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Cascading implications of a single climate change event for fragile ecosystems on the Qinghai-Tibetan Plateau

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Abstract. With changing climates globally, we see changes in not just average conditions, but also in extreme events, and such events require special attention due to their unpredictable yet significant impact on native biotas. One such event is the formation of a landscape scar at Zonag Lake caused by a climate change-induced outburst flooding event that occurred on 15 September 2011. During the winter, the scar region became a new birthplace for sandstorms, and since the flooding, remote sensing monitoring shows that between 2011 and 2020, there were 285 sandstorm days (between November and March), relative to none prior. The outburst flooding event and consequential sandstorms threaten the key lambing area of the Tibetan antelope (Chiru), affect the water balance of the Zonag Lake and downstream lakes, and may even impact on the flow in the Yangtze River. Active human intervention may be needed to repair this new desert spit and reverse the slew of consequences which may otherwise lead to significant population declines in one of the major Chiru breeding grounds due to the progressive loss of vegetation productivity across their main breeding area.

Key words: climate change; lake outburst flood; remote sensing; sandstorm; Tibetan antelope.

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INTRODUCTION

Climate change can have a multitude of very different impacts, from systemic changes in temperature and regional changes in precipitation patterns, to a slew of changes in the patterns and intensity of other climate-related events. The impact and speed of these climatic changes and their consequences can also vary dramatically depending upon the system and region, as can their implications for native biodiversity, and traditional approaches to mitigate or adapt to climate change are unsuitable for many of these more extreme climate change consequences. The Qinghai-Tibetan plateau represents an eco-fragile area of extraordinary value for biodiversity, and thus, small changes in climate may have dramatic consequences for ecosystem functioning and the native biota; therefore, any extreme climate events and probable cascading consequences of such events should be comprehensibly evaluated to facilitate adaptive management for the less foreseeable consequences of climate change.

Extreme climatic events can have a disproportionate impact on species which aggregate in large numbers, for example, Australian heatwaves have caused major die-offs of flying foxes

(Welbergen et al. 2008). When these species also utilize small numbers of areas for a part or all of their lifecycle, then such stochastic events can have a disproportionate effect on the population of a species and its prospects of future survival. Typically, island populations are regarded as most vulnerable to single extreme events such as typhoons that have the potential to wipe out entire populations, with a reduced probability of recolonization and increased extinction risk for species endemic to a limited number of islands (i.e., Robertson 1992). These examples show that any population or species dependent on a spatially limited resource may be especially vulnerable to changes that impact on that region as they are likely to be unable to shift their ranges or dependence on that resource even if the availability of key resources changes.

Such unpredicted climate-related events can trigger a more complex cascade of events which are less easy to predict, and yet nevertheless can represent a significant risk to species in eco-fragile regions with restricted ranges or habits during part or all of the year.

Such events are likely to become increasingly common under future climate change (Cai et al. 2014, 2015); thus, understanding the complexity of climate-related consequences that can ensue from such events is essential in trying to develop strategies to mitigate such events. No species experiences mean climate and ecophysiologically it is extreme conditions, and of course extreme events which are biologically most significant. Yet, most global analyses still largely focus on mean trends, and a greater appreciation of the diversity of different climate change-related events and their consequences is urgently needed (Vasseur et al. 2014).

Here, we describe one such event, where climate change induced a flood event, driving the desertification for part of one of the three main breeding areas for the Chiru, and driving the occurrence of large numbers of sandstorms which in turn may further submerge key breeding and foraging areas in the sand. We highlight the importance of understanding the complexity of climate-related events and their implications for the survival of species like the Chiru and suggest mechanisms to respond to the event to minimize its impacts on the Tibetan antelope. Species like the Chiru with small ranges for all or part of the year may be particularly vulnerable to chance events or extreme climate conditions, especially if areas for key behaviors such as breeding are impacted, and thus, the role of these climate events in defining species ranges and survival may be key to the conservation of species in such eco-fragile areas; thus, greater understanding is needed into the potential of such events to impact on populations. The flood event in this study triggered a chain of other unforeseeable ecosystemic changes, with potentially devastating consequences to the Chiru. In order to reduce or eliminate these impacts, the broader implications of different aspects of climatic change need to be considered, and a more multifaceted and holistic response is needed.

Study area and situation

Zonag (Zhuonai) Lake is located in the north of Qinghai Hoh Xil. This region is the key lambing area of the tens of thousands of Chiru (*Pantholops hodgsonii*) and is consequently known as "the big delivery room" as it represents the main breeding area for the Chiru (Zhang et al. 2017) and marks the end of their 300-km migration (Manayeva et al. 2017). Every year as the birthing season reaches its peak, tens of thousands of pregnant Tibetan antelopes from TRHR (Three-River Headwaters Region), Qiangtang Plateau of Tibet, and Hoh Xil gather around Zonag Lake (Fig. 1). In 2017, Qinghai Hoh Xil was included on the World Heritage List due to its unique biodiversity and environmental conditions.

Since the early 1980s, the Qinghai-Tibetan Plateau has experienced escalating warming and wetting weather trend (Yang et al. 2014). The significant increase in precipitation and associated runoff has been identified as the major reason for lake expansion across the plateau (Lei and Yang 2017). The average annual precipitation of Hoh Xil in 1961–2014 was 301.5 mm, with an average increase of 20.7 mm per ten years across this period. The annual precipitation in 2011 was 367.4 mm, which is more than 20% above the annual average for the years 1981–2010 (Liu et al. 2016*a*).

On 15 September 2011, after 2 months of continuous rainfall, an outburst event occurred in the moraine-dammed Zonag Lake. A large amount of water discharged from Zonag Lake flowed eastward, through the Kusai and

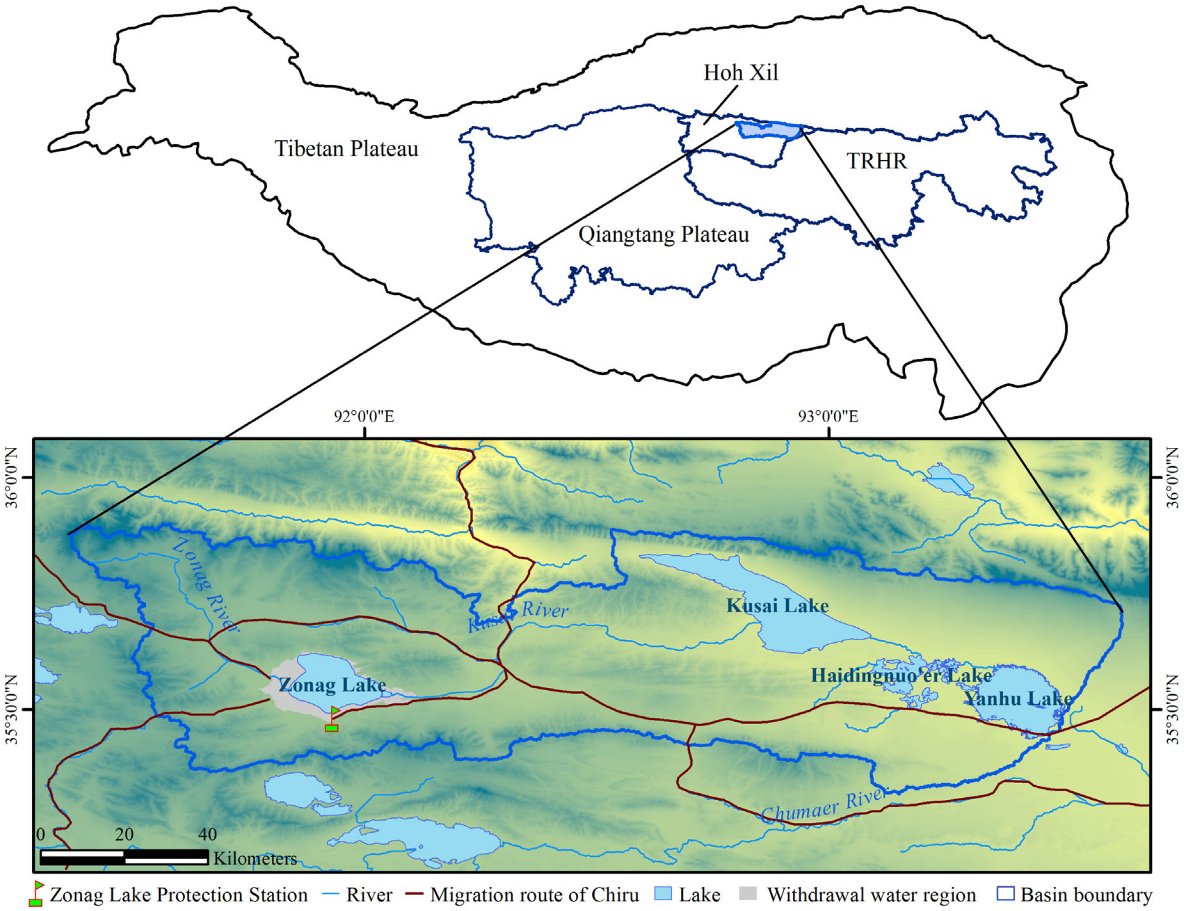


Fig. 1. The location of Zonag Lake and the downstream lakes. The migration route of Tibetan antelope (Chiru) is redrawn according to the paper map of the Hoh Xil National Nature Reserve. Zonag Lake Protection Station is a temporary shelter for wildlife and ecological environment protection especially for the Tibetan antelope.

Haidingnuoer Lakes, eventually flowing into Salt Lake (Fig. 1). This resulted in an expansion of the three lakes and led to a significant modification in the western, southern, and eastern shorelines of the Zonag Lake (Liu et al. 2016*b*, 2019). The retreat of the lake's water resulted not only in a large increase in the distance for the antelopes' access to lake water, but the creation of a new dry sand-filled river bed is caused by the erosion and affected the migratory path of the Tibetan antelope from the TRHR to the southern shore of Zonag Lake (Liu et al. 2016*a*, Pei et al. 2019). The development of this split was observed to cause changes in the sandstorm frequency and area of the lake, thus to impact on species access to food and water resources at a critical part of their annual activity cycle. Here, we examine the impacts of the spit on regional sandstorm frequency, the patterns of vegetation growth (to assay food availability), and ranging and populations of the Chiru to understand how events like these can impact on survival, and how we can develop pragmatic solutions to identify and counter such challenges to species viability.

In order to analyze the spatial impact of the development of the spit on the landscape of the region, field survey and satellite remote sensing data were used. The field survey data include the spatial location and land-cover-type information of survey sites.

ANALYSIS AND METHODS

Data

The satellite remote sensing data include 250 m MODIS (moderate resolution imaging spectroradiometer) TERRA and AQUA (originally known as EOS AM-1 and EOS PM-1) surface reflectance daily images obtained from 1 November 2011 to 31 December 2020; 250 m 16-day MODIS MOD13Q1 V6 vegetation indices product (the data of May 1–September 30 each year was used) during the period of 2000–2019; 30 m Landsat TM5 images (Row: 138, Path: 35) acquired on 24 January 2011 and 8 November 2011, 30 m Landsat 8 images (Row: 138, Path: 35) acquired on 11 January 2018, 12 February 2018, and 26 October 2018. Furthermore, continuous location tracking data in the lambing season (May 1–July 31) of 2 female antelope were used. A total of 70 valid data (the data are continuously received) across this time were used, with 36 and 34 before and after the outburst event, respectively. They were collected using Argos satellite transmitters between 2006 and 2014 (Xu et al. 2019).

Lake water boundary extraction

To map lake area and lake area changes from the Landsat imagery, based on the principle that the reflection of water gradually weakens from visible to short-wave infrared band, and the absorption is strongest in the near-infrared and short-wave infrared wavelength range, the modified normalized difference water index (MNDWI) was generated to enhance water features (Xu 2006*a*):

$$\mathrm{MNDWI} = \frac{\mathrm{Green} - \mathrm{SWIR}}{\mathrm{Green} + \mathrm{SWIR}}$$

where Green is the green band of Landsat TM5 band 2 and Landsat 8 band 3, SWIR is the short-wave infrared band of Landsat TM5 band 5 and Landsat 8 band 6. In this index, the regions with value larger than 0 are recognized as water. Then, the lake water boundary was extracted with 0 as the segmentation threshold.

Sandstorm identification and impact area estimation

In the MODIS true color reflectance imagery, if the lakeshore, lake surface, and adjacent areas of the lake are surrounded by dust, it means a sandstorm is occurring in the region during the satellite transit. In the study, all the MODIS images each year were visually interpreted, and the sandstorm days were identified and labeled based on the above rules.

In addition, in order to visually depict the impact area of sandstorms, the outer boundaries of each sandstorm are extracted manually, and the maximum impact area, the core impact area, and the main impact area are estimated by spatial superposition of all the sandstorm boundaries.

Population estimation

The affected distribution and density of Chiru across the area were quantitatively estimated by local patrols and complemented by position tracking data from Argos satellite. The directional distribution (standard deviational ellipse) and mean center were calculated with the position data before and after the outburst event, by using the Spatial Statistics Tools of ArcGIS Desktop 10.7.

Estimates from the local patrols who undertake monthly transects across the breeding ground were used. The patrols transverse the south bank of the lake where populations typically breed and assay how density and population vary between patrols. Patrols also occasionally cover other areas at greater distances from these core zones, to identify any changes in overall distribution that may have occurred. The main ranger station (protection station) is also located on the south bank (zone E), providing representative insights into herd health and behavior, in addition to obtaining an overview into overall herd distribution on traveling to or from the station. Different patrols were individually interviewed to assay any trends in population over the period and found to be consistent across all patrols interviewed. Though these methods are not totally standardized, the study is an opportunistic assessment of the impact of a natural event, and thus, these patrols are conducted only to assay population status and ensure nothing averse is happening in the reserve. Given that climate events like these are unpredictable, we have to make the best use of what data are available, in this case, the assessments of experienced rangers who have observed these populations over the course of many years. Thus, while less precise than standardized scientific surveys, such assessments are no less valuable, and the consistency between several independent interviews shows the assessments to be indicative of genuine change.

Vegetation change identification

The average annual maximum NDVI (normalized difference vegetation index) of the area affected by sandstorms (the core area, the major area surrounding it, and the whole basin) was calculated with the Google Earth Engine API (an application program interface; Gorelick et al. 2017). The annual NDVI of 2000–2019 was then mapped to better understand how the vegetation had changed over time.

RESULTS

Lake water area change

Based on the water boundary extraction results from the Landsat TM5 remote sensing images, the lake water area in Zonag Lake shrank by 39% (103 km^2) from 267 km^2 on 24 January 2011 to 164 km^2 on 8 November 2011. After the outburst, the major lambing area of Tibetan antelopes on the western lakeshore suddenly increased in distance to 3.6 km away from the water edge (Fig. 2). In actual fact, this research was initiated following the observation of a striking change in the area of Zonag Lake within a program monitoring changes in lake size in all lakes across the plateau.

A derived geological disaster: sandstorms

Following the withdrawal of water in the spit, the area became desertified, and in the winter, it became a generator for huge sandstorms; this has rapidly evolved into the greatest ecological problem of the region and repeats each spring. On 21 December 2011, the first post-flooding sandstorm occurred, covering almost the entire Zonag Lake region, then spreading to the eastern region of the Salt Lake, around 160 km away from the newly formed dry riverbed (Fig. 3). According to the daily MODIS remote sensing data, there were 285 sandstorm days during the period from November to March each year from 2011 to 2020 (Fig. 4), whereas before the event no sandstorms were recorded or detected by remote sensing for the region. Though 32 sandstorms annually may seem low, these are completely novel to the region and amount to 285 since the spit was formed, and can impact hundreds of kilometers in a single event, thus having a permanent impact on a huge area (Fig. 3), including key lambing area for the Chiru. The maximum boundary range affected by all the sandstorms is around 10,000 km^2 (red dotted line surrounded region in Fig. 3), and the area with a high risk of sand accumulation is around 422 km^2 (red solid line surrounded and yellow dotted region in Fig. 3). In the south of this high-risk region (Zone E in Fig. 2), population estimates from patrols stated that Chiru populations had declined around 30% since 2016. Spatial statistics show that the south of lake and riverbank, the Chiru's activity range (directional distribution) migrated significantly to the east and downstream, with area reduced to 357 km^2 from 429 km^2. The westernmost point, the mean activity center, and the easternmost point shifted about 6, 12, and 11 km east, respectively (Fig. 5).

The response of the vegetation growth

Between 2000 and 2010, the NDVI was mapped over three regions of the core area, the major area, and the whole basin (Fig. 3) increased significantly, then from 2011 to 2015, the NDVI of the 3 regions decreases, with the most abrupt decrease in the core area region. In the period of 2015–2019, after increasing for a short period, the NDVI of the three regions began to decline again. (Fig. 6). The intersection point between the core area and the major area NDVI curves in 2012 and intersection point between the core area curve and whole basin NDVI curves in 2017 show the continuing degradation and reduction in vegetation growth in the core area affected by sandstorm. The multiyear (2000–2010) average NDVI in the core region (0.2121) is greater than the major area (0.1991) and the whole basin (0.1803) before 2011, but after that, the multiyear (2012–2019) average NDVI of the core region (0.2073) is lower than the major area (0.22) and the whole basin (0.1997). That means the NDVI in the core area has ended its growth and started to decline. Furthermore, in 2018 and 2019, the average NDVI of the core area is lower than the whole basin,

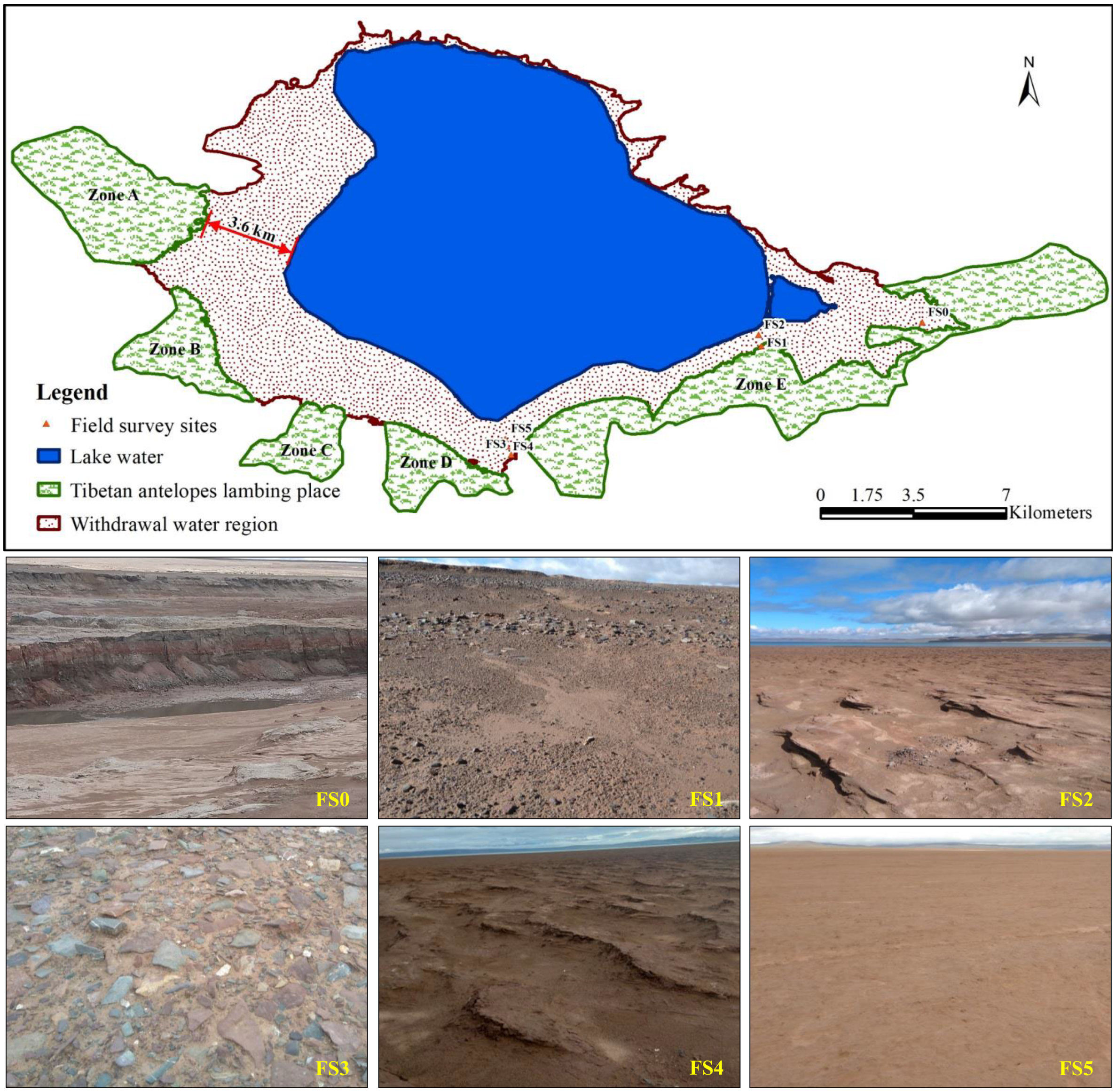


Fig. 2. Lake water withdrawal and the Tibetan antelopes lambing area after the Zonag Lake outburst flooding. FS0 is the Levee break point; FS1 and FS3 are near-shore retreating area; FS2 and FS4 are retreating area with severe wind erosion; and FS5 is the bare and flat original lake bed. The photographs are taken on 27 June 2018 during the field survey.

and the major area may show the same trend, at a slower rate.

Discussion

Climate and species-level impacts

Here, we showcase how a climate change-induced lake outburst created a new sandstorm source region, setting off a chain of other events and potentially devastating implications for local ecosystems and the main breeding ground of the Chiru. From other studies, it has been well established that beyond a certain threshold of degradation or land exposure, sandstorms increase significantly, for example, increasing 60% once 30% of a region was desertified (Xu 2006*b*). The

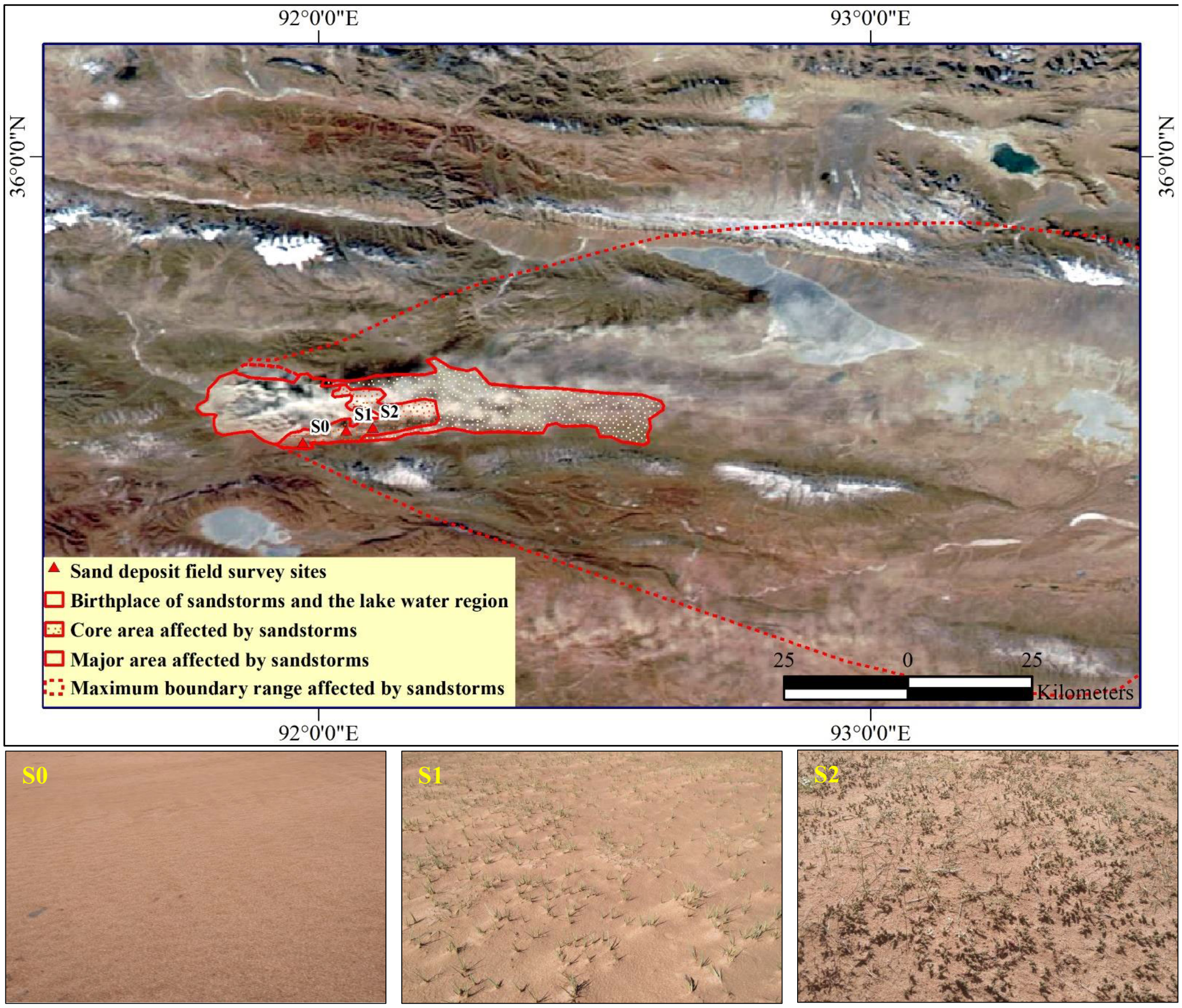
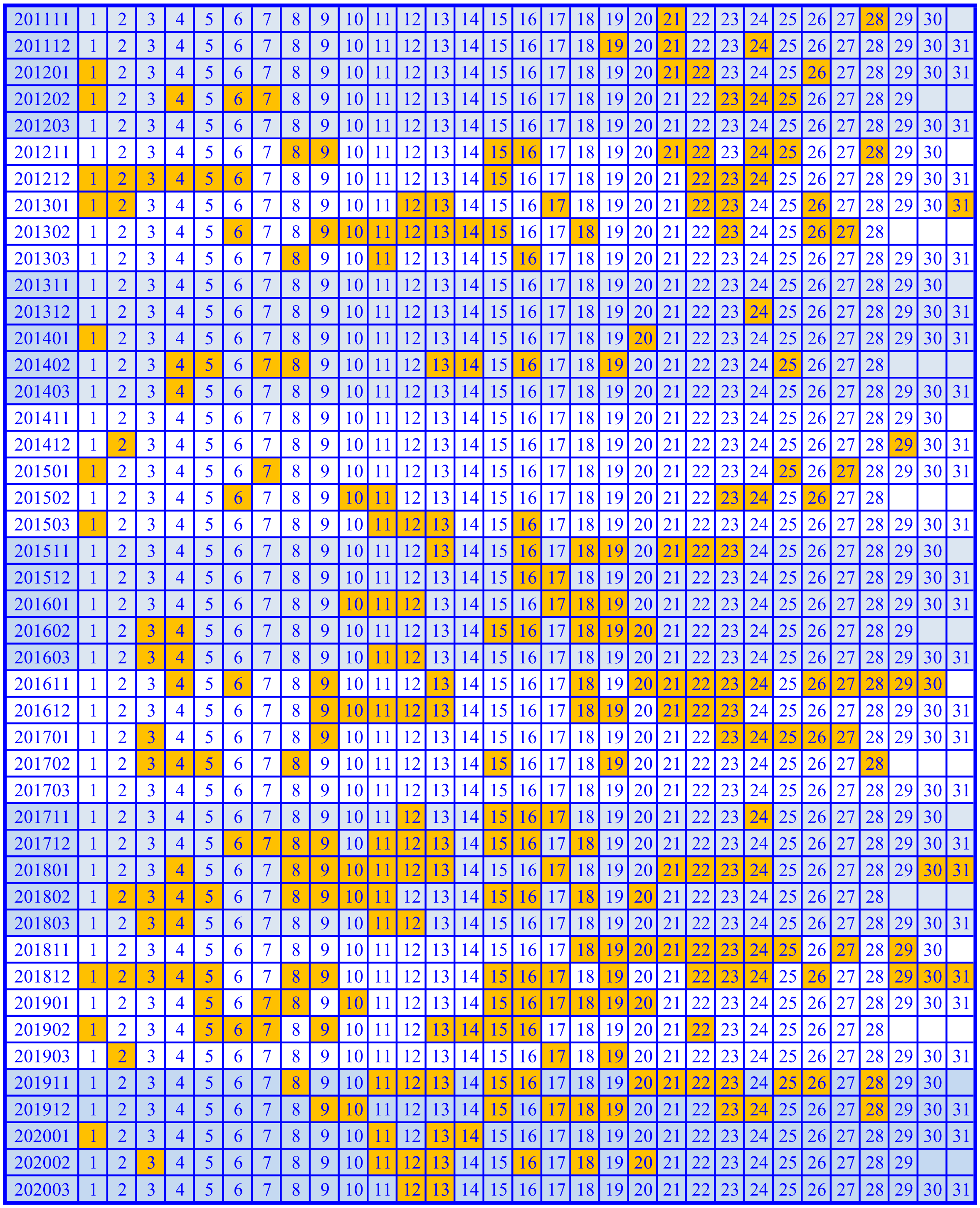


Fig. 3. The sandstorms affected area overlapping on the MODIS AQUA image with a huge sandstorm obtained on 21 December 2011. The red solid line surrounded area is the birthplace of sandstorms and the lake water region, the red solid line surrounded and red dotted region is the core area affected by sandstorms, the red solid line surrounded and yellow dotted region is the major area affected by sandstorms, and the red dotted line area is the maximum boundary range affected by sandstorms. They were acquired by superposing sandstorms moving paths at different times. S0 is the wind-driven sand deposited near the original lake bank, and S1 and S2 are the meadow heavily buried by deposited sand in different places. They were taken during field survey on 27 June 2018.

increase in such sand and duststorms has been directly linked to human activities (Sheng et al. 2003) and has previously been recorded to dramatically alter landscapes including the desiccation, shrinking, and disappearance of lakes in other parts of China (Chen et al. 1999, Bagan et al. 2010).

This is not the first time a single climatic event on the plateau has caused significant mortality to the Chiru (Schaller and Junrang 1988). In 1985, an intense snowstorm buried large areas of Chiru grazing habitat in snow, forcing Chiru to dig to obtain the grasses they rely upon and causing a significant number of animals to die due to malnutrition. If a single snowfall in a nonbreeding area for under one month can cause mortality, than other similar events such as sandstorms which also reduce the available grazing area may



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201903	1	**2**	3	4	5	6	7	8	9	10	11	12	13	14	15	16	**17**	18	**19**	20	21	22	23	24	25	26	27	28	29	30	31
201911	1	2	3	4	5	6	7	**8**	9	10	**11**	**12**	**13**	14	**15**	**16**	17	18	19	**20**	**21**	**22**	**23**	24	**25**	**26**	27	**28**	29	30	
201912	1	2	3	4	5	6	7	8	**9**	**10**	11	12	13	14	**15**	16	**17**	**18**	**19**	20	21	22	**23**	**24**	25	26	27	**28**	29	30	31
202001	**1**	2	3	4	5	6	7	8	9	10	**11**	12	**13**	**14**	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
202002	1	2	**3**	4	5	6	7	8	9	10	**11**	**12**	**13**	14	15	**16**	17	**18**	19	**20**	21	22	23	24	25	26	27	28	29		
202003	1	2	3	4	5	6	7	8	9	10	11	**12**	**13**	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Fig. 4. The sandstorm days (yellow highlighted) in winter of each year from 2011 to 2020.

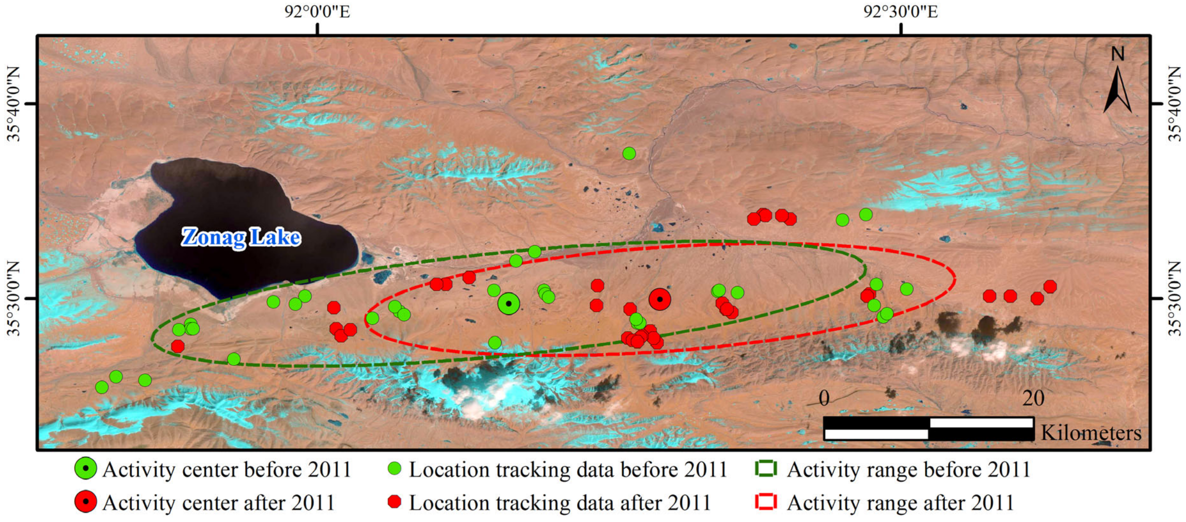

Fig. 5. Activity range of Chiru mapped with satellite tracking data. The background is Landsat 8 image obtained on 26 October 2018.

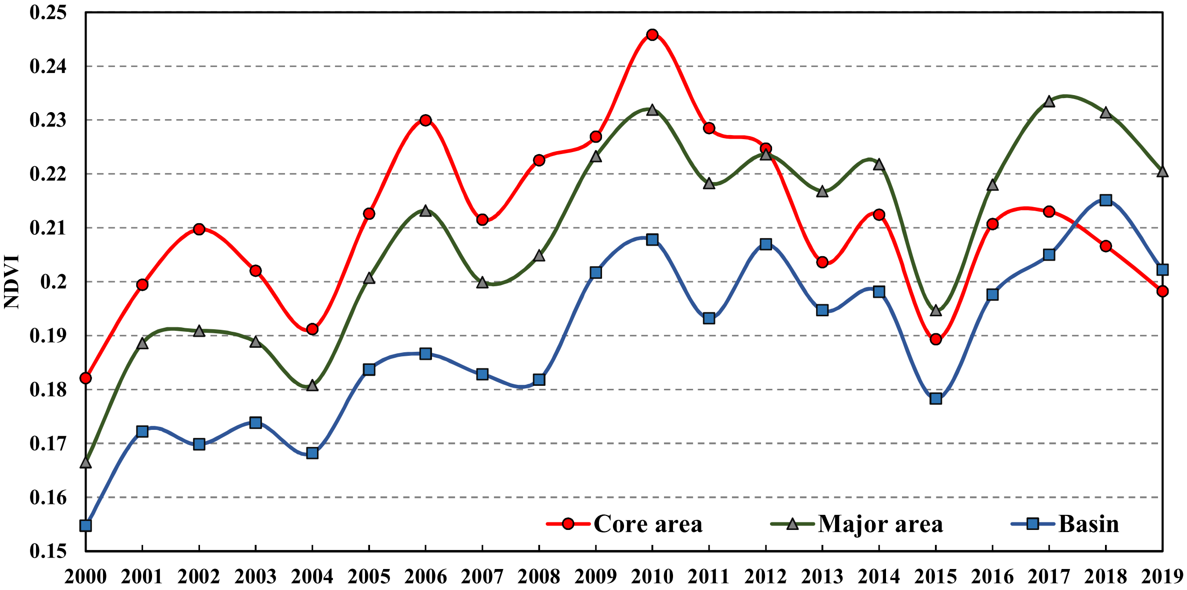

Fig. 6. Changes in vegetation growth in the core area and major area affected by sandstorms and overall the basin between 2000 and 2019.

be expected to have an even greater impact, especially as Zonag Lake is one of only three key breeding areas for the Chiru and is genetically distinct, and the species has a limited and specialized diet (Sun et al. 2014). As a consequence of these reductions in grazing land, the number of Chiru coming to the south bank and east of the estuary region (Zone E in Fig. 2) has decreased by about 30% since 2016. The main activity region of them in lambing season has moved far away from the Zonag Lake for about 12 km in the eastern direction, which when combined with the NDVI information shows they moved to less optimal areas. As this population has been separated from other populations for a significant period, this may either mark a major population decline or a shift to more marginal areas for grazing, though such a suggestion is not upheld by the observation of local rangers. As a consequence, this lambing area may in time disappear, considerably reducing the genetic diversity and total population of Chiru, as this is one of only three breeding areas (Nima and Gama, *personal communication*). The area impacted by sandstorms shows a progressive decrease in NDVI at a greater rate than the area overall, and thus, the suitability of the area for grazing is also likely to be unable to support breeding populations of Chiru into the future.

One event and a cascade of consequences

As no quantified observation data on lake depth variation and the sand movement yet exist, it is not yet possible to accurately quantify the future trend of the changes on the abovementioned assumptions and surveys, though evidence suggests that continuation of these trends will significantly impact on native ecosystems. Based on consistent monitoring with satellite remote sensing over the past 9 yr, it seems highly improbable that the scar will disappear naturally, and rather it may extend its impact through inundating the area with sand. Therefore, to prevent further degradation and possibly start a long-term remediation process, it is crucial to carry out long-term in situ observation of meteorological, hydrological, biological, and sandstorm dynamic processes in the region.

Sandstorms carry sand from the banks to the ice-covered lakes which will eventually fall on the lake bed decreasing the depth and further accelerating the volume of discharge (Fig. 7). If this process continues, it could lead to the continuous rise in water levels and the possible breakup downstream of the Salt Lake, which would change and stretch the northernmost source of the Yangtze River (Yao et al. 2016, Liu et al. 2019). These sandstorms will eventually bury the grassland under the sand which may drive further desertification, as has already occurred in a part of the area (Figs. 3, 5). Based on the spatial superposition analysis results of all sandstorm events in the study area and the field survey on 27 June 2018, obvious sand accumulation is forming within the area of 134 km^2 near the lake outlet (red solid line surrounded and red dotted region in Fig. 3), obliterating important grazing lands for Chiru and other species. The consequences have in fact been so severe that patrol officers believe the negative impact of sand cover on grassland in recent years has exceeded the population increases which resulted from grazing policy regulations in previous years (Nima and Gama, *personal communication*). Though exact estimates of population are almost impossible, as though many studies have examined the Chiru, impacts of events such as the construction of the railway, and underpasses on their population (Xia et al. 2007, Lin, 2014, Leclerc et al. 2015, Xu et al. 2019, Shi et al. 2020), none of these have accurate numbers of each of the Chiru populations. The closest estimate for the population of Hoh Xil is 60,000 (https://cases.open.ubc.ca/an-assessment-of-the-environmental-and-social-processes-in-the-protection-of-the-tibetan-antelope-pantholops-hodgsonii-in-hoh-xil-national-nature-reserve-tibetan-autonomous-region-china/), but no older estimates of the population exist in the literature. Thus, we had to rely on the evidence provided by experienced rangers who have monitored these populations over multiple years to provide a relative estimate of population changes based on the distribution and density of Chiru encountered during routine patrols. The driver of these declines, given that no such declines were observed from railway construction or highway development (Xu et al. 2019) and given that Argos notes a change in the center of distribution to a less sandstorm-impacted region, indicates that observed declines are a direct response to these sandstorms.

Previous research proved that the Chiru choose Zonag Lake for major lambing areas related to the regional high-altitude habitats with the highest year-around NDVI values and the summer peak of primary productivity (Sumiya et al. 2011). The regional NDVI reflected vegetation growth condition shows a change in the vegetation present across the area over time, and decreases in vegetation cover are greatest within the area impacted by sandstorms and suggest that they may provide insufficient resources to support breeding populations of Chiru into the future.

Though more field data are needed to establish the impact of this, former surveys found almost

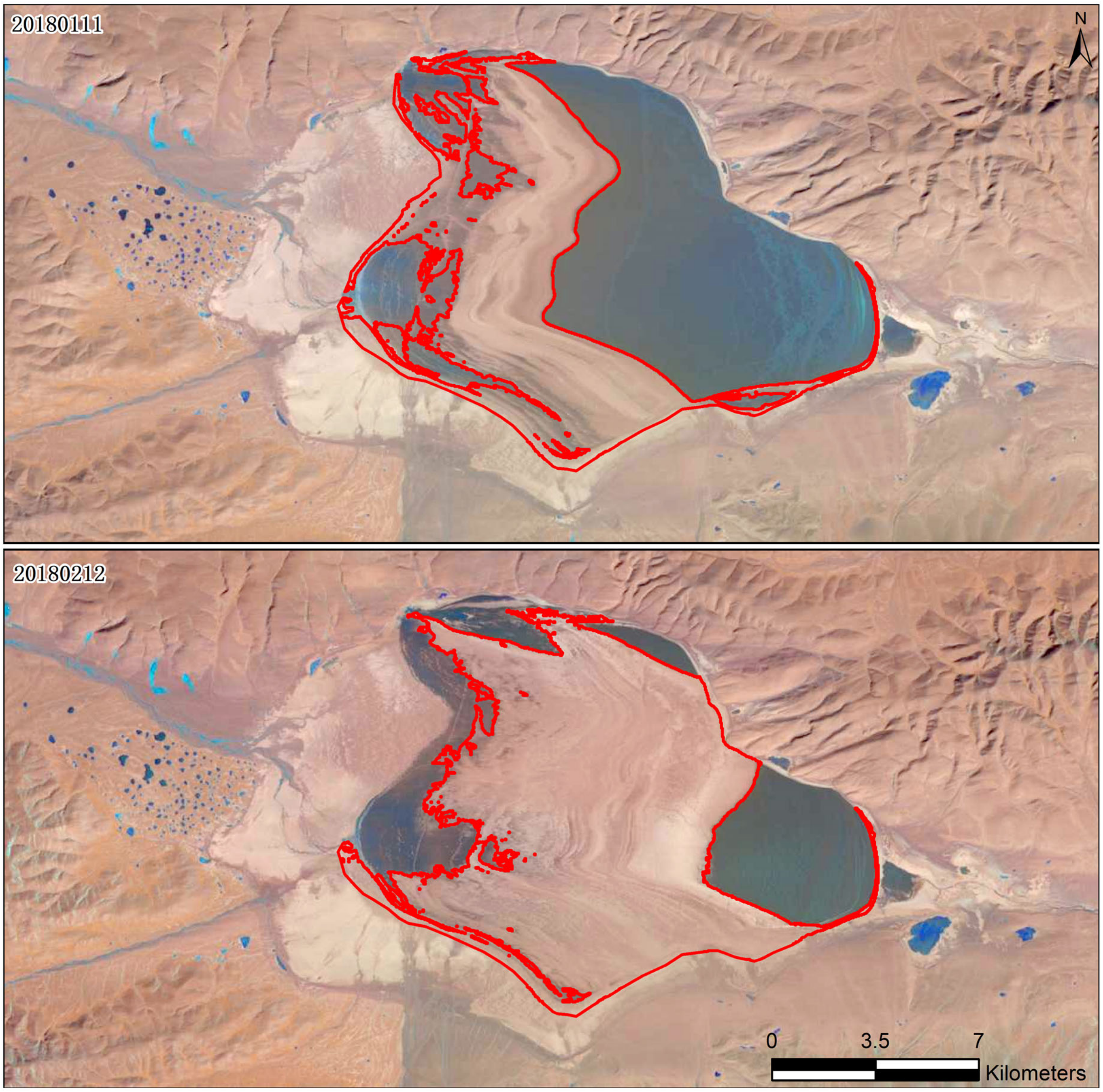

Fig. 7. Sand-covered lake ice (outlined in red) 11 January 2018 and 12 February 2018. Pictures are Landsat 8 satellite images.

6000 Chiru in this area, making it an area of undisputable importance (Schaller et al. 2007), and these areas are the center of breeding for the Chiru (Manayeva et al. 2017). Furthermore, though there are three major breeding areas for the Chiru, recent analysis shows there has been no exchange between the three regions for over 60,000 yr, so population declines in one of these areas have a significant probability of reducing the genetic diversity of the species and thus also have implications for the adaptability and survival of the Chiru under future change (Chen et al. 2018).

Managing the implications of climate change on wildlife populations

This study provides an example of how singular climate change events can have lasting impacts on ecosystems, and yet, as few such studies exist, it is impossible to calculate the impact of such changes of frequently understudied ecosystems. Here, we clearly demonstrate how the creation of a small desert resulting from a single lake outburst has induced over 285 sandstorms and presents a threat to biodiversity such as the Chiru in this unique and eco-fragile region, and that active intervention may be needed to ensure dramatic declines in species dependent on these regions do not occur. This region is the major breeding ground for the Chiru, yet its inaccessibility means that no studies of the impact of these phenomena have been conducted but it undoubtedly represents a significant threat. Studies on other similar regions strongly advocate restoration, revegetation, and shelterbelts as the only mechanisms to prevent increased desertification as a consequence of increasing sandstorms (Sivakumar 2005, Gaoming 2008) and that such mechanisms are likely to be crucial to recovery.

With increasing changes in climate, including an increased frequency of extreme and unusual events, finding ways to manage the impact of such events may prove critical to the continued retention of biodiversity in certain ecosystems, especially in eco-fragile regions. Novel approaches will need to be considered to respond to such changes, including top-down protocols to ensure funding is available to develop the necessary interventions to counter the long-term implications of climate-induced environmental problems.

In this example in order to avoid irreversible degradation, front-line protectors firmly believe that effective human intervention must be taken as soon as possible. Without the effective and efficient implementation of such approaches, the Tibetan antelope may abandon this lambing area, and other suitable areas are highly unlikely to exist for this population. Furthermore, these sandstorms may threaten the entire TRHR and the services (i.e., water provision) which the area is responsible for. In this case, ecologically sound interventions such as aircraft sowing of drought-resistant vegetation within the spit or straw checkerboard barriers (Lü et al. 2016, Kang et al. 2017) should be carefully explored. In addition, fixed or mobile observation equipment, such as video and infrared cameras, should be built in the lambing area to accurately monitor and assess changes in the number and migration habits of Tibetan antelopes.

Here, we outline one example of how a single climate event can set in motion a chain of environmental issues, which without active intervention are likely to cause permanent and potentially devastating implications for an ecosystem and species like the Chiru which depend upon it. Deciding on approaches that facilitate and prioritize proactive strategies to counter the impact of such extreme events is something which has been left out of dialogues on discussions of climate change, yet such structures and systems may be crucial for the long-term conservation of eco-fragile regions globally. We can suggest potential solutions to mitigate the impacts of this climate event on the endangered Chiru through strategies to halt or reverse further desertification in a key breeding area, by restoring and revegetating the spit to prevent further desertification and prevent sandstorms and associated submersion of grazing areas with sand. However, further policies and mechanisms are needed to leverage funding and allow for rapid action and intervention following from single climate events where, like here, they show the potential to have profound and lasting impacts on native ecosystems.

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