lower Wetland (UC1)
204 cores using the Plum model for the Bayesian analysis of ^{210}Pb dating (Aquino-López et al.,
205 2018). Sediment accretion and mass accumulation rates were also calculated for the entire Upper
206 Wetland core set using the full age-depth model ($^{210}\text{Pb}_{\text{xs}}$ and radiocarbon dates) created in
207 *Bchron* (Parnell, 2016). Accretion rates (r_i ; $\text{cm} \cdot \text{yr}^{-1}$) for each core section, i , at each depth, x , at
208 each time, t , were calculated as:

$$209 \quad r_i = \frac{x_i - x_{i-1}}{t_i - t_{i-1}} \quad (\text{Eq. 1})$$

210 Accretion rates were then used to calculate mass accumulation rates:

$$211 \quad \text{MAR}_i = r_i \times \rho_i \quad (\text{Eq. 2})$$

212 where MAR_i is the mass accumulation rate ($\text{g} \cdot \text{cm}^{-2} \cdot \text{yr}^{-1}$) for a depth interval i , and ρ_i is the
213 corresponding bulk density ($\text{g sediment} \cdot \text{cm}^{-3}$).

214 *2.4 Sediment Fingerprinting*

215 We used the sediment fingerprinting method developed in Dutton et al. (2013) to trace the source
216 of sediments from each layer of the Seasonal Wetland and Upper Wetland cores. A brief
217 description of our methods is described here, and a more detailed description is in
218 Supplementary Material 1.

219 We collected 39 composite soil samples throughout 7 different major lithology groups of the
220 Lower Mara region to build a composite sediment fingerprint for that region (Fig. S2). Samples
221 were dried, gently disaggregated, and sieved to $< 63 \mu\text{m}$. Samples were then analyzed for 59

222 elements with a multi-acid total digestion on an ICP-MS by Bureau Veritas Acme Labs
223 (Vancouver, BC Canada).

224 Source signatures were previously developed for Kenyan sources (Upper Mara, Middle Mara,
225 and Talek) and for hippos (hippo feces) for a subset of the elements analyzed during this
226 sampling campaign (Dutton et al., 2013). We built upon those signatures by collecting additional
227 suspended sediments from the Upper Mara ($N = 3$) and Talek ($N = 7$) from 2012 through 2015.
228 In total, 28 elements were measured within both campaigns and considered for use as tracers.

229 Source signatures for Upper Mara and Talek were based on suspended sediment samples
230 collected in the river, and Middle Mara and Lower Mara were based on soil samples from the
231 different lithologies of those sub-catchments. We minimized potential artifacts of these different
232 sample types by only analyzing the fine fraction of the soil samples ($<0.63 \mu\text{m}$), which is a
233 widely accepted approach to reduce potential particle size influence on elemental signatures
234 (Collins et al., 2017). Additionally, we collected suspended sediment samples during different
235 flow events and discharges to capture the natural variability occurring within each sub-catchment
236 (Dutton et al., 2013).

237 We used a simplified tracer screening approach similar to Blake et al. (2018). First, we removed
238 elemental concentrations from the depositional samples that fell outside the minimum detection
239 limits or the natural range of the sources. We then used a Kruskal-Wallis H -test to identify
240 tracers that showed significant differences between the potential sources (Supplementary
241 Material 2) (Kruskal and Wallis, 1952; R Core Team, 2018). To characterize the discrimination
242 ability of the combination of elements, we used a step-wise Discriminant Function Analysis
243 (DFA) based on the minimization of Wilk's lambda and a jackknifed Discriminant Function
244 Analysis (jDFA) (Venables and Ripley, 2002; Weihs et al., 2005). Overall success with the

245 leave-one-out classification (jDFA) was 93%. We then used MixSIAR, a Bayesian mixing
246 model, to estimate the source proportions for each core slice (Moore and Semmens, 2008; Stock
247 et al., 2018; Stock and Semmens, 2016). We then applied the Bayesian age-depth model
248 incorporating the modelled ^{210}Pb and radiocarbon dates to the source proportions for each core
249 slice to determine sediment source proportions through time.

250 *2.5 Mercury*

251 We measured total mercury concentration in sediment layers from universal cores from three
252 different locations along a transect through the Mara Wetland: Upper Wetland, Middle Wetland
253 and Lower Wetland (Fig. 1). Samples were dried, ground with a mortar and pestle, and analyzed
254 on a Direct Mercury Analyzer (DMA80, Milestone, Shelton, CT, USA).

255 *2.6 Carbon and Nitrogen Isotopes*

256 The dried and ground sediment samples from the Upper Wetland core set (UC11, RC21, and
257 RC23) were fumigated in hydrochloric acid vapor for 48 hours to remove inorganic C
258 (Jaschinski et al., 2008; Ramnarine et al., 2011). We then measured the percent by mass of total
259 organic carbon and total nitrogen, as well as the stable isotope ratios of carbon (total organic
260 $\delta^{13}\text{C}$) and nitrogen (total $\delta^{15}\text{N}$), on a Costech elemental analyzer (Costech Analytical
261 Technologies Inc., Valencia, CA, USA). Stable isotope ratios were normalized to air ($\delta^{15}\text{N}$) and
262 Vienna Pee Dee Belemnite ($\delta^{13}\text{C}$) scales and reported in per mil notation, where $\delta^{15}\text{N} = [(R_{\text{sample}} -$
263 $R_{\text{air}})/R_{\text{air}}] \times 10^3$ and $\delta^{13}\text{C} = [(R_{\text{sample}} - R_{\text{PDB}})/R_{\text{PDB}}] \times 10^3$.

264 All statistical analyses were computed in R 3.5.1 in RStudio 1.1.453 (R Core Team, 2018;
265 RStudio Team, 2016). All R code and data for conducting the analyses and preparing the figures

266 are provided in Supplementary Material 2, 3, and the Mendeley Data online data repository
267 (Dutton et al., 2019).

268 **3.0 Results**

269 *3.1 Dating and Age-Depth Model*

270 The Seasonal Wetland core showed evidence of mixing throughout the upper portion of the core
271 with no discernable pattern in the ^{210}Pb data (Fig. 2). The radiocarbon dating chronology for the
272 Seasonal Wetland core set (UC7, RC9, RC10, RC11, and RC12) further indicated a strong
273 mixing of sediments (Table 1). We found ^{14}C ages alternating between modern and
274 approximately 300 [yr BP] from 4 tested samples down to at least 159cm below the sediment
275 surface (Table 1). The bottom of the deepest part of that core set (RC12) was at 189cm below the
276 sediment surface and it was dated at 2625 ± 50 ^{14}C age [yr BP] (Table 1), indicating that the
277 mixing zone within that core set stopped somewhere between 159cm and 189cm. Mixing of
278 sediments within this core was likely due to the geomorphology of this wetland section and the
279 presence of frequent disturbances in the channel. The river flows through a constrained channel
280 at this sampling point, and we sampled immediately upstream of a bifurcation in the channel
281 where we believed sediment would accumulate. However, the data suggest this location was not
282 a stable depositional zone, so we did not create an age-depth model for this core.

283 Excess ^{210}Pb activity from the Upper Wetland, Middle Wetland, and Lower Wetland showed a
284 general decrease in activity through the depth of the core and the potential presence of mixing in
285 the upper portion of the cores. Bayesian-modelled dates based on the excess ^{210}Pb activity were
286 computed for each depth in the Upper Wetland, Middle Wetland and Lower Wetland cores (Figs.
287 2 and 3). In all three cores, the Plum age-depth model indicated more rapid sediment accretion

288 and accumulation in recent years; however, this pattern was more pronounced in the Upper
289 Wetland core and declined going downstream to Lake Victoria (Upper Wetland, Middle
290 Wetland, and Lower Wetland) (Fig. 4). Model confidence was greatest in the Upper Wetland
291 core (Fig. 3).

292 The use of ^{210}Pb derived age-depth models requires an independent corroboration to establish
293 that the model is reasonable (Smith, 2001). We attempted to use ^{137}Cs as an independent time
294 marker but detected very low levels of it in all four cores (Fig. S3). The Upper Wetland Core had
295 a small peak at 29cm that doubled background levels ($\sim 6 \text{ Bq Kg}^{-1}$). We constructed an age-depth
296 model for the Upper Wetland core using the ^{210}Pb data and the independent time marker of the
297 ^{137}Cs peak and the dates after 1960 were very similar. However, accumulation rates and dates
298 prior to 1960 were non-sensical (indicating an exponential decrease in erosion between the 1950s
299 and 1960s, see Supplementary Material 2), so we utilized the age-depth model without the use of
300 the ^{137}Cs peak. Our inability to utilize ^{137}Cs in this system may be due to the general low levels
301 of fallout in the southern hemisphere and because ^{137}Cs may be non-conservative and mobile in
302 the anoxic sediments of the Mara Wetland (Benoit and Rozan, 2001; Comans et al., 1989; Davis
303 et al., 1984; Drexler et al., 2018; Wang et al., 2017). Other studies in equatorial Africa have also
304 reported low ^{137}Cs levels that made the radioisotope unreliable as an independent stratigraphic
305 marker (Nyarko et al., 2016). Because we were unable to use ^{137}Cs as an independent time
306 marker, we compared our age-depth models to historical trends of precipitation, the historical
307 water level of Lake Victoria, and prior watershed erosion modelling to establish that our ^{210}Pb
308 derived age-depth models are reasonable (see discussion).

309 Elevated ^{210}Pb concentrations in the Upper Wetland core suggest that ^{210}Pb has been imported to
310 this area in excess of expected atmospheric deposition (Turekian et al., 1983). It is likely that

311 land use changes within the basin and variable inputs of rainfall and sedimentation since the
312 1960s affected the ^{210}Pb input to the wetland (Baskaran et al., 2014). Although the
313 concentrations diverge substantially, the modeled sediment accumulation rates are quite similar
314 overall (Fig. 4), providing some confidence that artifacts are temporally constant or otherwise
315 insubstantial and accounted for within the confidence intervals of the Plum Bayesian model.

316 The radiocarbon dating chronology for the Upper Wetland core set (UC11, RC21, and RC23)
317 showed that the core ranged from present to 1839 years BP (Table 1). Results from the Bayesian
318 age-depth model indicated that sediment deposition was not linear through time, and that
319 deposition rates were most rapid in recent years (Fig. 5).

320 *3.2 Sediment Fingerprinting*

321 We found changing sediment sources over time in the Upper Wetland Core set (UC11, RC21,
322 and RC23) (Fig. 6). The Upper Mara was responsible for the greatest proportion of sediments
323 throughout the set of Upper Wetland cores (Fig. 6). Lower Mara and Talek sources make up the
324 next two largest sources of sediment in the core. The proportion of sediments from Upper Mara
325 began declining in the late 1700s, with the other sources increasing in proportion. Changes
326 became most pronounced in the mid-1970s (Fig. 6). The proportion of sediment contributed by
327 the Upper Mara declined markedly from ~50-60% of the sediments in the wetland to ~40% in
328 the late 1980s. At the same time, sediment contribution from the Talek portion of the basin
329 increased from <10% to ~20%. Sediment loads from the Lower Mara have provided
330 approximately the same proportion of sediments relative to the other sources (~30%).

331 In addition to changes in the source of sediments, the total amount of sediment accumulating in
332 the wetland from each portion of the basin has continued to increase, particularly since the

333 1960s, coincident with the rise in populations of human and cattle in Kenya and Tanzania (Figs.
334 7A and 7B). The largest quantity of sediment is provided by the Upper Mara, followed by Lower
335 Mara and then Talek and Middle Mara.

336 The MixSIAR mixing model confirmed that the core slices in the Seasonal Wetland core (UC7)
337 are all likely well mixed with one another, with no change in sediment source over the depth of
338 the core (Fig. S4). Plots of key elements as well as bulk density, nitrogen, carbon, and mercury,
339 confirm a relatively homogeneous upper core section indicative of a mixed column of sediments
340 (Figs. S5 and S6). In contrast, plots of key elements from the non-mixed Upper Wetland core
341 exhibited clear changing patterns throughout the depth of the core in multiple elements (Figs. S7
342 and S8) which would be indicative of a non-mixed core.

343 *3.3 Mercury*

344 Mercury data for the Upper Wetland core had a historic baseline ~20 ppb that began increasing
345 gradually in the 1700s (Fig. 8A). Concentrations briefly stabilized at ~30 ppb in the 1950s before
346 increasing in the 1960s to ~50 ppb, which is 2.5 times historic background concentrations. In
347 1984, concentrations began declining to ~25 ppb, found in the upper region of this core.

348 We also examined patterns in mercury concentration over the last 50-100 years along a transect
349 through the wetland (Fig. 8B). Mercury concentrations in the Middle Wetland core increased
350 from 25 to 35 ppb from 1950 to 2000, which is similar to the concentration changes in the Upper
351 Wetland core. Concentrations have begun to increase again at this site in the last 20 years, rather
352 than declining as at the Upper Wetland site. The Lower Wetland core shows a different pattern,
353 with a slight decrease in mercury levels from 1900-1990, followed by a sharp decrease and
354 recovery of mercury concentrations (Fig. 8B).

355 3.4 Carbon and Nitrogen Isotopes

356 The percent C and N in the Upper Wetland began increasing in the early 1900s, peaked from
357 1960-80, and then declined to levels just below the historic baseline from 1990 to present (Fig.
358 9A). Interestingly, both the percent C and N, and the C:N ratio (Fig. S9), declined through the
359 1970's and 80's to modern-day levels.

360 C and N stable isotope ratios follow different patterns over this time period (Fig. 9B). Looking at
361 a longer historical time period, from 1000-1950 AD, $\delta^{13}\text{C}$ is relatively constant at -14 to -16‰,
362 which aligns with the isotopic ratio of C4 savanna grasses in the Mara watershed (Fig. 9B)
363 (Masese et al., 2015; Masese et al., 2018). From ~1950-70, this value declines to -20‰, which is
364 closer to the ratio of C3 plants such as trees. The $\delta^{13}\text{C}$ ratio then increases in 1980-90 to an
365 intermediate value of -17‰.

366 For $\delta^{15}\text{N}$ ratios, the historical baseline was relatively stable between 2-4‰ from 1000 to 1960
367 (Fig. 9B). The $\delta^{15}\text{N}$ ratio increased gradually from 1960 to 1980, and then increased dramatically
368 through the 1990's, when it stabilized at elevated values around 6‰ over the past 20 years.

369 4. Discussion

370 Multiple lines of evidence suggest ecological conditions in the Mara River basin were fairly
371 stable over paleoecological time scales (2000-1000 years before present), but there has been a
372 period of rapid change in the basin over the last 250 years, particularly since the 1960s, likely
373 due to anthropogenic factors. The earliest changes in the basin began in the mid-1700s, including
374 increased sediment, mercury, and nutrient loads, and these changes corresponded with the advent
375 of the Industrial Revolution and the increased presence of colonial settlers in East Africa by the

376 late 1800s (Shillington, 2012). More pronounced changes in the origin and quantity of sediments,
377 mercury concentrations, and C and N stable isotope ratios began in the 1960s.

378 The highest proportion of suspended sediment has always come from the Upper Mara, which is
379 to be expected since this region has the highest elevational changes and the highest rainfall
380 (McClain et al., 2014). However, the proportion of total sediment entering the wetland from the
381 Upper Mara region has decreased from ~50% to ~40% since the late 1700s, and particularly in
382 the 1950s and 1960s, even as the quantity of sediment from the Upper Mara has increased (Figs.
383 6 and 7). Much of this change in proportional load is due to increased quantity and proportion of
384 sediment from the Talek portion of the basin, which increased from <10% of total sediments in
385 the 1970s to ~20% in recent years.

386 Contemporary research from 2011 through 2014 measuring high temporal resolution sediment
387 fluxes found that the combined Middle Mara-Talek sub-catchment contributes twice the
388 sediment flux as the Upper Mara sub-catchment (Dutton et al., 2018). This study found that the
389 Middle Mara and Talek sub-catchments contributed an average of 8% and 21% of the sediments
390 from 2010 through 2015 compared to 33% from the Upper Mara. Although within the same
391 order of magnitude, the difference between the two methods may reflect the transport and
392 storage of sediments within the river channel or banks. Sediments mobilized from Talek and
393 other areas of the basin may take several years to decades to reach the wetland. Previous studies
394 have shown the floodplains and river channels are important for sediment storage dynamics in
395 rivers (Wallbrink et al., 1998; Walling et al., 2003). Overall, these data suggest recent land-use
396 change in the Talek may be causing this portion of the basin to become an increasingly important
397 source of sediments in the region which have not yet reached the wetland. A delay in the timing
398 between when sediment is mobilized in the catchment and when it reaches the Mara Wetland

399 would suggest there may be some error in our estimates of the time of land use change in the
400 basin. However, we expect this time lag to be relatively short, given the alignment of sediment
401 dynamics in the wetland with known timing of land use change in the basin.

402 Our findings provide support for earlier work using remote sensing showing that the Mara
403 Wetland has expanded in size since the 1970s due to sediment accumulation in the upper
404 portions of the wetland (Mati et al., 2008). In all the cores analyzed, the Plum Bayesian age-
405 depth models indicate more rapid sediment accumulation in recent decades (Fig. 4). As sediment
406 deposition accelerated, the Plum models suggest the wetland served as a sediment trap, with
407 higher rates of sediment accumulation occurring in the upstream portions away from Lake
408 Victoria. Interestingly, the age-depth model indicated that sediment accumulation rose rapidly in
409 the Lower Wetland after 1996 and fell again just prior to 2009 (Fig. 4). This change likely
410 coincided with a rapid increase in the water level of Lake Victoria in 1998 and subsequent
411 decline in water level up to 2007 (Vanderkelen et al., 2018). As Lake Victoria rose, hydrological
412 connectivity likely increased between the lower and middle portions of the wetland and the
413 mainstem river upstream, which would have reduced water residence time in the wetland and the
414 corresponding buffering capacity of wetland vegetation and allowed more sedimentation to reach
415 further through the wetland towards Lake Victoria (Bavor and Waters, 2008; Kansiime et al.,
416 2007). A similar, but smaller, peak was also observed in the Middle Wetland between 1998 and
417 2009 (Fig. 4).

418 Sediment accumulation dynamics in the wetland also likely reflect large-scale precipitation
419 patterns in the basin. The sediment fingerprinting analysis from the Upper Wetland core
420 identified an overall increase in sediment accumulation from all sources since the 1960s.
421 However, there has been an oscillation in sediment accumulation rates from all sources since the

422 late 1970s (Fig. 7B). This pattern may reflect the natural decadal oscillation in rainfall patterns in
423 concert with increasing rainfall extremes experienced in the Mara since the 1960s (Fig. 10)
424 (Bartzke et al., 2018). A series of wetter years with extreme floods would be capable of
425 transporting more sediments than those transported by the succeeding period of drier years with
426 extreme droughts. The sediment accumulation rates from the age-depth model roughly
427 corresponded to historical rainfall records, showing decreased sediment accumulation rates in
428 periods of extreme droughts and higher sediment accumulation rates after periods of higher
429 annual rainfall (Fig. 10).

430 Further support for our age-depth models and sediment accumulation rates can be found by
431 comparing our sediment accumulation rates to modelled erosion rates using land use, slope, and
432 soil characteristics in the basin. Using land cover data from 2003, Defersha et al. (2012) used the
433 *Erosion 3D* model to calculate the expected amount of erosion in the combined Upper Mara,
434 Middle Mara and Talek sub-catchments to be $0.3 \text{ g cm}^{-2} \text{ yr}^{-1}$. Using the results of our age-depth
435 model, sediment fingerprinting proportions and calculated sediment accumulation rates, we
436 found that the amount of erosion in 2003 from the combined Upper Mara, Middle Mara and
437 Talek sub-catchments was approximately $0.2 \text{ g cm}^{-2} \text{ yr}^{-1}$ (95% confidence intervals between 0.08
438 and $0.35 \text{ g cm}^{-2} \text{ yr}^{-1}$, Fig. 7). Additionally, the trend of a contemporary increase in sediment
439 accumulation rate found with our ^{210}Pb age-depth model is independently supported by an
440 increase in modelled erosion rates based on satellite-derived land cover changes using the
441 Revised Universal Soil Loss Equation in the Lower Mara sub-catchment between 1986 and 2013
442 (Århem and Fredén, 2014), and satellite-derived land cover changes from the Upper Mara,
443 Middle Mara, and Talek sub-catchments between 1976 and 2014 indicating an increase in
444 agricultural lands (Mwangi et al., 2018), which historically accounts for the highest rate of

445 erosion in the basin (Defersha et al., 2012). Contemporary high temporal resolution
446 measurements from 2012 to 2015 of suspended sediment flux from the Upper Mara, Middle
447 Mara and Talek sub-catchments also indicate the potential for yearly increases, although yearly
448 trends were not calculated because several months were missing from each hydrological year
449 (Dutton et al., 2018).

450 Age-depth modelling using ^{210}Pb in catchments with dynamic sediment regimes can be
451 challenging (Abril et al., 2018; Kirchner, 2011). Data that violates the age-depth model
452 assumptions can lead to incorrect dates and spurious sediment accumulation rates (Abril et al.,
453 2018; Bachmann et al., 2018). The Plum model we use to analyze ^{210}Pb dating is based on the
454 CRS model, but does not require that ^{210}Pb measurements quantify the total inventory of ^{210}Pb
455 (Aquino-López et al., 2018; Mabit et al., 2014). The non-monotonic decreases in ^{210}Pb that we
456 observed in the upper portion of our cores could represent an increase in the sediment
457 accumulation rate or the presence of mixing (Arias-Ortiz et al., 2018), which can result in an
458 overestimation of sediment accumulation rates (Arias-Ortiz et al., 2018; Mabit et al., 2014). Our
459 ^{210}Pb concentrations by depth may not represent the ideal conditions for age-depth modelling, so
460 we have used both independent corroborations of our estimated sedimentation rate and a
461 statistical framework that incorporates uncertainty (Aquino-López et al., 2018). Additionally, we
462 focus our analysis on decadal trends in the upper portions of our cores rather than attempt to
463 infer high temporal resolution year-to-year changes due to the uncertainty present in our models
464 (Fig. 3). Our age-depth models and sediment accumulation rates are congruent with
465 contemporary increases in suspended sediment concentrations, prior watershed erosion
466 modelling using remote sensing of land use change, historical precipitation regimes, and the
467 historical water level for Lake Victoria.

468 Mercury concentrations followed a similar pattern as sediment dynamics in the basin. There was
469 an initial modest increase in mercury concentrations after the late 1700s that was likely caused
470 by atmospheric deposition reflecting global increases in industrialization (Driscoll et al., 2007).
471 The more rapid increase in the 1950s and 1960s was likely due to a combination of deforestation
472 and artisanal mining (Gamby et al., 2015; Telmer and Veiga, 2009), which was also reflected in
473 the large changes in sediment source and quantity during this time. Mercury binds to organic
474 material and will remain in forested soils, only becoming mobilized when the soils are disturbed
475 through deforestation or other land use conversions (Gamby et al., 2015; Schwesig et al., 1999).
476 Similar increases in mercury concentration were documented in response to loss of native land
477 cover in the Amazon during the same time period (Roulet et al., 2000). However, the decline in
478 the 1980s, stabilizing at concentrations only slightly elevated above the historical baseline,
479 suggests there has been a reduction in mercury loads into the Mara Wetland over the last 20
480 years (Fig. 8). The recent decrease in mercury concentration could be due to the higher relative
481 impact of initial loss of native land cover that is now stabilizing, or to conservation initiatives in
482 the upper basin aimed at decreasing soil erosion and runoff (Gamby et al., 2015). There are no
483 available data about the historical occurrence or frequency of artisanal gold mining in the Mara
484 River basin, which impedes our quantifying the proportion of mercury contamination that can be
485 attributed to this process.

486 All mercury concentrations are below the National Oceanic and Atmospheric Administration's
487 (NOAA) Effects Range-Low (150 ppb; ERL) concentration, which was associated with adverse
488 biological effects in 10% of studies reviewed by NOAA, suggesting that current mercury
489 contamination is unlikely to pose an ecological risk in the Mara Wetland. Our data also suggest
490 the wetland may be acting as a sink for mercury contamination in the upper and middle reaches.

491 This region of the wetland is hypoxic due to high decomposition rates of organic material, and
492 mercury in low oxygen environments is transformed into methyl mercury, which is the form
493 most toxic to living organisms (Hong et al., 2012; Sweet and Zelikoff, 2001). However, mercury
494 can bioaccumulate within the food web and be present in toxic levels within piscivorous fish
495 (Driscoll et al., 2007), which can be difficult to estimate from ambient environmental
496 concentrations (Munthe et al., 2007). Because we did not directly measure mercury
497 concentrations in fish, we cannot completely rule out the possibility of harmful levels of mercury
498 within the food web.

499 Patterns of land use change in the basin are also reflected in increasing concentrations of C and
500 N in wetland sediments over time, likely due to increased organic loading into the river. This
501 pattern is generally mirrored by the C:N ratio, which can indicate the relative degree of aquatic
502 or terrestrial production in the river (Cross et al., 2003; Kaushal and Binford, 1999). Terrestrial
503 production that has entered the river typically has a higher C:N ratio, while aquatic production
504 occurring within the river typically has a lower ratio. Thus, the increase and peak in C:N that
505 occurs from ~1950-1970 and aligns with the increased percent of C and N loading likely
506 indicates an influx of terrestrially-derived production entering the river as a result of
507 deforestation and land cover change (Kaushal and Binford, 1999; Neill et al., 2001) (Figs. 9 and
508 S9).

509 Both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were relatively stable over historical time scales from ~2000 years BP until
510 significant anthropogenic change began occurring in the latter half of the 20th century (Fig. 9B).
511 The general trend in the $\delta^{13}\text{C}$ of organic carbon to more negative values may indicate increasing
512 tree cover relative to grass cover on the landscape. Trees in this region are predominantly C3
513 plants with a $\delta^{13}\text{C}$ around -28‰, and savanna grasses are predominantly C4 plants with a $\delta^{13}\text{C}$

514 around -14‰ (Masese et al., 2015; Masese et al., 2018). Some of this decline (~ 2‰) can also be
515 explained by a negative shift in $\delta^{13}\text{C}$ due to fossil fuels in the atmosphere (Cerling and Harris,
516 1999; Francey et al., 1999). More complicated subsequent changes (between 1950-1990) could
517 arise from a combination of factors. Significant changes in wildlife populations did occur during
518 this time, and hippos in particular load large amounts of savanna grass into the river during daily
519 feeding migrations (Subalusky et al., 2015). The earliest surveys of hippos in the Mara,
520 conducted in 1959, showed very low numbers that were likely lower than historical abundances
521 (Darling, 1960). Populations then increased exponentially in surveys conducted in 1971 (Olivier
522 and Laurie, 1974) and 1980 (Karstad and Hudson, 1984), and then generally stabilized through
523 2006 (Kanga et al., 2011). The apparent decrease and subsequent increase in organic C from
524 savanna grasses might thus represent a lagged response to the decline and recovery of hippos.
525 Other factors also may also contribute, including changes in plant community composition in the
526 landscape and in the wetland, changing size of the wetland, and other landscape level patterns
527 including increased burning and deforestation.

528 Changes in $\delta^{15}\text{N}$ indicate an increase in anthropogenic nutrient loading into the river beginning
529 in the 1960s and becoming more significant in the 1980s until stabilizing more recently. Other
530 studies have shown that anthropogenic inputs (via agricultural runoff and sewage) are elevated in
531 nitrogen, and that anthropogenic N is enriched in ^{15}N producing elevated $\delta^{15}\text{N}$ compared to non-
532 anthropogenic sources (McClelland et al., 1997).

533 Changes in erosion processes throughout the basin were likely caused by significant changes in
534 land use and land cover that were coincident with both the eradication of rinderpest and
535 increasing deforestation in the basin. Rinderpest was first found in the Mara region in the 1890s
536 (Percival, 1985) and decimated populations of wild and domestic animals; however, it had been

537 virtually eradicated by 1963 (Talbot and Talbot, 1963), likely due to the vaccination campaign of
538 domestic animals by the local governments (Mariner et al., 2012) and the development of a
539 natural immunity by wildebeest (Plowright and McCulloch, 1967; Sinclair, 1979; Taylor and
540 Watson, 1967). The corresponding increase in livestock and wildlife in the mid-1960s also
541 coincided with the beginning of legal and illegal settlements in the Mau Forest (Baldyga et al.,
542 2008).

543 **5. Conclusions**

544 The Mara Wetland is influenced by changes in the Mara River basin and likely plays an
545 important role in mitigating how those changes influence Lake Victoria. The wetland acts as a
546 sediment trap, with sediment accumulating at higher rates in the Upper Wetland than the Lower
547 Wetland. This wetland function has likely reduced the impact on Lake Victoria of increased
548 sediment transport from the basin since the mid-1900s. Sediment deposition may have
549 contributed to an increase in the size of the Mara Wetland that was proposed to have occurred in
550 the mid-1900s (Mati et al., 2008). The Mara Wetland also appears to act as a sink for mercury
551 contamination, as a large peak in mercury concentration in the Upper Wetland has yet to emerge
552 in the Middle or Lower Wetland sites. Although retention of mercury in the wetland may
553 positively impact the mercury concentrations reaching Lake Victoria, it does raise conservation
554 and health concerns due to the potential transformation of mercury into methyl mercury, which is
555 the form most toxic to people and animals (Hong et al., 2012).

556 We also observed that downstream effects of landcover and land use change can be significant
557 and can be exacerbated by changing precipitation patterns (Nearing et al., 2005). Increasing
558 extreme rainfall events have likely exacerbated the already increasing sedimentation rates within

559 the basin (Mango et al., 2011). Throughout East Africa, sedimentation has likely increased and
560 will continue to increase as the region continues to receive a higher frequency of extreme rainfall
561 events (Bartzke et al., 2018; Muthoni et al., 2018). Basin-wide historical changes we observed in
562 the Mara Wetland cores are likely indicative of changes occurring throughout the region (Guzha
563 et al., 2018) and provide a historical context to the consequences of increasing development
564 coupled with increasing rainfall variability. Combining age-depth modelling with sediment
565 fingerprinting can help reconstruct historical sedimentation patterns in the context of land use
566 changes in understudied regions.

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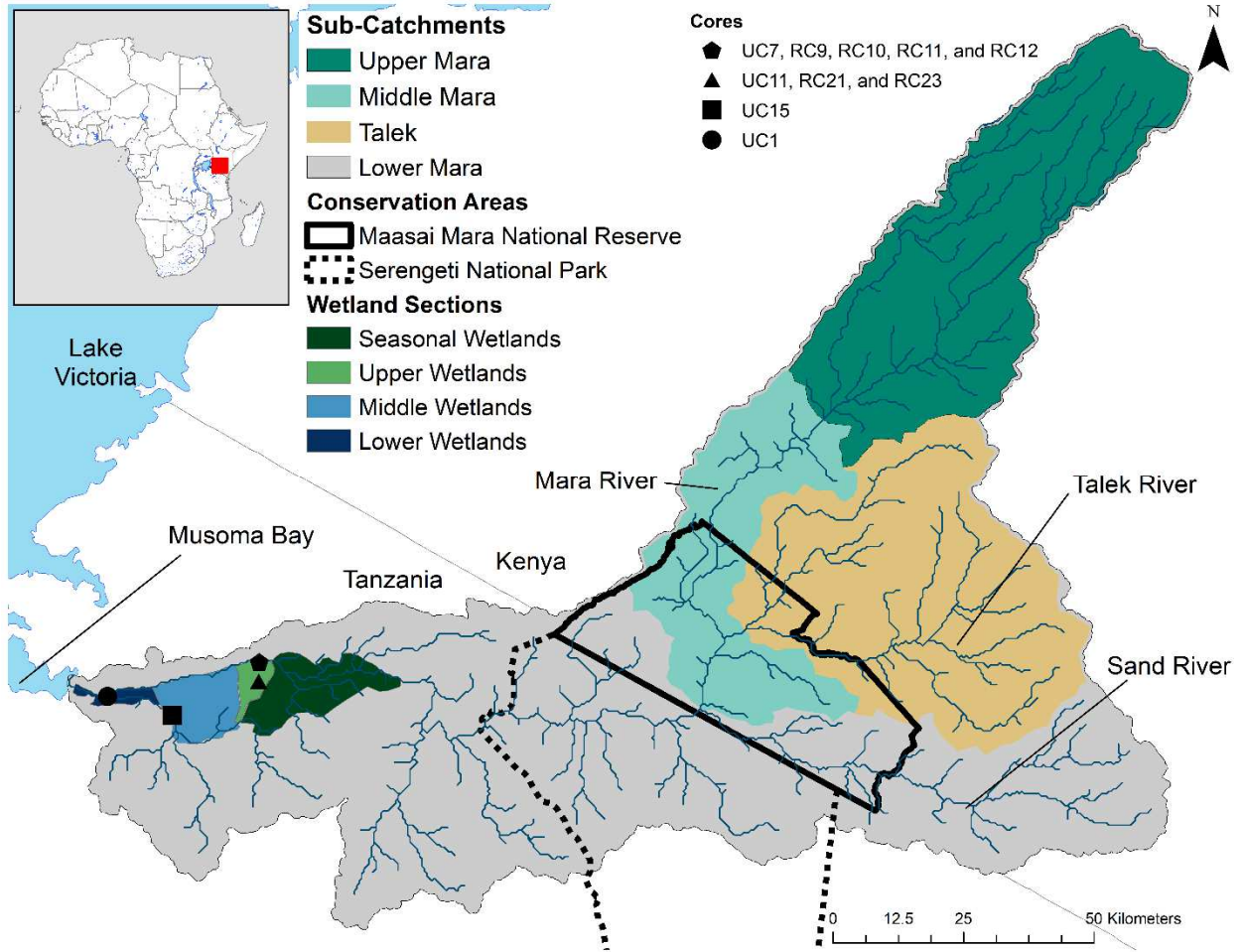


Figure 1. The Mara River basin is a trans-boundary basin shared between Kenya and Tanzania. Sediment source fingerprints were developed for the four sub-catchments. Sediment cores were collected to represent the four sections of the Mara Wetland.

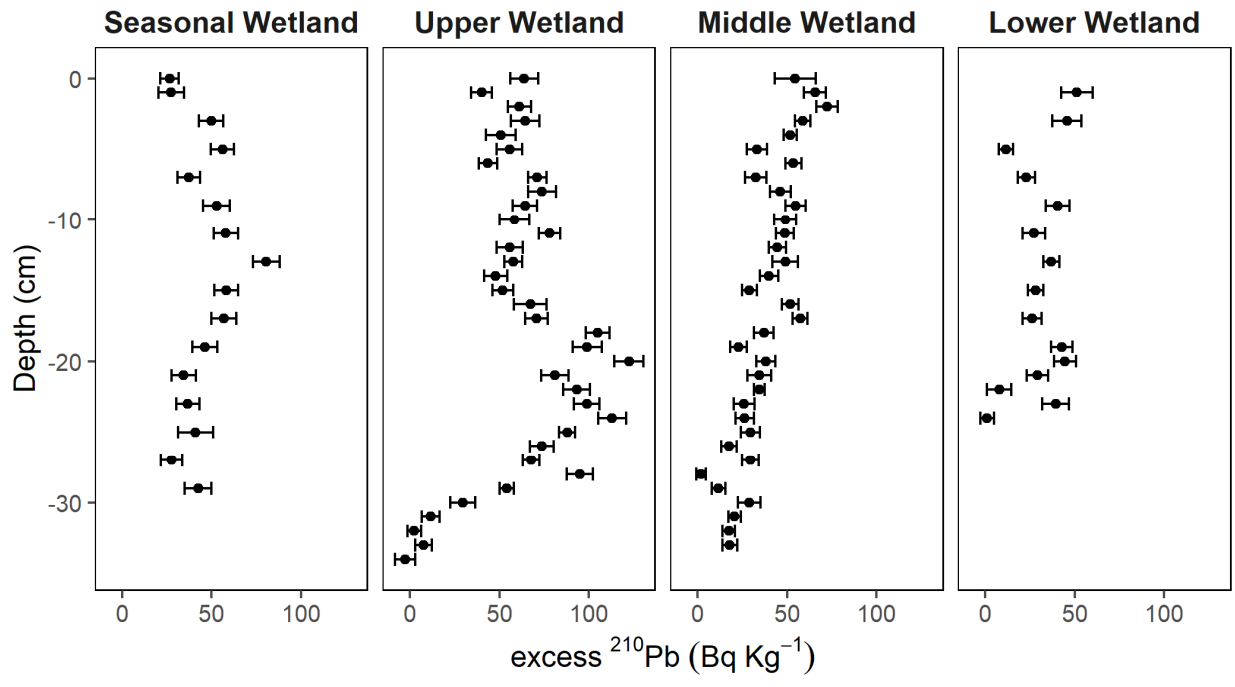


Figure 2. Excess ²¹⁰Pb concentrations (mean and standard deviation) for the four cores (Seasonal Wetland, Upper Wetland, Middle Wetland, and Lower Wetland).

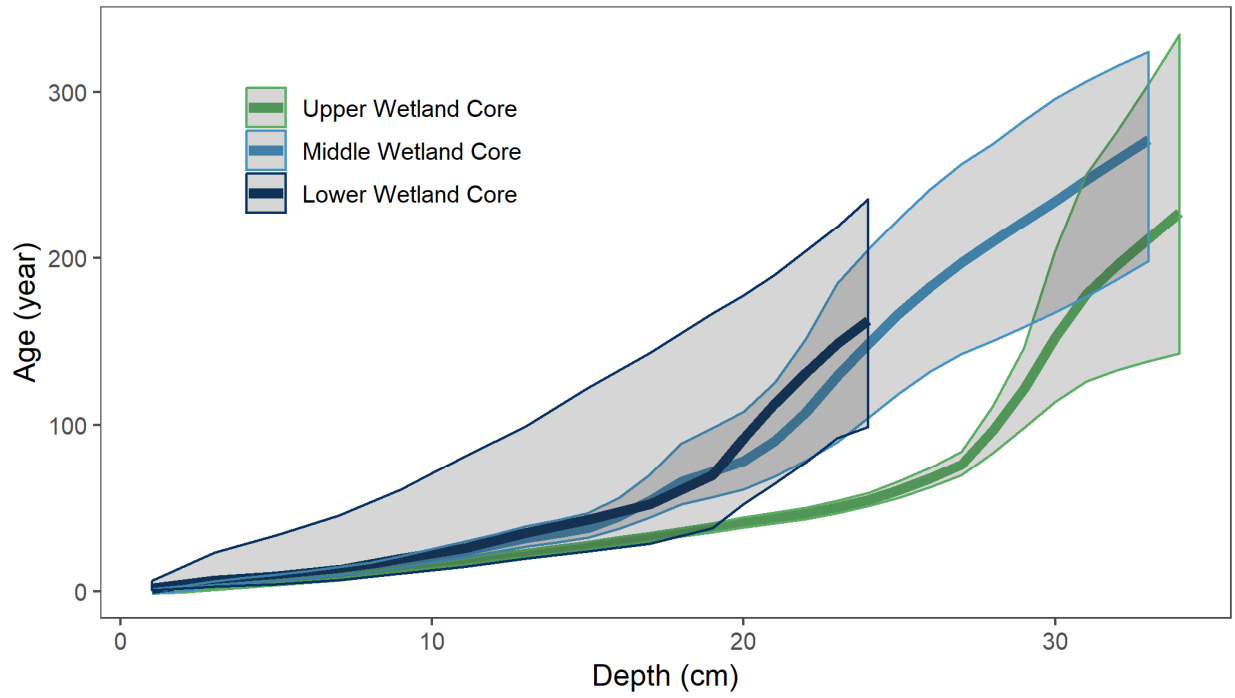


Figure 3. Plum Bayesian age-depth models for the Upper Wetland core (light green), Middle Wetland core (light blue) and Lower Wetland core (dark blue). Shaded area represents 95% confidence region. Colors match the wetland regions represented in Figure 1.

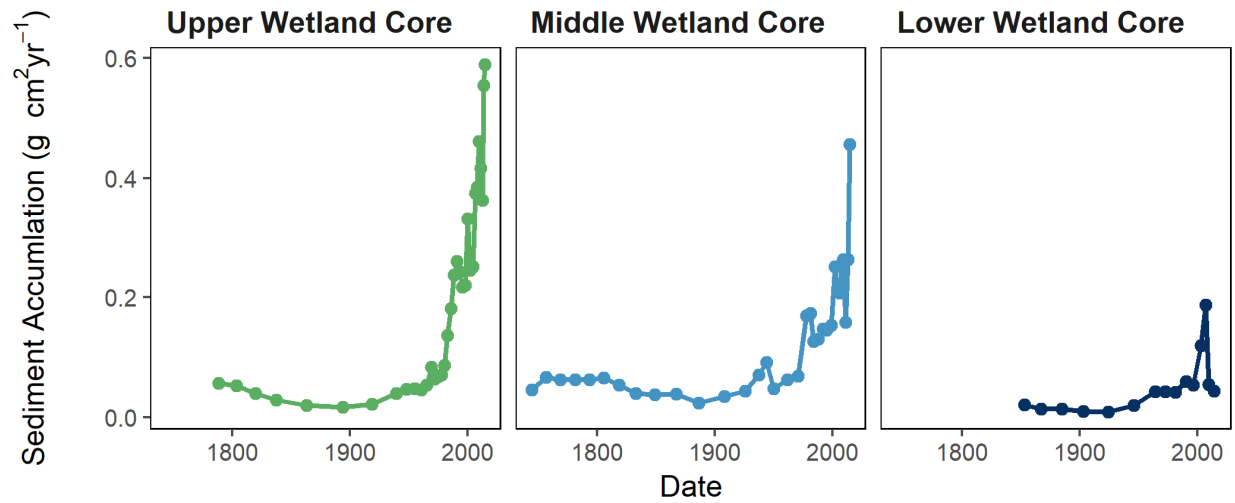


Figure 4. Sediment accumulation chronologies in cores from a lake in the Upper Wetland (UC11, left column), the Middle Wetland (UC15, middle column) and the Lower Wetland near Lake Victoria (UC1, right column) using the Plum model. Colors match the wetland regions represented in Figure 1.

Upper Wetland Age-Depth Model

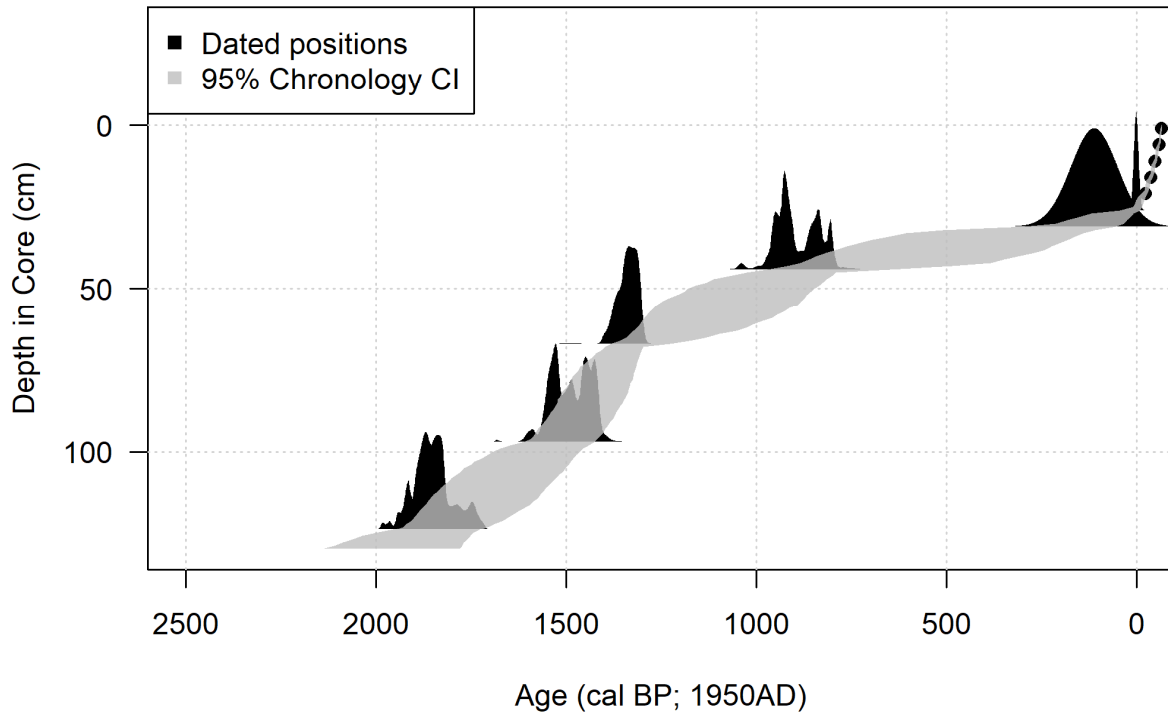


Figure 5. Bayesian age-depth model for the Upper Wetland core set (UC11, RC21, and RC23) using radiocarbon and ²¹⁰Pb dating. Points and the two density probability curves on the right represent the ²¹⁰Pb dates from the Plum Bayesian age-depth model (taken every 5 cm, 7 dates total); radiocarbon dates are represented as the four density of probability curves on the left (Parnell, 2016). Age in 'cal BP' refers to the age in calibrated years before present, the present being 1950 by convention.

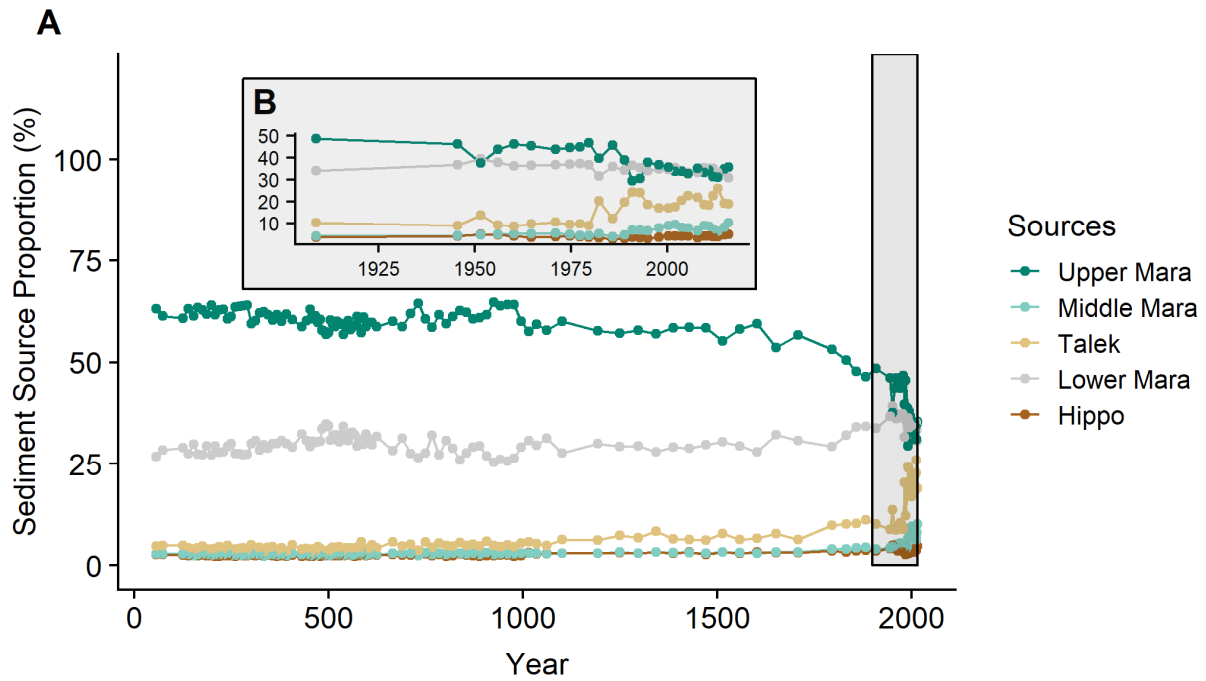


Figure 6. **A.** Sediment fingerprinting source proportion in the Upper Wetland set of cores (UC11, RC21, RC23) for approximately 2000 years. Source proportions from 1900 to present day highlighted in gray. **B.** Source proportions from 1900 to present day. Colors match the regions represented in Figure 1.

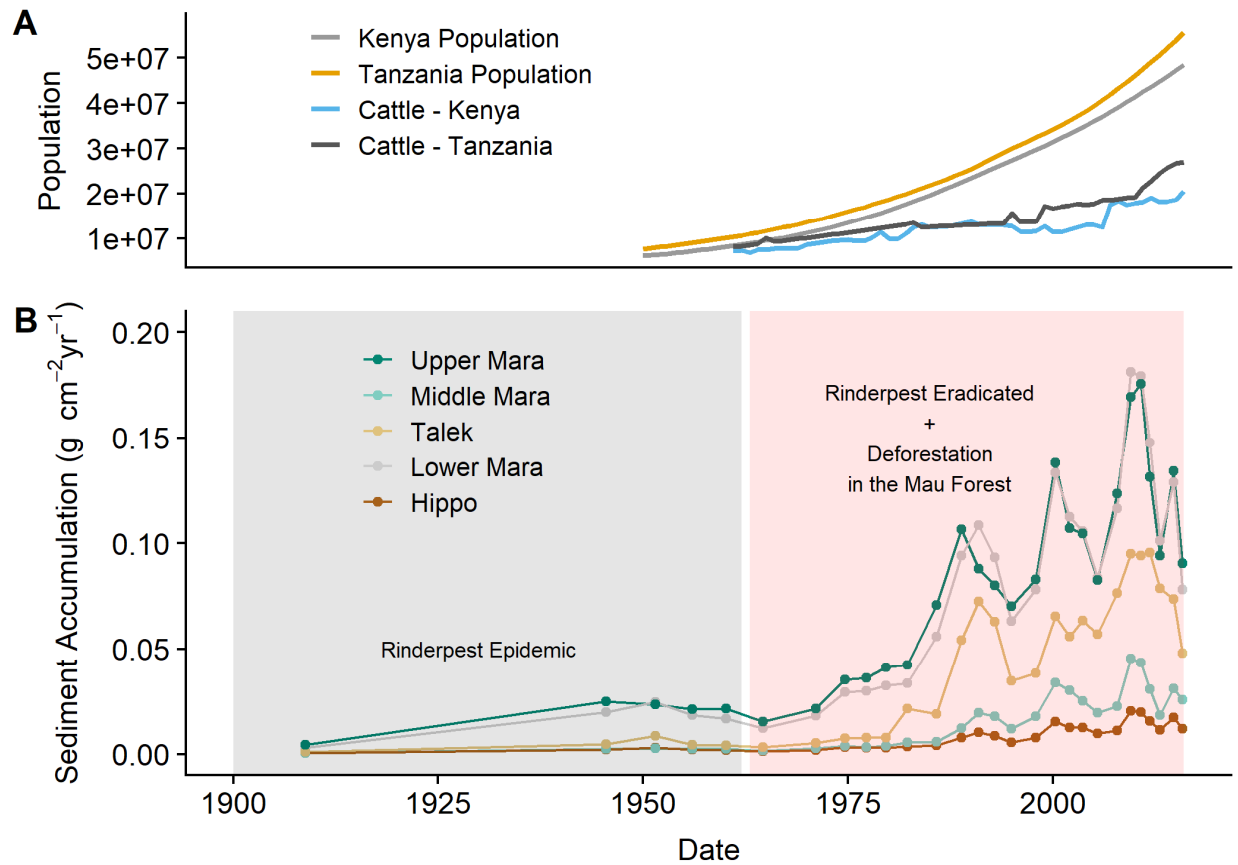


Figure 7. **A.** Kenya and Tanzania human population and cattle population numbers from 1950 to present (FAO, 2018). **B.** Sediment accumulation from 1900 to present day in the Upper Wetland Core (UC11). Colors match the regions represented in Figure 1. Gray box indicates the time of the rinderpest epidemic in the Mara-Serengeti (~1894-1962) (Talbot and Talbot, 1963). Red box indicates the eradication of Rinderpest in the Mara-Serengeti and the deforestation in the Mau Forest (~1964-Present) (Baldyga et al., 2008; Talbot and Talbot, 1963).

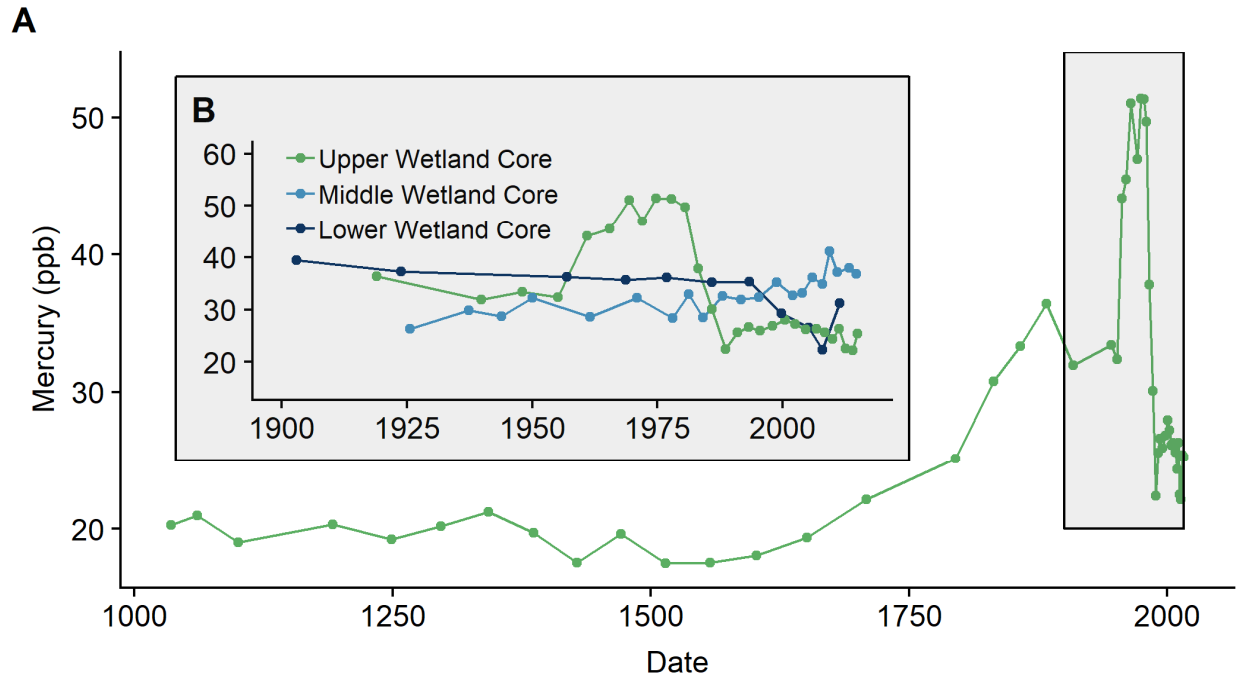


Figure 8. **A.** Mercury concentration (in parts per billion) in a sediment core from the Upper Wetland from 1100 AD to present day. Mercury concentrations from 1900 to the present day highlighted in the gray box. **B.** Mercury concentrations (in parts per billion) from the Upper Wetland (red), Middle Wetland (orange) and Lower Wetland (blue) sediment cores. Colors match the regions represented in Figure 1.

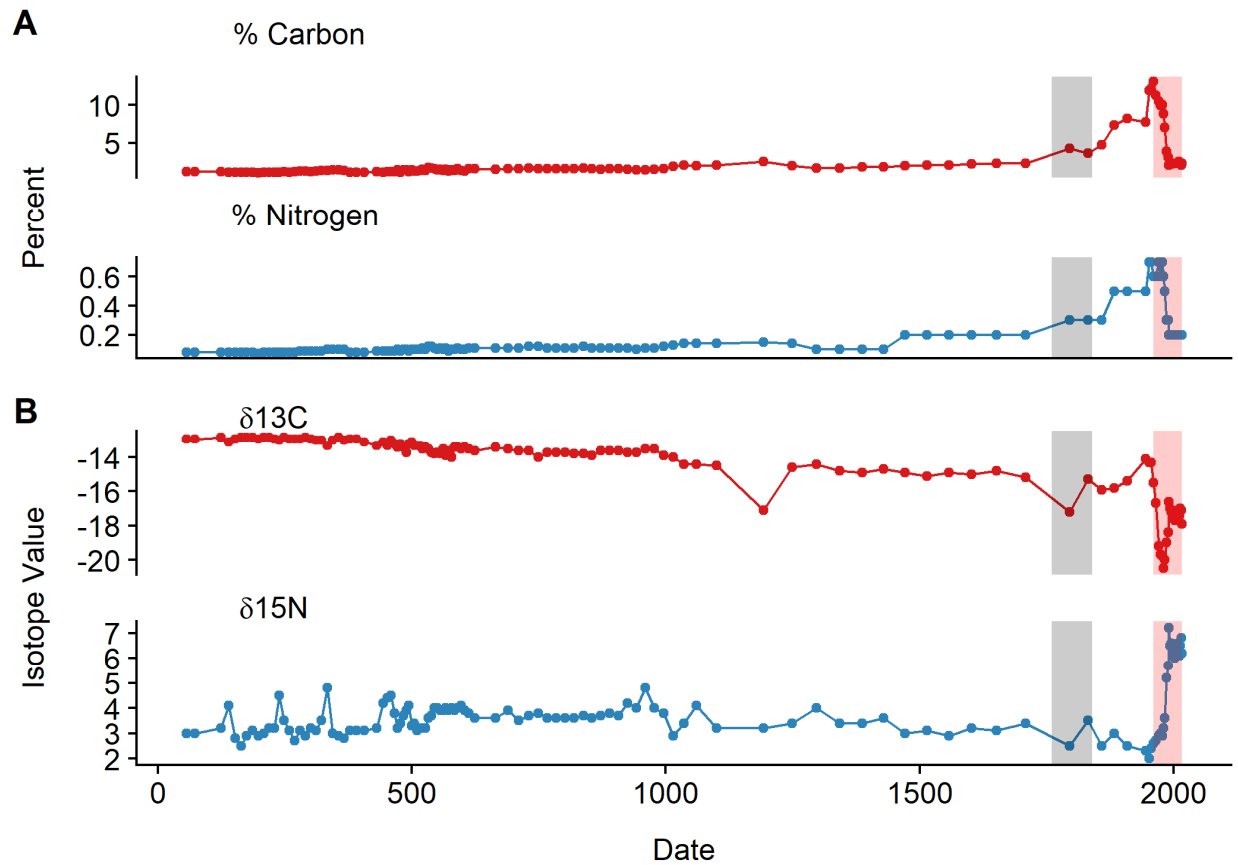


Figure 9. **(A)** Percent of carbon (C) and nitrogen (N) and **(B)** $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in the Upper Wetland core (UC11) from 0 AD to present day. Gray box indicates the Industrial Revolution (~1760-1840) and the red box indicates the deforestation in the Mau Forest (~1964-Present) (Baldyga et al., 2008).

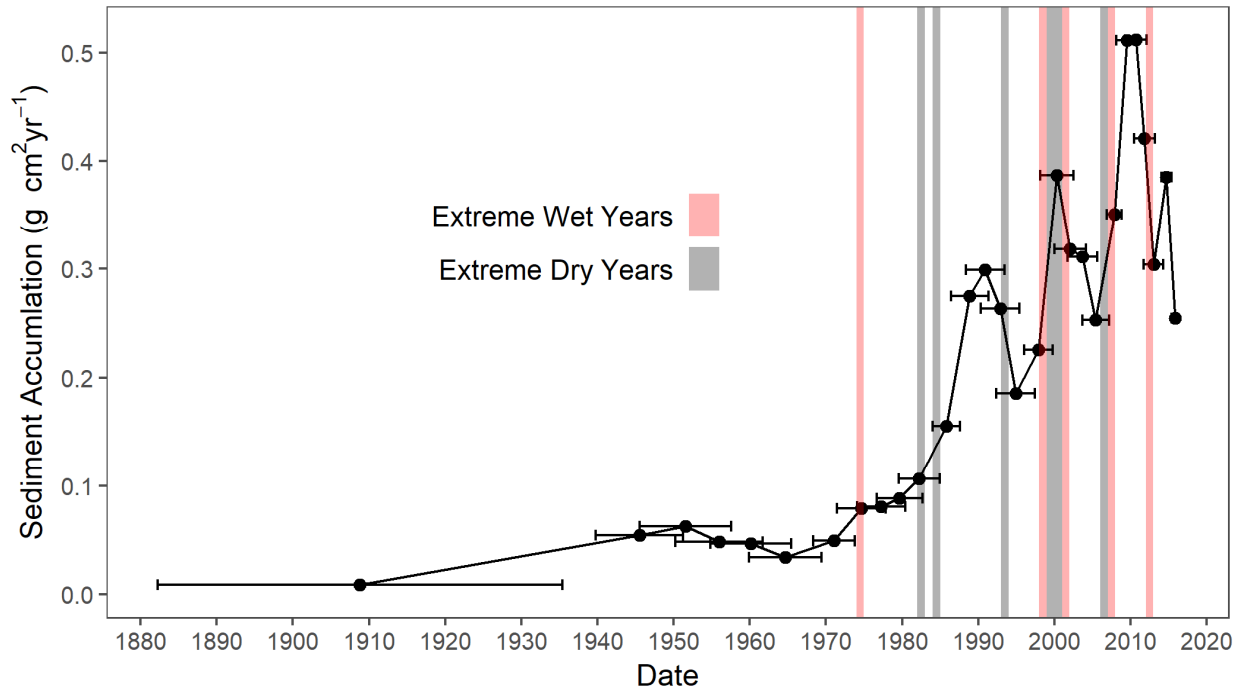


Figure 10. Sediment accumulation for the Upper Wetland core from 1900 until 2015. Horizontal error bars indicate Bayesian modelled uncertainty from the age-depth model. Years experiencing extreme rainfall with a greater than a 10-year return interval for wet years (red) and dry years (gray) are indicated as shaded bars (Bartzke et al., 2018). Yearly rainfall data only available since 1965.

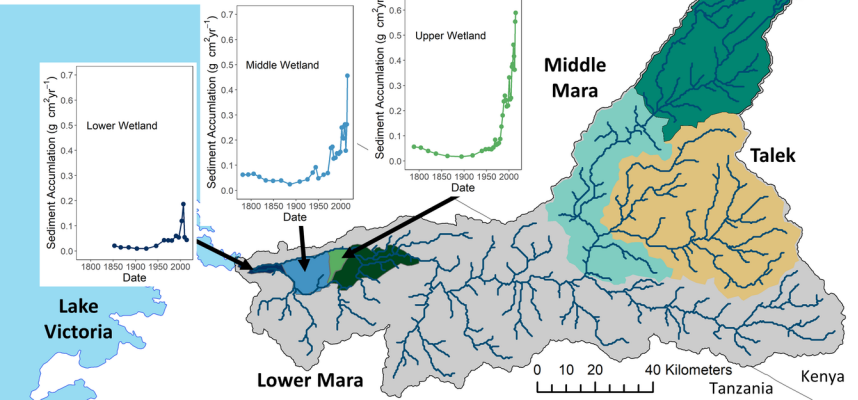
Tables

Table 1. Radiocarbon chronology of the Seasonal Wetland core set (UC7, RC9, RC10, RC11, and RC12) and the Upper Wetland core set (UC11, RC21, RC23) from the Mara Wetland.

Laboratory code	Material	Core Set	Core	Depth (cm)	Thickness (cm)	14C age [yr BP]	Calibrated age [cal yr BP, $\pm 1 \sigma$] ¹
CAMS# 173870	TOC of bulk sediment	Seasonal Wetland	RC9	48	1	300 \pm 30	362 \pm 106
CAMS# 173869	TOC of bulk sediment	Seasonal Wetland	RC10	88	1	Modern	Modern
CAMS# 173871	TOC of bulk sediment	Seasonal Wetland	RC11	128	1	285 \pm 30	336 \pm 119
CAMS# 174604	TOC of bulk sediment	Seasonal Wetland	RC12	159	1	Modern	Modern
CAMS# 172566	TOC of bulk sediment	Seasonal Wetland	RC12	189	1	2625 \pm 50	2691 \pm 147
CAMS# 174605	TOC of bulk sediment	Upper Wetland	UC11	44	1	995 \pm 45	898 \pm 97
CAMS# 174606	TOC of bulk sediment	Upper Wetland	RC21	67	1	1445 \pm 35	1393 \pm 74
CAMS# 174607	TOC of bulk sediment	Upper Wetland	RC23	97	1	1610 \pm 40	1518 \pm 102
CAMS# 172565	TOC of bulk sediment	Upper Wetland	RC23	124	1	1910 \pm 45	1839 \pm 119

¹ Using the IntCal13 calibration curve (Reimer et al., 2013) in *Bchron* in R (Parnell, 2016).

The Mara Wetland buffers Lake Victoria:
Higher rates of sediment accumulation in
upstream portions of wetland



Rapid and increasing sediment
accumulation in the Mara
Wetland from major portions of
the basin since the 1960s

