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Impact of surface water extraction on water quality and ecological integrity in Arusha National Park, Tanzania

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Abstract

Surface water has been extracted from Arusha National Park (ANP) to meet human demand for over 30 years; however, there has been no evaluation of the impact of extraction on surface water quality, budget or ecological integrity. A reduction in water availability and flow is likely to also have impacts on the distribution and space use of large mammals. To assess the surface water quality and budget, 30 water sources were measured for three months over the dry and wet seasons. Nearly 70% of water is extracted, with the complete extraction of surface water common during the dry and early wet seasons. However, extraction did not lead to a decrease in downstream water quality, but wetland plant diversity was highest in areas with no surface water extraction. Extraction also influences large mammal space use: abundance along seven transects was typically higher upstream of extraction sites, especially in the case of large herbivores. Impacts of extraction therefore include the disconnection of streams, changes in space use of large mammals, decreases in plant diversity and changes in species composition of the riparian wetlands. We therefore recommend that monitoring and evaluation of extraction as well as sustainable water use practices be introduced as a matter of urgency.

Key words: ecological integrity, habitat use, surface water budget and quality

Résumé

Depuis plus de 30 ans, de l'eau de surface est prélevée dans le Parc National d'Arusha pour répondre à la demande humaine mais il n'y a encore eu aucune évaluation de l'impact de ces prélèvements sur la qualité des eaux de surface, sur l'économie et sur l'intégrité écologique. Une diminution de la disponibilité en eau et du débit est susceptible d'avoir aussi un impact sur la distribution et sur l'utilisation de l'espace par les grands mammifères. Pour évaluer la qualité et l'aspect économique de l'eau de surface, nous avons mesuré 30 sources d'eau pendant trois mois allant de la saison sèche à la saison des pluies. Près de 70% de l'eau est prélevée, et il est fréquent que toute l'eau soit extraite pendant la saison sèche et au début de la saison des pluies. Cependant, le prélèvement d'eau n'a pas entraîné de dégradation de la qualité de l'eau en aval même si la diversité végétale des zones humides était plus élevée dans les zones où il n'y avait pas de prélèvements d'eau de surface. Ces prélèvements influencent aussi l'utilisation de l'espace par les grands mammifères : leur abondance le long de sept transects était typiquement plus élevée en amont des sites d'extraction, spécialement celle des grands herbivores. Les impacts des prélèvements comprennent donc une déconnection des cours d'eau, des changements d'utilisation de l'espace par les grands mammifères, une diminution de la diversité et des changements de la composition des espèces des zones humides riveraines. Nous recommandons d'intégrer d'urgence un suivi et une évaluation des prélèvements d'eau ainsi que des pratiques durables d'utilisation de l'eau.

Introduction

It is known that water extraction can affect water quality as well as quantity (e.g. Rhodes, Newton & Pufall, 2001) and that the effects extend to both the aquatic and terrestrial communities. For example, water extraction for agriculture in the rivers upstream of Kruger National Park in South Africa resulted in a marked deterioration in water quality and a decline in water discharge particularly in the dry season (Du Toit, Biggs & Rogers, 2003). The impact of disturbance on surface water is multidimensional because

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of the wider role played by water in the ecosystem. Although ecosystem function and structure can be maintained under regimes of controlled resource extraction, unsustainable use can lead to ecosystem collapse if insufficient water is available to maintain ecological integrity (MacKay, 2001). Water quality is negatively correlated with the catchment area altered by human use; and due to the reduced dilution of inputs, water extraction is associated with the increased nonpoint source pollution downstream (Rhodes, Newton & Pufall, 2001).

A number of studies have shown the importance of surface water to wildlife, particularly for those species that are water dependent. African mammal density and landscape use are determined by the volume of permanent water and vegetation productivity (Sinclair, 1977). For example, elephants prefer to use habitats close to surface water resulting in their distribution and abundance, particularly in the dry season, being controlled by surface water availability (Chamaillé-Jammes, Valeix & Fritz, 2007; Shannon *et al.*, 2009). However, changes in water distribution affects the species differently. Smit, Grant & Devereux (2007) demonstrated that herbivores respond differently in terms of distribution with regard to surface water, such that browsers show less of a response than large grazers to anthropogenic changes in water availability.

For at least 30 years, water has been extracted from Arusha National Park (ANP), Tanzania, for irrigation and domestic use by the surrounding villages, towns and the city of Arusha, which has a population of over 416,000 (Arusha National Park (ANP), 2003; National Bureau of Statistics (NBS), 2012). There is currently no regulation or monitoring of the impact of water extraction on minimal environmental flows within the park. Moreover, no targeted studies have been carried out in the park to assess water budget or extraction-related impacts on the ecosystem (Arusha National Park (ANP), 2003). However, there is anecdotal evidence of significant negative ecological effects downstream of the extraction points. Some work has been conducted on water quality but is largely confined to a few unextracted, fluoride-rich water sources (Walker & Milne, 1955; Kilham & Hecky, 1973; Hecky, 1971; Nanyaro, Aswathanarayana & Mungure, 1984; Mount Meru Conservation Project (MMCP), 2002).

Most of the studies of water extraction have concentrated on how unsustainable practices affect downstream protected environments including national parks that depend on water sourcing from unprotected areas (Elisa, Gara & Wolanski, 2010). In contrast, this study focuses on the impact of extraction in an upstream protected area. The objectives of the study were to (i) assess the flow rates and water quality of the extracted and unextracted surface waters in ANP; (ii) infer the patterns from records of rainfall changes in ANP over the last 40 years; and (iii) establish how water extraction affects wildlife space use and riparian vegetation species composition.

Materials and method

Study area

The Arusha National Park (ANP) encompasses an area of 552 km^2 and is located in the northern part of Tanzania at a latitude 03°12′ to 03°18′ and longitude 36°45′ to 36°56′ (Fig. 1). Three important geomorphological features within the park are Mount Meru (4566 m absl), Ngurdoto Crater and the enclosed alkaline (pH 10) Momella Lakes (Mount Meru Conservation Project (MMCP), 2002; Arusha National Park (ANP), 2003; Tanzania National Parks Authority (TANAPA), 2012; Maleko *et al.*, 2012). The park receives an annual rainfall of more than 600 mm per year, and there are two rainy seasons: a short season between November and December and a longer period of rain from mid-March to late May. Temperature varies between 15°C and 34°C, and January and February are the hottest months. The cold season extends from June to August, but temperatures at mid-day do not drop much below 15°C (Beesley, 1972 & Maleko *et al.*, 2012). ANP has a number of different habitats including forest, open glades, fresh and alkaline lakes, rivers and streams. The park is home to a number of species including amphibians (10), birds (500) and mammals (40).

Data collection

We collected the data over three months from January to March 2013. January and February encompassed the dry season, while March represented the onset of the wet season. The sampling sites reflected geographical coverage and key habitats for wild mammals across the park. For water quality assessment, 30 sites were sampled, covering eighteen extracted and twelve unextracted water sources. We assessed the water quality parameters likely to affect

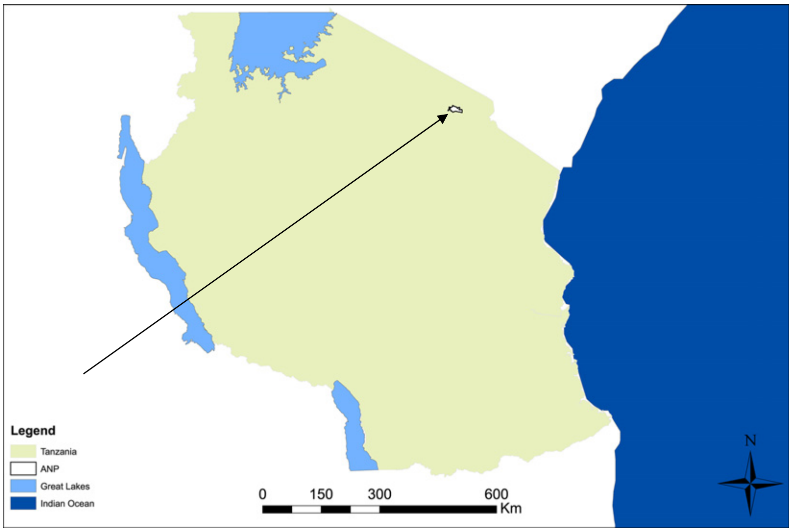

Fig 1 Map of Tanzania showing the location of Arusha National Park (ANP)

water consumption by wild animals, including dissolved oxygen (DO), salinity, pH, conductivity, temperature, nitrate and fluoride concentrations. The water budgets of the same eighteen extraction sources and nine unextracted sources were measured monthly on the same day as the water quality measurements.

Spot gauging was used to assess the water budget. Depending on the morphological nature of water source, either the volumetric method (amount of water collected in a given time) or the flow velocity (using a GEOPACKS stream flow meter) plus cross-sectional area were used to measure discharge. At each site, one discharge measurement was taken at the upstream site before the water is extracted. The downstream water volume was obtained either directly or by subtracting the amount of extracted water from the upstream measurement. Rainfall patterns were assessed from rainfall data taken at two sites: one station within the park (15-year record) and one adjacent to the park (43-year record). Salinity, pH, conductivity, dissolved oxygen and temperature were measured in the field using electronic field meters (Extech EC500 ExStik II Extech Instruments, Nashua, NH, USA; salinity, pH, conductivity) and AMT08 (Amtast, Lakeland, FL, USA; dissolved oxygen, water temperature). Sampling for nitrate and fluoride was carried out only in January and March; these times were to capture changes between the dry and wet seasons. Fluoride and nitrate concentrations were measured in the laboratory using the ion-selective electrode method at Ngurdoto Defluoridation Research Station.

Seven mammal transects were walked once per month, corresponding to the water sampling schedule. The transect sites were selected based on the location and status (partial/complete extraction) of water extraction sites, habitats and areas of high animal density (Earth Watch Institute (EWI), 2004). The one-month interval allows sufficient time to ensure the independence of each sample (Caro, 1999). Some streams and springs flow relatively short distances; therefore, a 1-km transect length was considered adequate to reflect the impact of water extraction on mammals. To ensure the counting of mammals that are relatively closely associated with a particular water source, transects were laid along the streams 500 m upstream and 500 m downstream. Maximum distance visible on both sides of the transect was 100 m. The total number of mammals (large, medium and small herbivores and primates) in each transect was recorded. Transects were walked quietly, and as soon as a mammal was sighted on either side of the transect, the observers stopped and recorded the number of animals sighted and the distance from the transect to the point where the animal was first sighted. The sighting angle was also recorded.

A vegetation survey was conducted in three riparian wetlands (Ngongongare 1, Ngongongare 3 and Mweka), situated downstream of water extraction points, and Malama which served as control because its water was not subject to upstream extraction. A single transect of 60 m long was laid out parallel in the upstream–downstream direction of water flow. Sixty metres was used because the smallest wetland was only 60 m in length.

Five quadrants of 1 m^2 spaced at an interval of 15 m were surveyed for each wetland (Barker, 2001). Except for the first quadrant that was positioned randomly, the rest of quadrants alternated from right to left at a 5 m distance from the transect line to capture the variation at longitudinal and lateral dimensions. In each transect, plant species were identified and species abundance was recorded. Species unidentified or not clearly identified in the field were pressed and taken to the National Herbarium in Arusha for further identification.

Data analysis

The impact of extraction on wetland vegetation density was assessed using the Shannon–Wiener diversity index to calculate obligate species (OBL) and facultative wetland-associated species (FACW) diversity and species evenness. A single-factor analysis of variance (ANOVA) was used to assess intersite differences in species richness and diversity (Mabry, 2008). Further, a *t*-test was applied to each individual variable (species richness, diversity and evenness) for the different pairs of wetlands. Significance was in all cases defined as $P < 0.05$.

We compared the abundance of focal mammal species (grouped into primates, large herbivores and small herbivores) upstream and downstream of the extraction sites. Binomial tests to establish the probability of abundance trends across sites were run which subset the data by species type and transect. To further investigate how extraction impacts on abundance across different species and transects, a Poisson generalized linear mixed model was used to accommodate the distribution count data. The main effects in the model were transect, treatment (upstream versus downstream), species and transect–treatment interaction.

Results

Water quality and quantity

On average, dissolved oxygen (DO) levels in the park streams ranged from 7.5 mg/l in February to 9 mg/l in March. Dissolved oxygen levels showed some variation between sites and seasons and generally increased in the wet season reaching a maximum of 11 mg/l (113% saturation), while in the dry season concentrations were comparatively lower, with a minimum of around 5 mg/l (54% saturation) in the Malemeo River. There were no trends in the level of dissolved oxygen upstream and downstream of the extracted water sources, and the difference in DO levels was small, with a maximum difference of 2 mg/l.

Salinity ranged from 15 to 450 ppm at the extracted sites in both seasons and did not vary upstream and downstream by more than 60 ppm. Salinity levels in unextracted water sources varied markedly with sources like Jekukumia River recording up to 2370 ppm, while River Temi measured just 30 ppm. Nearly 40% of extracted sources were within World Health Organization (WHO)'s fluoride limits for potable water (1.5 mg/l), but some others had unsuitably high levels (Fig. 2). Unextracted sources such as Maiyo contained the highest levels of fluoride of up to 60 mg/l. Salinity and fluoride levels were slightly higher in both extracted and unextracted water sources in the dry season and also varied spatially with water courses on the eastern side of the national park being more saline rich and fluorine rich (Fig. 3). Most water sources had a temperature between 15°C and 20°C. Nitrate levels were generally low, ranging from 0.1 to 7 mg/l, and pH ranged between 6.5 and 8.5.

Extraction mirrored supply, and for the extracted water sources, the total amount removed for human consumption is high, taking 66.6% of the water and so leaving only a third for the downstream ecosystem (Fig. 4). Seventy per cent of the extraction sources removed all water in the dry season. Rainfall records for 43 years at Ngaramtoni indicated a high interannual rainfall variability and a trend for decreasing rainfall in and around ANP.

Wetland vegetation

Wetlands where water was not extracted had the highest plant biodiversity. Malama wetland recorded the highest mean species diversity (1.57) and evenness (0.79), whereas Mweka where 100% of the water was extracted showed the lowest species diversity (1.11) and evenness (0.58). Ngongongare 1 wetland with complete water extraction recorded a smaller ($P < 0.05$) average FACW and OBL species richness, compared to the unextracted Malama wetland. The invasive *Ageratum conyzoides* was, on average, almost four times and 45 times more abundant in Mweka than in Ngongongare 1 and Ngongongare 3, respectively. This species was not observed in the Malama wetland.

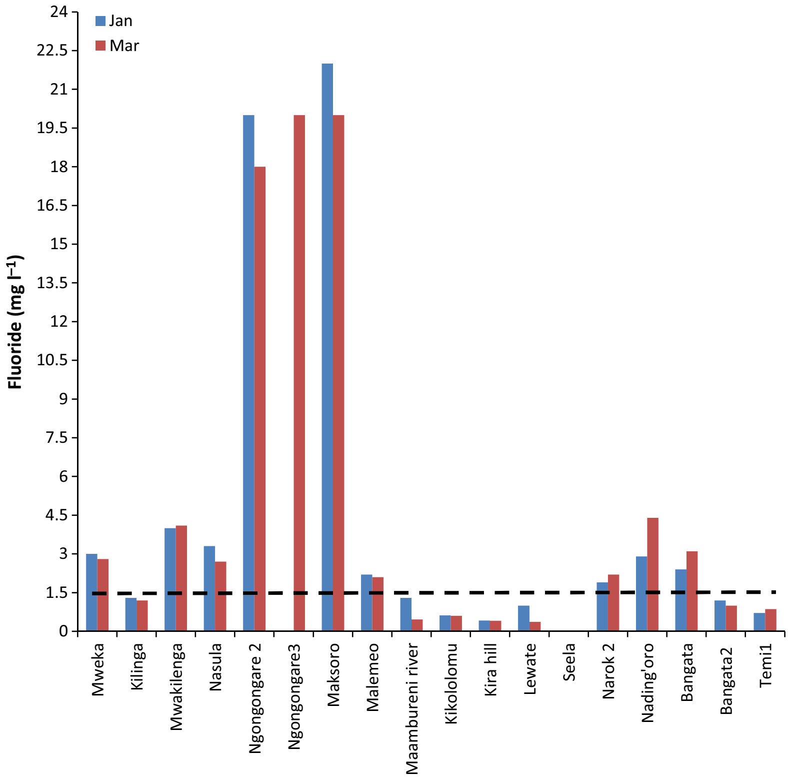

Fig 2 Fluoride concentration in the extracted sites in January and March 2013. The dashed line shows the WHO drinking water quality guideline

Mammal survey

The river systems varied in terms of both mammal abundance and differences across mammal groups between upstream and downstream of the abstraction points. Five of the seven transects had higher abundance upstream than downstream. Mwakilenga showed the largest difference, where upstream abundance was eleven times higher than downstream abundance. Malemeo and Kilinga also showed a strong difference in the same direction. In general, the number of individuals varied between the upstream and downstream sites, but with upstream recording a higher overall average abundance. There were also differences across different mammal groups (Table 1). Large herbivores (elephant, *Loxodonta africana*; buffalo, *Syncerus caffer*; giraffe, *Giraffa camelopardali*; waterbuck, *Kobus ellipsiprymnus ellipsiprymnus*; warthog, *Phacochoerus africanus;* and wild pig, *Potamochoeruslarvatus*) abundance upstream was higher than that downstream from extraction sites. Abundance of primates (black and white colobus monkeys, *Colobus guereza spp. caudatus*, and the blue monkey, *Cercopithecus mitis*) was also higher upstream than that downstream. In contrast, small herbivore (bushbuck, *Tragelaphusscriptus*; dik–dik, *Madoquakirkii*; and Harvey's red-duiker *Cephalophusharveyi*) abundance was not impacted by surface water availability (Table 1).

Differences between the groups of mammals suggest that species respond differently to extraction, and differences between transects in both habitat characteristics and the degree of extraction translated into differential impacts on animals. This same pattern is suggested by the linear model. The interaction between transect and extraction suggests that the impact of water extraction on animal abundance varied across transects (Table 2).

Discussion

Across transects, dissolved oxygen concentration was suitable for aquatic life as concentrations were above 5 mg/l, which is the threshold stress level (Hunt & Christiansen, 2000). As expected, salinity was highest in the dry season due to evaporation, but with only slight differences within sites. The comparatively higher levels of fluoride and salinity in the eastern and north-eastern parts of the park are explained by the interaction between the water and the fluoride-rich bedrock (Kilham & Hecky, 1973; Nanyaro, Aswathanarayana & Mungure, 1984;

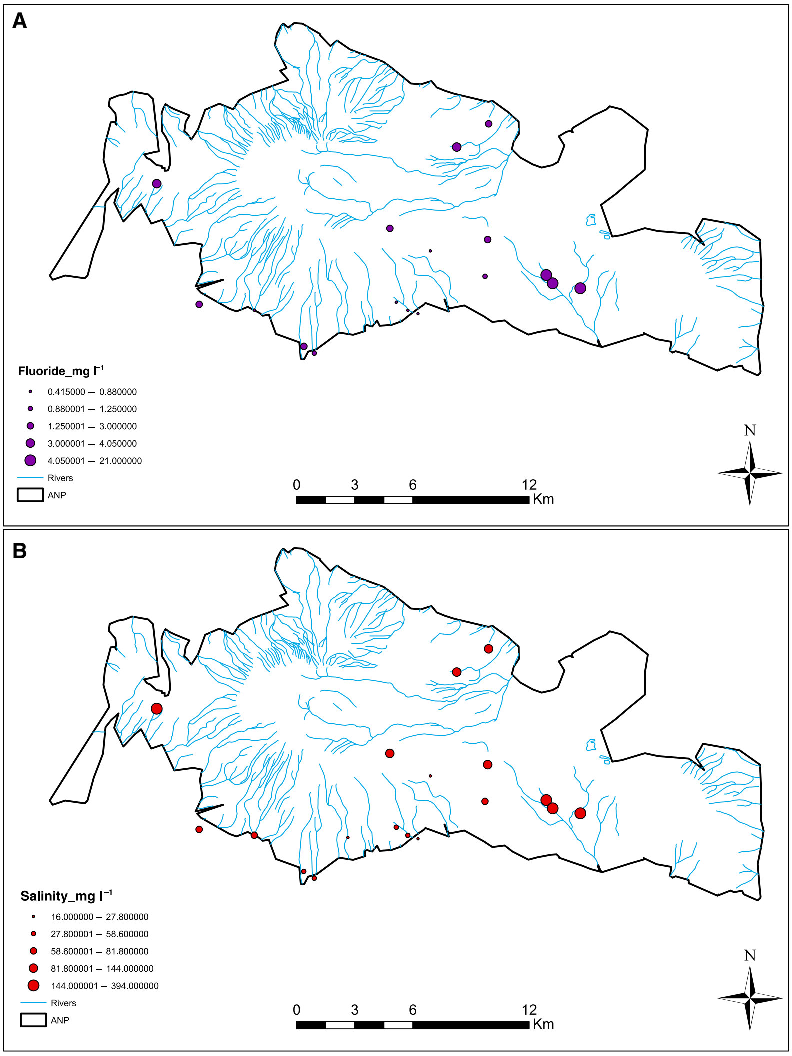

Fig 3 Map of spatial variation in concentration (mg/l) of (a) fluoride and (b) salinity in the rivers and streams of ANP

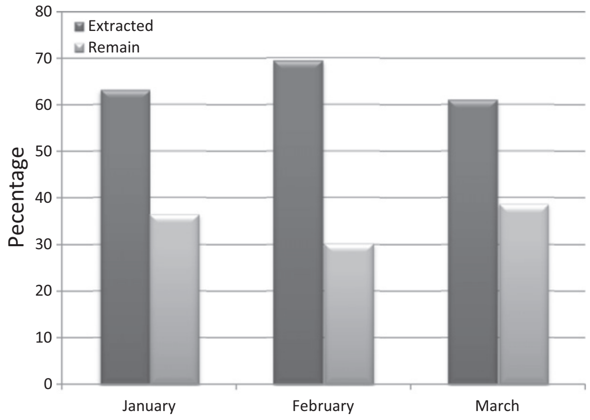

Fig 4 Water budget of the extracted water sources showing the percentage of water extracted from the park and that remains in the park

Ghiglieri *et al.*, 2011). Only about 40% of extracted sources are within the World Health Organization (WHO)'s fluoride limits for human drinking water (1.5 mg/l), and the others had unsuitably high levels, for example Ngongongare (8 to 22 mg/l).

Ninety-seven per cent of the surface water (except the Momella Lakes) had salinity levels <2000 ppm, and the remaining three per cent had salinity levels below 3000 ppm. This level of salinity is below safe upper limits for consumption by many domestic animals (Western Australian Agriculture Authority (WAAA), 2008). However, like domestic animals, wild terrestrial animals also have different tolerant levels to salinity. In South Africa, studies have shown that sheep can tolerate a salinity level of up to 10,000 ppm for a few months (Wolanski *et al.*,

Table 1 Binomial test results on average abundance by species category (excluding Ngongongare 1 and Ngongongare 3)

Species category	Upstream	Total	Binomial probability
Monkey	7	8	0.07
Large herbivores	11	13	0.02
Small herbivores	2	10	0.11

Table 2 Factors influencing the abundance of large herbivores upstream and downstream from water extraction points

	Wald chi-square	Numerator d.f. (denominator = 25)	Significance
Transect	107.267	6	$P < 0.001$
Upstream versus downstream	6.392	1	$P = 0.011$
Species category	348.757	11	$P < 0.001$
Transect × upstream/ downstream	42.871	6	$P < 0.001$

1999), whereas elephants in the Tarangire ecosystem in Tanzania may avoid water with salinity level higher than 2000 ppm, when there is alternative less saline water. In the Serengeti, excessive salinity (>5000 ppm) in the southern grasslands may trigger the annual mass migration of wildebeest towards the north where the water is less saline (Gereta *et al.*, 2004; Gereta, Mwangomo & Wolanski, 2009). There was no indication that extraction led to a marked deterioration in downstream water quality, and hence, water quality would not be a limiting factor to wildlife distribution in the ANP.

Under the current water extraction regime in ANP, about 70% of the surface water is abstracted for human use and thus about a third is available for downstream ecosystems during the dry season period of January and February. Almost 70% of the surface water sources subject to extraction were completely depleted in the dry season, leaving nothing for the downstream environment. Moreover, about 30% of the water courses were also subjected to complete abstraction in the first month of the wet season. This indicates the absence of controls on minimum environmental flow. In proportion to the total available water, the largest amount was extracted in February (69%), and the lowest (61%) in March, probably because people could supplement their requirements with rain water. Impacts of overextraction include the disconnection of streams, laterally and longitudinally, and hence isolation of the surrounding environment. The loss of biodiversity of wetland plants in turn reduces the food for herbivores and increases water loss through evaporation. Water abstraction, especially in the open riparian wetlands such as Mweka and Ngongongare1, was also associated with encroachment by *A. conyzoides*, which is probably more tolerant to dessication than native wetland flora (Gereta & Wolanski 1998; Government of Western Australia, 2000; Wolanski, 2012).

Arusha National Park is also subject to large interannual rainfall variability, and therefore, in drought years, water quantity is critical for people but quality is poorest because of less flushing and dilution (Gereta & Wolanski, 1998). Climate change does not seem to be resulting in a decrease in the annual rainfall but interannual rainfall variability is increasing both in ANP and elsewhere in East Africa (Wolanski, 2012). The current unsustainable water extraction practices in ANP may be exacerbated by this variability plus the rapidly growing human population. The adjacent Arumeru District has a population growth rate of 3.1% and a density of 228 inhabitants/km^2, which is almost five times higher than the national average (46 inhabitants/km^2) according to the 2002 National Census (Arumeru District Council, 2009). The River Ngarenanyuki, which originates from ANP but is not abstracted within the park, once flowed from Mount Meru north to the Amboseli Basin; however, as a result of high water demand for irrigation, it now extends about 30 km beyond the park boundary, which is 120 km less than previously. ANP is at risk of isolation following human encroachment on wildlife corridors (Istituto Oikos, 2011). The Kisimiri corridor remains the only reliable corridor connecting ANP to other protected areas (Natron Game controlled area, Enduimet Wildlife Management Area, Kilimanjaro and Amboseli National Parks). Such isolation may limit the accessibility by wild animals to water and other important resources located between and outside the two protected areas.

There was greater mammal abundance upstream of abstraction sites during the dry season, particularly of large herbivores. Such difference can be explained mainly by surface water availability as it was the key distinguishing environmental factor between the upstream and downstream transects. Other factors such as grazing cannot be ruled out but are not thought to play a leading role. In the dry season, surface water availability is the limiting factor guiding distribution, especially of large herbivores and water-dependent species (McNaughton & Georgiadis, 1986; Chamaillé-Jammes, Valeix & Fritz, 2007). The water-dependent buffalo usually spends most of the day resting and grazes during the night (Estes, 1992), and this probably explains why downstream counts that were made in the daytime were higher than upstream counts. Although water availability was the strongest factor influencing species distribution and abundance, the marked variation in abundance across species and transects might also be explained by intraspecific differences in habitat preference (Van wieren & Van langevelde, 2008). In this study, the small herbivores dik–dik, red-duiker and bushbuck seemed to be heavily influenced by habitat rather than by water and therefore were more abundant in dense and bushy downstream areas.

There was a significant difference in average OBL and FACW species richness between Ngongongare 1 and Malama. This observation clearly reflects the influence of water, with wetlands in unextracted and partially extracted sources recording higher OBL and FACW diversity as these plants prefer fully wetland conditions (Woldu, 2000; United States Department of Agriculture (USDA), 2012). Invasive species was another negative impact possibly due to water extraction. Invasive species (*A. conyzoides*) was abundant in Mweka and Ngongongare 1, but none in unextracted Malama, suggesting that its occurrence is closely related to water distribution (Government of Western Australia (GWA), 2000).

In conclusion, it is apparent from our study that excessive human extraction of water upstream of ANP results in the disconnection of streams laterally and longitudinally, disturbance to the natural distribution of wild mammals and a change in species diversity and composition of the riparian wetlands. If this practice is not to lead to the severe and perhaps irreversible decline in species diversity in ANP, then sustainable water abstraction practices must be introduced as a matter of urgency.

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