Chapter 10
Dryland Social-Ecological Systems in Americas

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Abstract American drylands account for circa 20% of the global drylands and form a critical part of the global ecosystems. This study comprehensively assessed the ecology and socio-economic status of American drylands by analyzing original and published data. The research findings reveal that North and South American drylands have more differences than commonness. In terms of commonness, both North and South American drylands have higher productivity and soil fertility than other drylands of the globe. Under this high ecosystem productivity context, North American drylands are the high agricultural productivity regions and South America is the largest beef exporter in the world. There are several aspects of differences between North and South American drylands. North American drylands possess an ecosystem productivity twice that of South American drylands. Precipitation has significantly decreased in North America drylands, while South American drylands have become wetting over the past three decades. Population in both North and South American drylands have increased. Vegetation coverage trends exhibit a weak rising trend in South America, while North America drylands have become significantly greener, mainly due to croplands irrigation. The driving forces on land use change and ecosystem productivity in North American drylands comprise a variety of factors, while those on South American drylands are relatively simpler, mostly caused by one driving agent. In dealing with the dual pressures of climate change and socio-economic developments, countries in both North and South America have implemented a series of drylands ecosystem protection measures, such as setting national park and conservation agriculture. These efficient and successful experiences can be examples for other dryland ecosystem protection around the world.

Keywords Drylands · North America · South America · Climate change · Socio-economic developments

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10.1 Introduction

North and South America are called America in combination, and they are two separate continents in the Western Hemisphere. The two continents are under the umbrella of totally different climates. For North America, climates transit from the prevailed subarctic climate in the North to the tropical climate in the south, sequentially harboring arctic, subarctic and tundra, desert and semiarid, savanna, and tropical rain forest ecosystems along the climate gradient. Among them, the arid and semi-arid climates are prevailed in the interior regions, where rain-bearing westerly winds are obstructed by Rocky Mountains. The wide variety of climates breeds diverse vegetation, including conifer taiga forests of Canada, Pinus ponderosa and Pinus edulis dominated ecosystem in Colorado plateau and Canyon-lands regions, and grasslands in great plains. Shrubs, like Artemisia tridentate and Cercocarpus montanus, are extensively grown in open spaces between trees.

For South America, the climate transits gradually from tropical in the north to marine in the South. Fed by adequate rainfall, the Amazon River basin accommodates the most extensive tropical rainforest in the world. On the other hand, moistures carried by the westerly winds mostly precipitate on the west side of the Andes and leaves its eastern part extremely dry. The cold Peru Current also causes northern Chile dry. Typical dryland forests are mainly located in the Gran Chaco, primarily composed of Maranhão Babacu and Caatinga.

10.2 Major Characteristics of Drylands in the Region

10.2.1 Dryland Distribution

Drylands occupy approximately 30% of American continents and American drylands account for circa 20% of the global drylands. They stretch from central Canada to the central and western parts of the United States, the entire northern half of Mexico, parts of the Caribbean, the Pacific coast and southern parts of South America (Fig. 10.1). According to the definition of the United Nations Convention to Combat Desertification (UNCCD), the aridity index (AI), calculated by P/PET (P annual precipitation, PET annual potential evapotranspiration), define drylands as regions with AI < 0.65. The AI also classifies drylands into four different types, e.g., dry subhumid ($0.5 \leq \text{AI} < 0.65$), semi-arid ($0.2 \leq \text{AI} < 0.5$), arid ($0.05 \leq \text{AI} < 0.2$) and hyper-arid ($\text{AI} < 0.05$) regions (Middleton and Thomas 1997).

A high proportion of Americas' drylands belong to temperate drylands (97%), except the small proportion of tropical dryland distributed in Latin Americas. More than half of the North America drylands (54%) can be assigned to the semi-arid type. The second most prevalent type is dry subhumid (22%), which is mostly distributed along the edges of the drylands. Approximately a quarter of the North American drylands are distributed in the arid zone, primarily in the interior western part of the

Fig. 10.1 The drylands in North and South America determined by the average aridity index from 1981 to 2019

United States, the Baja Peninsula, and coast of the Gulf of California in Mexico, along with one region in central Mexico and some regions straddling the border between Mexico and the United States. The hyper-arid zone covers only less than two percent of North America's drylands, mainly located at the northern tip of the Gulf of California. Chihuahuan desert, as the largest desert in North America, stretches all the way from the southwestern United States deep into the Central Mexican Highlands.

The drylands of South America are approximately 552 million hectares, covering circa 31% of the region's total land area. They are primarily distributed in the semi-arid zone (46%) and dry subhumid zone (41%), with only eight and five percent in the arid and hyper-arid zones, respectively (Table 10.1). South American drylands are mostly distributed in two main topographical areas, which are the high mountains of the Andes in the west South America and the Brazilian and Guiana Highlands in the east South America.

The United States and Argentina are home to the largest area of drylands over North America and South America, respectively. In the United States, Argentina, Canada, Mexico, Brazil, Bolivia, Colombia, Ecuador and Praguay, the drylands are mainly classified as the semi-arid. The drylands in island countries mostly belong to the sub-humid type (Fig. 10.2).

The primary factor limiting vegetation growth in drylands is water shortage. Low soil moisture supply and high atmospheric water demand are considered as the two main drivers causing dryness stress on vegetation. Temperature and humidity are the two basic factors defining vapor pressure deficit (VPD) (Fig. 10.3). As a

Table 10.1 Area of each type of drylands in Americas

Sub aridity zones	North America		South America	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Dry sub-humid	1,431	22.45	2,527	45.78
Semi-arid	3,473	54.50	2,267	41.07
Arid	1,355	21.26	444	8.04
Hyper-arid	114	1.79	282	5.11
Total	5,982		5,520	

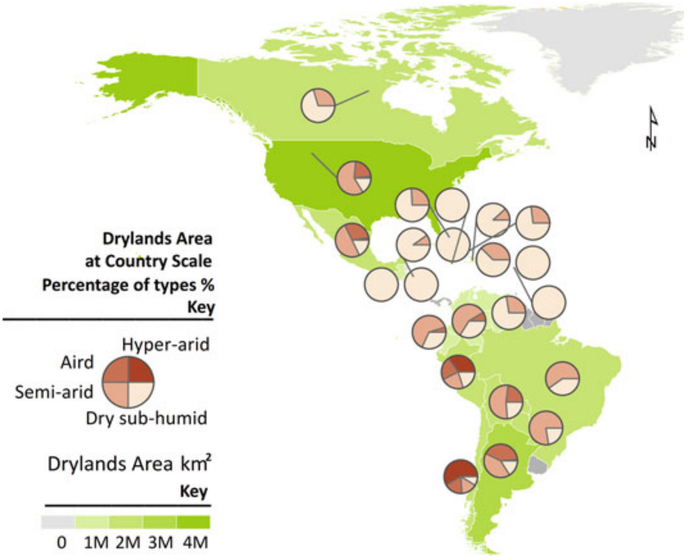

Fig. 10.2 The area and percentage of each type of drylands in North and South America

proxy for plant water stress, VPD is what actually affects plant growth via moderating the transpiration process, and reflects the effect of temperature and precipitation on the relative humidity and transpiration demand (Seager et al. 2015). The warming-driven increases in vapour pressure deficit hasten evaporative water loss and deplete surface moisture, in turn amplifying atmospheric drying through the land–atmosphere feedbacks (Lian et al. 2021).

The distribution of drylands and arid climate are the joint results of atmospheric circulation and large-scale topography interacting with synoptic-scale and mesoscale weather systems. The drylands over southwestern North America are strongly influenced by the subtropical highs together with the descending branch of the Hadley cells (Scheff and Frierson 2012). Moreover, some dryland regions in South America and the western United States are heavily impacted by topography because high mountains produce the foehn effect and block the passage of rain-bearing air

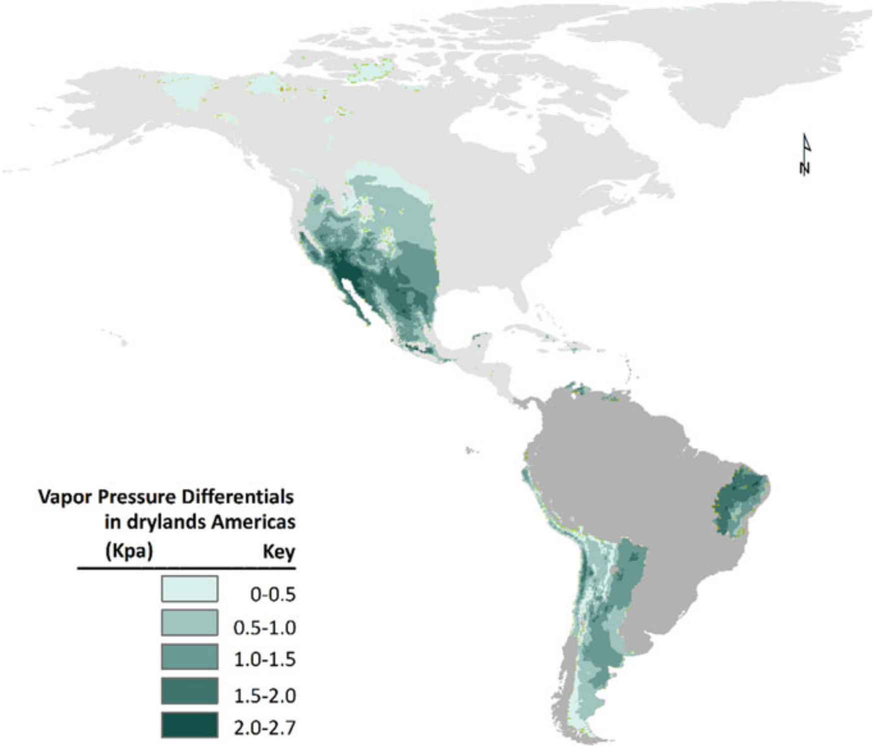

Fig. 10.3 The vapor pressure deficit (VPD) of American drylands

(Huang et al. 2017a). Over the past half-century, the semi-arid regions of the American continents have expanded significantly. The newly formed semi-arid regions were mainly developed from arid regions in southwestern North America that had become wetter caused by enhanced westerlies in recent years (Huang et al. 2016a; Li et al. 2019).

It is predicted that drylands would expand under future climate scenario (Morales et al. 2011; Koutroulis 2019). In North and Central America, the arid regions will occupy most of New Mexico, western Texas, and most of northern Mexico. By the end of this century, the semi-arid regions will expand eastward by 2–3° of longitude in the Great Plains. Only a few dry regions in southern South America may get wetter. Potential dryland expansion means lower ecosystem carbon sequestration and a greater risk of desertification (Huang et al. 2017b), severely affecting usable land availability and threatening food security.

10.2.2 Dryland Ecology and Biogeographical Characters

Dryland Climate and Soils

The dry condition of American drylands is due to the co-influences of the Pacific currents and Andes Mountain barrier. For the ocean current, warming phases are known as El Niño and cooling phases are known as La Niña. The prevailing climates in the drylands of North America are mainly formed due to the planetary-scale atmospheric circulation in the subtropical and mid-latitudes. The westerlies and the mid-latitude cyclones produce the dryer climate in the west and southwest of North America. Changes in atmospheric circulation patterns, in combination with the oceanic temperature rhythms regulated by El Niño and La Niña events, result in annual climate variations comprising severe drought years and wetter-than-average years throughout the region. The southwestern region of the drylands is also affected by monsoon events, which are localized climate patterns characterized by seasonal fluctuations in temperature and precipitation.

In South America, Andean areas feature dramatic temperature fluctuation and decreasing rainfall from east to west. The high Andes accommodate cold areas in central Peru, Bolivia and Chile with temperatures ranging from −2 to 12 °C and precipitation ranging from 610 to 1,420 mm. Temperatures in the tropical wet-dry areas of the Brazilian highlands and Ecuador can reach 18–35 °C. In eastern Brazil, the area around Parnaíba and the São Francisco River is characterized as an interior warm zone, receiving only 100 mm annual rainfall. In southern Chile, the annual rainfall can reach 2,500 mm. The warm and cold deserts in Patagonia and northwest Argentina are characterized by an arid climate. In Patagonia, the highest temperature is about 20 °C. Temperatures in the Atacama Desert can reach 18 °C, with almost no rainfall in the whole year.

Soil provides foundation to support the ecosystem functions and services, which includes nutrient cycling, carbon storage, water security, food, and fiber production. Tracing down to the basic processes underpinning other ecosystem function and services is the nutrient cycling. Unlike other global drylands, such as in Africa and Australia, the drylands in Americas have generally less nutrient constrain according to FAO Harmonized world soil (Fig. 10.4). The extensively distributed Cyanobacteria in arid and semiarid regions of North America play a significant role in nitrogen fixation (Eldridge et al. 2020; Maestre et al. 2013). Higher nutrient availability, which means less nitrogen limitation and higher soil organic matters content, can improve soil carbon storage capacity and vegetation carbon sequestration capacity.

Biodiversity in Drylands

Species diversity pattern highly hinges on their origins and evolution. In South America, dryland plants were developed in the Paleocene (66–56 million yr ago (Ma)) while in North America, they were developed in the beginning of the Late Cenozoic (33.9 Ma) (Thompson and Anderson 2000). The long developing history of dryland plants across the continents, and their roles as the origin of many unique plant lineages make them an important host to a diverse flora. There are some typical

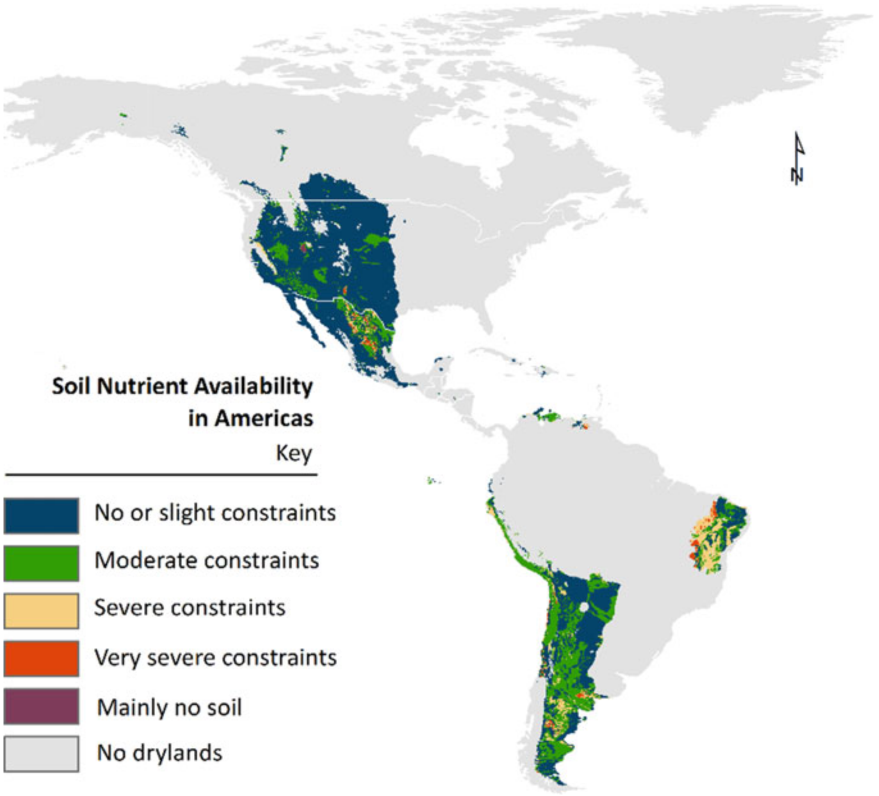

Fig. 10.4 Soil nutrition availability of North and South America drylands

plant species distributed in drylands over Americas, such as the Cactaceae in Sonoran Desert, Mexico and the southern United States; Caatinga in southwestern Andes and Pinus edulis in Canyonlands.

North America harbors a vast array of dryland ecosystems, including the Sonoran Desert, the northernmost drylands of the world, and the conifer taiga forests of Canada, etc. In Mexico and the southern United States, the Cactaceae family has the highest diversity. Forests of Pinus ponderosa and Pinus edulis are found all throughout the Colorado Plateau, with Pinus ponderosa and Pinus edulis being the most common species in the Canyonlands. Artemisia tridentata and Cercocarpus montanus, for example, might occasionally find a home in the open spaces between the trees (Maestre et al. 2021; Shreve 1942).

South America is home to a large area of important dry forests, mainly located in the Gran Chaco, the Maranhão Babaçu, and the Caatinga, as well as the driest forest of South America that features a xeric shrubland composed of succulents and thorny trees with a high *degree* of endemism (Fernandes et al. 2020). The Caatinga is also an important center accommodating the diversified Cactaceae family along the southwestern Andes (Ortega-Baes and Godínez-Alvarez 2006).

Soil moisture is an important environmental filter on plant species composition for dryland ecosystem, and drought is especially harmful to endangered species because of their narrow physiological tolerance and poor competitiveness (Bartholomeus et al. 2011). Future climate is expected to impact dryland plants, particularly threatening endangered plant species such as *Magnolia dealbata* in Mexico, *Artemisia tridentata Nutt.* in western U.S., and many other vascular plants.

Human activities like grazing, fire, deforestation, and farmland agriculture are also having resonant impacts on plants. These activities lead to the fragmentation or destruction of plant habitats, as well as the introduction of invasive competitors from other habitats (Garza et al. 2020). Habitat loss is the most widespread cause of species endangerment in some regions of America, including but not limited to *Tabebuia chrysantha*, *Astronium* graveolens, *Manihot walkerae* in U.S. and Mexico, and *Caesalpinia echinata Lam* along the Atlantic Coast. Apart from endangered plants, human activity explains a significant portion of variations in wildlife animals, such as terrestrial mammal in Argentinian. Intensified human activities could threaten species' persistence in biomes, which could be worse if climate changes act as a negative layer on biodiversity (de Oliveira et al. 2012).

Climate change and human activities pose the greatest threat to biodiversity in America drylands (Darkoh 2003), especially on those endangered species. Much work remains to disentangle the respective effects of the above two driving factors. American drylands are expected to experience increasing climatic aridity and land use pressure in the future (Ferner et al. 2018). To protect endangered species, identifying the factors that determine their distribution and abundance is critical (Amat et al. 2013).

Land Cover and Land Use

Grassland/cropland and shrublands are the two dominant vegetation types in the drylands of Americas as in other global drylands. In North America, the two land-use categories constitute 45% of the drylands in this region. In North America, the Great Plains represent a broad swath of the semiarid agroecosystem, bordered by Rocky Mountains to the west and high-rainfall areas to the east, stretching from the Canadian border in the north to Texas and New Mexico in the south (Hansen et al. 2013). Rainfed cropland, perennial cropland, irrigated cropland, and fallow are the several forms of dryland croplands in North America. The Canadian Prairies, the United States and Mexican Great Plains, and the inland Pacific Northwest of the United States with wheat are all areas of North America with high density dryland farming (Tritcum aestivum L.). Dryland farming is important in northern and central Mexico, mainly about the cultivation of maize (Zea maize L.), sorghum (Sorghum bicolor L.), pulses, and oil seeds, in addition to wheat. A two-year cycle of wheat and summer fallow is the traditional and still widely used farming strategy. The two most common cropping systems in the western margin of the south Great Plain are winter wheat (Triticum aestivum L.)-summer fallow and winter wheat-sorghum (Sorghum bicolor L.)-fallow. In South America, grassland and croplands together occupy 38% of the drylands, with grassland making up 81% of the total and cropland making up the remaining 19%, while other wooded land accounts for 45% of drylands and barren land for the remaining 17%. Two widespread uses of those lands are extensive livestock production or pastoralism and the rainfed or irrigated cropland. The rangelands include the Patagonian rangelands and the Dry Chaco rangelands, etc. Rangelands are the second primary land use in drylands of South America. For example, two thirds of continental Argentina are arid and semiarid rangelands. These rangelands include five phytogeographic regions: (1) Puna, (2) Chaco Occidental, (3) Monte, (4) Caldenal, and (5) Patagonia.

Scientific management and technology application on dryland agriculture represent a frontier line in American drylands, especially in North America. Even with the support from science and technology application, dryland agriculture suffered declines in agricultural productivity over the past few decades as a result of drought. Irrigation in Americas' dryland agricultural system is considered as a potential adaptation strategy to reduce the negative impact of drought on crop yields (Tack et al. 2017), and the sustainable irrigation strategies were widely applied in Great Plains to increase the water use efficient of crop (Comas et al. 2019; Himanshu et al. 2019). On the other hand, the agricultural insurance program in U.S. is the world's largest in premium volume. It has been developed since 1920s and then severed as a powerful and efficient tool to help secure the income of the American farmers as compared to other countries. Recently, the program was expanded to a wider horizon of crop products (Smith and Glauber 2012). From 2000, new private commercial agricultural insurance system was also introduced in Brazil and Chile to help the producers against losses due to disasters or price declines (Mahul and Stutley 2010).

As a lesser-known treasure, the North and South America's drylands are covered by extensive forests (Bastin et al. 2017; FAO 2010). In total, forests cover 37% of the region's drylands. The South America's drylands contain 197 million hectares of forest, which corresponds to 18% of the global dryland forest area and 5% of the global forest area. Forest area follows a clear decreasing gradient with increasing aridity. An estimated 61% of the dryland forest is in the dry subhumid zone, 38% in the semi-arid zone, 1% in the arid zone and less than 1% in the hyperarid zone. Forest is the second most common land use (30%) in North America's drylands. It comprises 206 million hectares of forests, equal to 19% of the global dryland forest area and 5% of the global forest area. More than half of the forests grow in the dry subhumid zone, and the remaining 41% grow in the semi-arid zone. A small portion (5%) is in the arid zone, and no forests are identified in the hyperarid zone. The forests of North America's drylands are composed of 40% coniferous, 38% broadleaved and 21% mixed coniferous and broadleaved. Forests in drylands generate a wealth of environmental services, which normally exhibit higher resilience in response to global changes than other vegetation types (Table 10.2).

Forests play a critical role in offsetting atmospheric CO_2 levels rising by sequestering CO_2 (Huang et al. 2020). U.S. initiates the first wave of forest carbon study in the 1980s (Sharpe and Johnson 1981; Cooper 1983). During 1990 and 2015, forest C stocks in North and Central America have increased, while that of South America has decreased substantially (Köhl et al. 2015). Vegetation in drylands can contribute

Table 10.2 Areas with forest and ≥10% tree canopy cover in the drylands in 2015. The estimations are based on satellite images and following the same definition of drylands (in mega hectares). Dashes indicate non-existing information for a given source because estimates are expressed either in terms of “tree cover” or in terms of “forest” (Bastin et al. 2017)

Source	FAO (2010)	Bastin et al. (2017)		
Sensor	Landsat	Very high-resolution imagery		
Method	Sampling	Sampling	Sampling	Sampling
Year	2005	2015		
Type	Forest	Forest	>20% tree cover	>10% tree cover
South America	123	197	192	208
North America	166	204	201	238

significantly to interannual variations of ecosystem carbon stock. Considering the high proportion of drylands area in America, assessing their capacity in sequestering carbon should be a research priority in the future dryland study.

10.2.3 Disturbance and Degradation

Two primary types of disturbances on grassland, savanna, and shrubland in the drylands are fire and grazing. Grazing is normally characterized as a combination of human interventions and herbivory (grazing or browsing by livestock and wildlife) in grassland, savanna, and shrublands. Rangelands are extensively managed to support grazing animals, whereas pastures are more intensively managed and may involve seeding, fertilization, irrigation, and weed control. On the other side, grassland and savanna in Americas are fire-prone ecosystems. There are multiple fire-dependent biomes distributed in Pantanal region, and the extensively distributed cerrado in Brazil, Venezuela, and Chile. Mesic savannas need fire to maintain their structure and biodiversity. In 2000 alone, savannah burning represented some 85% of the area burned in Latin American.

Land use change is the main type of disturbances on forests in South America (Abril et al. 2005). Conversion between soybean land and neotropical deforestation has existed in South America for a long time (Gasparri et al. 2013). According to satellite observations, 3.8% dryland forests disappeared between 2001 and 2010, mainly because of soybean cultivation and livestock production (Clark et al. 2012). As the largest tropical dry forest, Caatinga is considered as one of the most endangered ecosystems in the world. “Slash and burn” practices are traditional in this area, whose abandonment has caused soil salinization. Forest succession and health are highly dependent on frequent fire in North America. However, the series of human management, particularly fire suppression, logging, and livestock grazing, have totally modified their succession cycle and growth environment, and make them increasingly vulnerable to large-scale severe wildfires and insect pest.

A significant portion of dryland ecosystem are highly frequent fire adapted. With fire exclusion and suppression, woody encroachment has replaced grasslands in many places (Li et al. 2022; Miller et al. 2017; O'Connor et al. 2020). The vegetation transformation will in return reshape the fire regimes and alter the water and nutrition resource availability. Fire can not only affect the bi-stable dynamics between grasslands and shrublands, also is highly relevant to forest sustainability. Forests of western North America mainly consist of Ponderosa pine and dry mixed-conifer species. Those forests are subject to a relatively short fire return interval of less than 35 years. The frequent low-severity fires maintain the key compositional and structural elements in these forests, also helping remove the old-growth and overmature stands in achieving sustainable forestry (Hurteau et al. 2014). On the other hand, fire disturbance should be paid mounting attention in face of projected warmer and drier environment, as well as an extended drought period. "Precision restoration" such as logging to lower the unnatural high tree density and improve the diversity of tree species should be taken into consideration as a more reasonable conservation strategy (Copeland et al. 2021).

The modified fire regime also conveys high pressure on the sustainability of the social, economic and the ecological components. Both fire frequency and burned area increased across the Southwest of US, especially the high-severity fire occurrences in xeric mixed conifer and mesic mixed conifer/spruce-fire ecosystem from 1984 to 2015 (Singleton et al. 2019). The ecological and socio-economic impacts of fire have been increasing drastically in California in recent decades (Hurteau et al. 2014; Keeley and Syphard 2021; Miller et al. 2009). Such as in 2017 and 2018, the devastating fire years, 147 people died in fires, about 35,000 homes and businesses were destroyed, and approximately US$ 34 billion in insured properties were lost (Safford et al. 2022). These lessons teach us that we should put more focus on restoring key ecosystem function instead of suppressing fires for those fire-frequent ecosystems.

A large proportion of Americas' drylands have undergone some levels of degradation. Assessments by the USDA Natural Resource Conservation Service suggests that ~21% of the western rangeland area has been degraded to some degree (Herrick et al. 2010). Today very little, only 1–2%, of the original prairies still exist. Much of the prairies has been turned into agricultural uses (Squires 2018). In North America, the arid and semi-arid western rangelands, together with cultivated drylands of the southwest and Great Plains, comprise the regions of the United States most susceptible to wind erosion and associated soil loss. Specifically, the Great Plains are particularly prone to flash droughts from episodic precipitation deficits (Mo and Lettenmaier 2016). And projected future ecological drought has shown that the western Great Basin will face an increasing chronic drought stress (e.g., longer dry periods) (Bradford et al. 2020).

10.2.4 Dryland Livelihoods

In social dimensions, the multi-stakeholder of agriculture and livestock production systems engagement is needed for the sustainable management of drylands in Americas. Grazing livestock is the principal practice of exploiting natural vegetation in Americas' drylands. Because pastoralism is the sole practice that can simultaneously provide secure livelihoods, conserve ecosystem services, promote wildlife conservation, and honor cultural values and traditions, it is considered the most economically, culturally, and socially appropriate strategy for maintaining the well-beings of communities in drylands. The grazing industries and ranching systems are the prevailing land-based resource utilization model in drylands of North America. Livestock products are the main outputs of grazing lands and continue to be the fastest growing agricultural subsector. Central and South America provide 39% of the world's grassland-based meat production (beef) (Irisarri et al. 2019). Moreover, rangelands are coupled socioecological systems, shaped through interdependent land use practices and ecological processes. External forcing, such as those from regional precipitation patterns or episodic shocks, and the non-equilibrium nature of most rangelands systems (Reynolds et al. 2007) complicates the relationships among climate, management, and forage availability. Under the ongoing socioeconomic and environmental transformations in drylands, all these needs imply the necessity of cross-disciplinary work among livestock production, sociology, natural resources, economy, and rural development.

Except the agropastoralism in drylands as supporting the fundamental livelihood in Americas, the iterate biofuels production systems in the west of South America are promising. They not only have climate change mitigation potential, also can fulfill the desire for economic growth in the agriculture sector supported investment in biofuels as a rural development strategy (Correa et al. 2021). To minimize the conflicts between energy exploitation and biodiversity conservation, policy amendments and new governance initiatives have emphasized the social and environmental dimensions of biofuels. For example, the United States has modified their biofuel use targets and policies by adding sustainability requirements (Hunsberger et al. 2014).

10.2.5 The Economy of the Drylands in Americas

Human Population Over Drylands and Regional Variations

The gridded population data were obtained from the Socioeconomic Data and Applications Center (SEDAC). In 2015, North America and the South America population account for 13.51% of the global total. In North and South America, 26.8% of the total population live in the drylands (0.17 billion in North America and 0.09 in South America), mostly concentrated over the semi-arid drylands of both North America and South America. The average population densities in hyper-arid, arid, semi-arid, dry sub humid of North and South America are 8.6, 51.53, 245.85 and 32.23 person

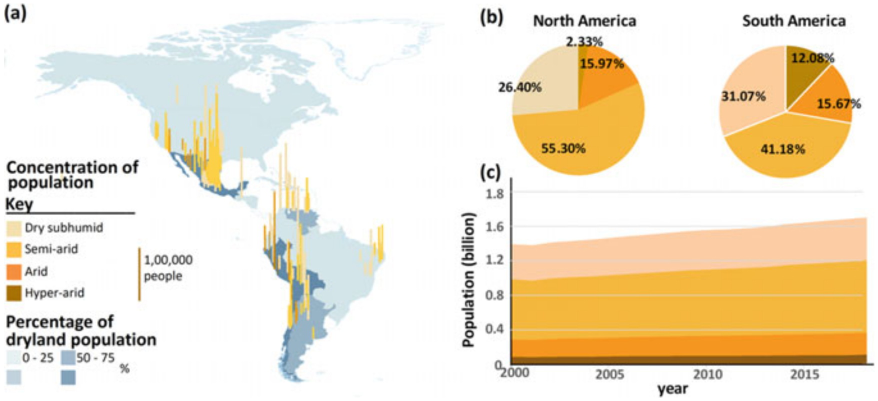

Fig. 10.5 Distribution of population over drylands in Americas. Countries without dryland distribution are not shown

per km^2, respectively. Mexico, home to the largest amount of population, is also the only country listed as the top ten largest dryland population countries over the world. Population in drylands (arid, semi-arid, and dry sub humid regions) of South and North America increased from 1.36 billion in 2000 to 1.71 billion in 2018 (Fig. 10.5).

Net-Migration from 2010 Through 2015 Over Dryland Regions

The Net migration (immigration minus emigration) is obtained through an indirect estimation technique, as the difference between population change and population natural growth. Net migration represents the difference between immigration and emigration (Fig. 10.6) (Neumann et al. 2015). Migration over drylands in Americas generally is in-migration. This trend indicates that the development conditions are beneficial for population growth, opposite to most of the other drylands over the world. Hyper arid and arid regions have the strongest appealing for the in-migrations, possibly caused by therein mega-city, such as Las Vegas and Phoenix in western U.S.

Artificial Lighting and GDP Reflected Human Activity

Both GDP and Nighttime lights can be used to indicate economic developments. Economic development can also be measured by Gross Domestic Product (GDP). According to the current developed global gridded GDP maps (Kummu et al. 2018), drylands account for more than 30% of the global GDP from 1990 to 2015 in Americas. The mean GDP are 0.31, 1.15, 3.59, and 1.65 × 10^{13} US Dollars in hyper-arid, arid, semi-arid, and dry sub-humid regions, respectively. GDP in drylands of Americas almost doubled since 1990, increasing from US\$ 3.6 × 10^{13} in 1990 to US\$ 6.7 × 10^{13} in 2015 (Fig. 10.7a–c). The GDP increasing rates were slightly higher in hyper-arid and arid regions (2.57 and 2.00%/yr) than in the semi-arid and arid sub-humid region (1.97 and 1.94%/yr) in Americas. Nighttime lights (NTL, the unit of Nighttime lights intensity is nW cm^{-2} sr^{-1}) generally represent the degree of urban socioeconomic development to some extent. The high NTL areas are mainly located

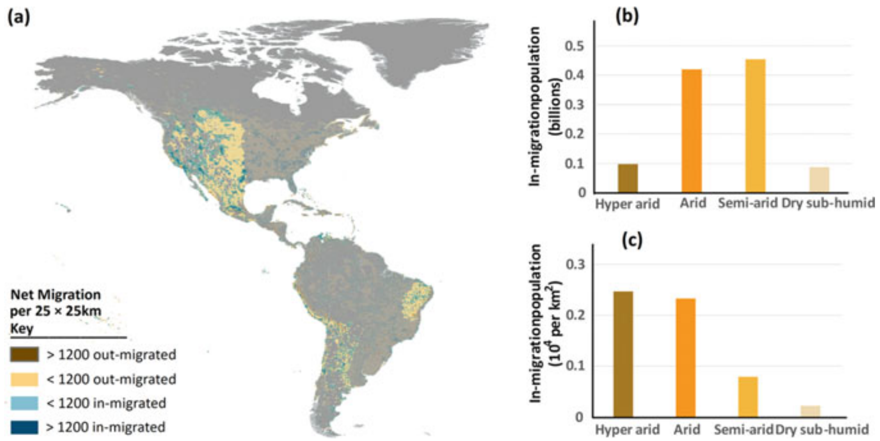

Fig. 10.6 The population migration over drylands in Americas. The upper right inset shows the total in-migration population of each sub-region of drylands, while the bottom right inset indicates the density of in-migration. Countries without drylands are not shown

in urban areas with high population density (Fig. 10.7d, e). The average intensity of nighttime lights were 0.98, 1.17, 0.61 and 1.00 in hyper arid, arid, semi-arid, and dry sub-humid regions in 1992. The average nighttime lights intensity were 2.31, 3.06, 2.14, and 2.76 in hyper-arid, arid, semi-arid, and dry sub-humid regions in 2015. The average nighttime lights intensity nearly tripled from 1.05 in 1992 to 2.43 in 2015. It is also interesting to note that the arid (0.025 nW cm^{-2} sr^{-1} yr^{-1}) and hyper-arid (0.023 nW cm^{-2} sr^{-1} yr^{-1}) regions became brighter at a doubled speed as compared to semi-arid (0.013 nW cm^{-2} sr^{-1} yr^{-1}) and dry sub-humid (0.011 nW cm^{-2} sr^{-1} yr^{-1}) regions during 1992–2010. This phenomenon indicates that the drylands in Americas experienced a balanced development as in other continents. A stable economy development in such western states of U.S. as California, Texas and Nevada contribute significantly to the social well-being boosting in drylands of North America.

10.3 Change and Driving Factor of Drylands in Americas

10.3.1 Dryland Climate Trends

Figure 10.8 shows the climate trends from 1982 to 2020. TEM and PET exhibit high correlations. Most drylands in North America exhibit significant warming trends (TEM, $p < 0.05$), which likely drive increased PET. PRE and ET have a similar pattern. PRE was observed to significantly decrease ($p < 0.05$) in North America over the past three decades, usually associated with decreases in ET.

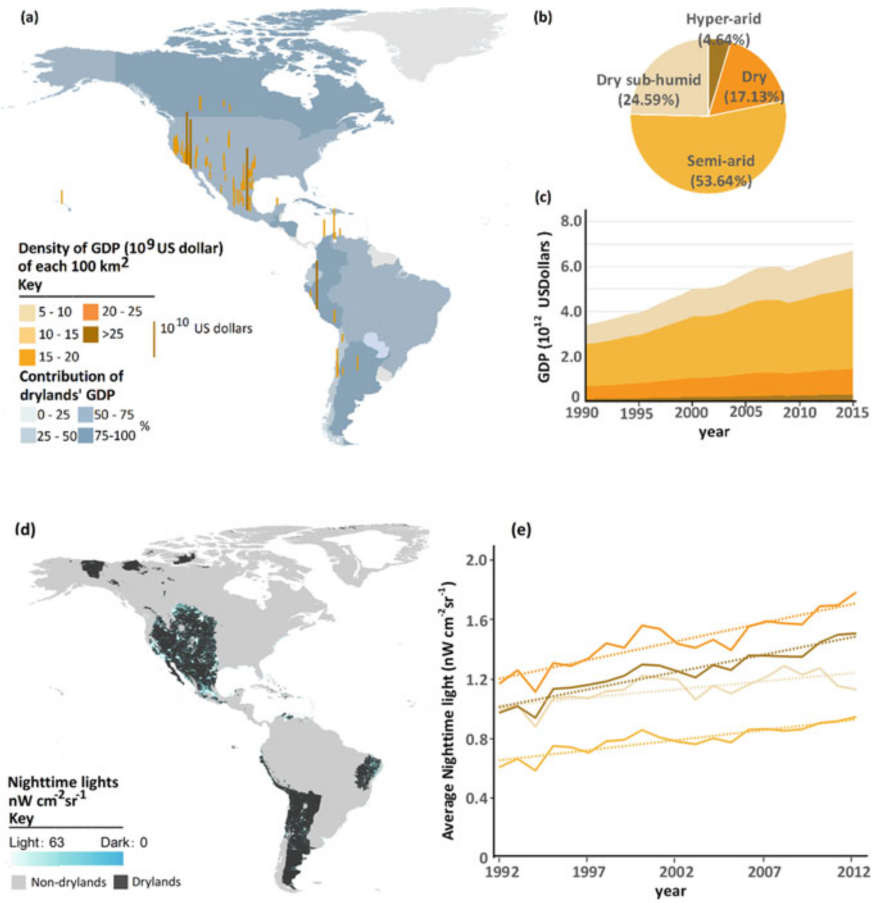

Fig. 10.7 **a** The GDP over drylands in 2015. Countries without drylands are not shown. **b** The contribution of GDP over different aridity level regions to the whole drylands GDP in Americas. **c** The total GDP changes in different aridity level regions in drylands of Americas. **d** The nightlight over drylands in Americas in 2015. Countries without dryland are shown as white. **e** Temporal variation of nighttime lights averaged in different aridity level regions in drylands of Americas. The lights detected are from cities and towns, gas flares, and fires

The spatial pattern of the SM trends is also roughly similar to that of AI. The spatial distribution of AI has similar trend with PRE but exhibits dissimilar pattern from that of the TEM trends. The drylands in eastern South America have become climatically wetting; but the southern North America and southern South America have become climatically drying. Simultaneously, the area ratio of drylands calculated in accordance with the standard of annual AI < 0.65 shows a significantly decreasing trend ($p < 0.05$) in most of North America, which indicates the area of drylands has been significantly reduced in Southwestern North America. SM shows

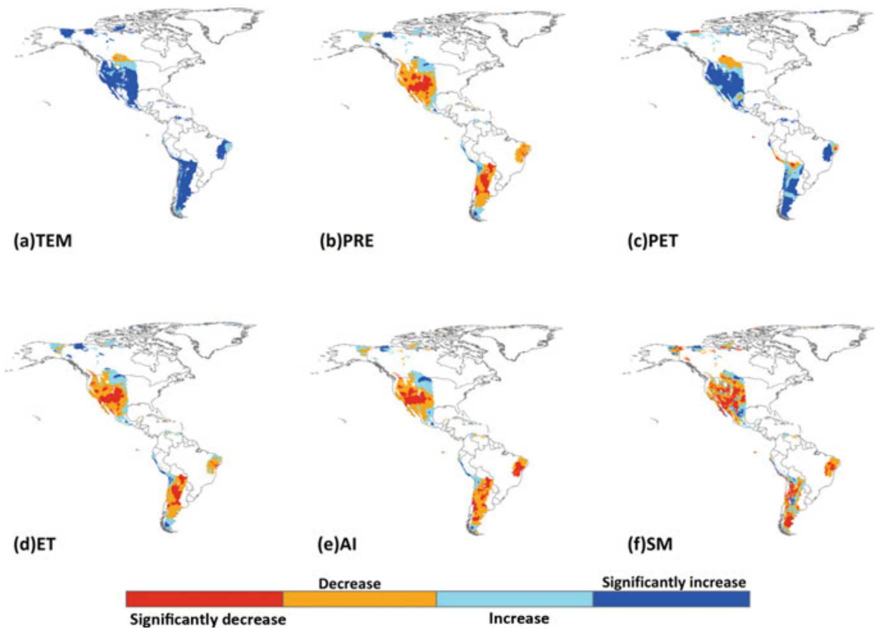

Fig. 10.8 Spatial distributions of trends in **a** temperature (TEM), **b** precipitation (PRE), **c** potential evapotranspiration (PET), **d** evapotranspiration (ET), **e** AI, and **f** soil moisture (SM) over drylands from 1982 to 2020

a significantly decreasing trend in southwestern North America drylands over the past four decades, indicating a decreased water yield over there.

Under the global context of warming, climate change will further exacerbate the vulnerability of dryland ecosystems by increasing PET globally. Warming is projected across American continent in the twenty-first century, and the most apparent will occur in winter of high latitude regions, where the greatest temperature increase approximates 15 °C in the vicinity of Hudson Bay (Maloney et al. 2014). Precipitation is projected to decrease significantly in the southwest of South America and south of North America (Cook et al. 2018). Mean annual rainfall can decrease by 8–14% in the Central United States under moderate to high emissions scenarios. Projected changes to drought characteristics under these scenarios are pronounced, with seasonal-scale droughts projected to lengthen by 12–30%, intensify by 17–42% and increase in frequency by 21–24% by the end of this century (Depsky and Pons 2021).

10.3.2 *Land Cover Change and the Driving Force*

North America drylands have been expanding, including semiarid and arid lands for 1997–2011 relative to 1982–1996. On the contrary, the southern portion of South

America has exhibited a wetting trend, resulting in the conversion from arid to semi-arid and hyper-arid to arid (He et al. 2019). By classifying land use change into types of a single event change (e.g., deforestation) or multiple events change (e.g., crop-grass rotation), we see clear patterns over South and North America (Fig. 10.9) (Winkler et al. 2021). About half of the areas are assigned to a single event change, such as deforestation in tropical South America. In contrast to single event changes, multiple event changes dominate in developed countries of North America (e.g., in the United States). Here, agricultural intensification (such as the United States) and/or major transitions in the agricultural sector, have taken place in the past few decades. Most agricultural land use changes (land transitions related to cropland or pasture/rangeland) occur in the form of multiple events change. Some of these changes are directly or indirectly linked to land management and agricultural intensification. The type of cropland-pasture/rangeland transitions can indicate areas of crop rotation or mixed crop-livestock systems as in the United States (Rosenzweig et al. 2018). Most multiple event land use changes occur between managed and unmanaged land, such as the abandonment of cropland.

Figure 10.10 shows land use/cover change dynamics (forest, cropland and pasture/rangeland) per 1 × 1 km grid cell from 1960 to 2019 (Winkler et al. 2021). The difference between North and South America is more pronounced in term of pasture/rangeland change, since pasture expansion in Brazil occurs in a large area while a

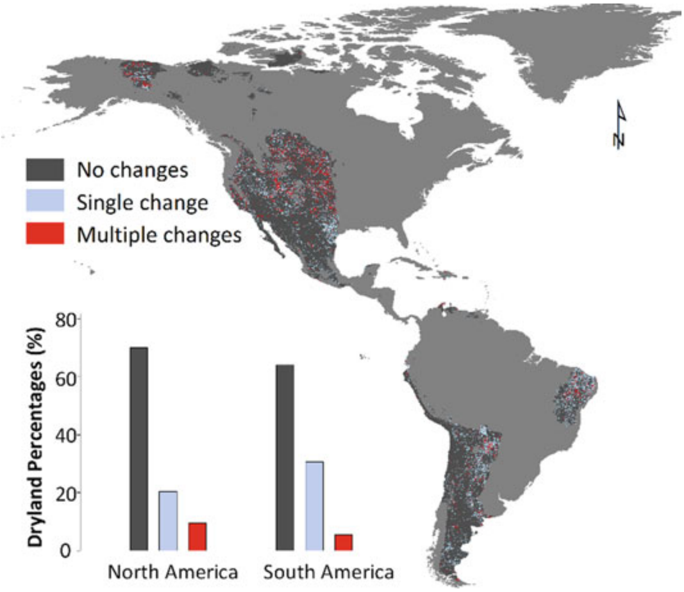

Fig. 10.9 Spatial extent of North and South America land use/cover change per 1 × 1 km grid cell from 1960 to 2019. The spatial extent of land use/cover change is displayed in light blue (areas with single event change) and red (areas with multiple event change) during 1960–2019. The bottom left barplot shows the percentage of land use/cover change over North and South America drylands

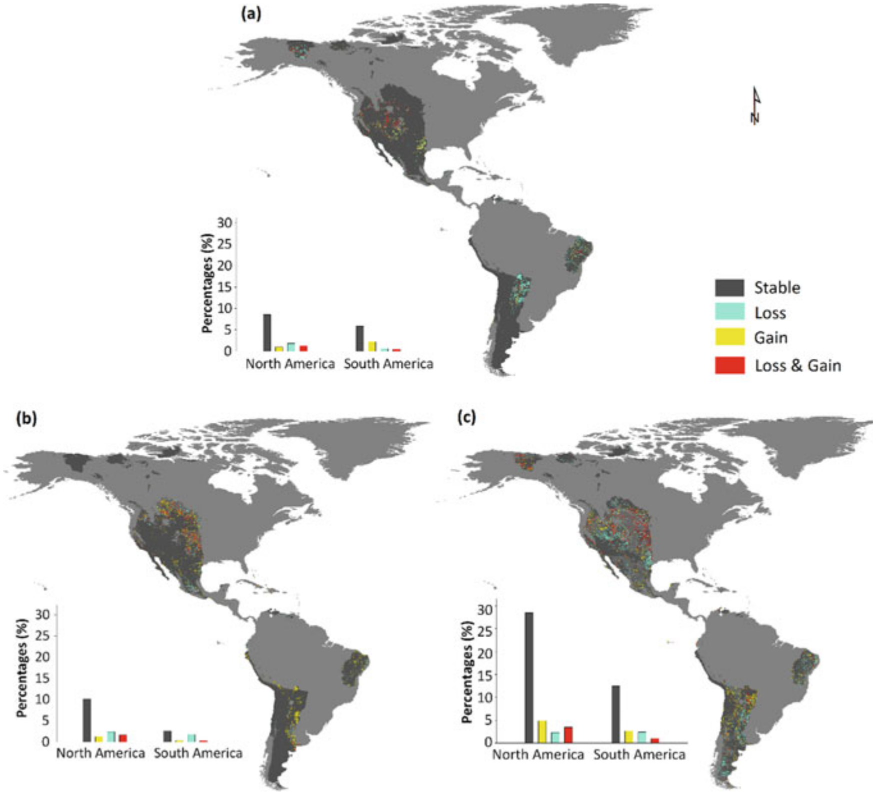

Fig. 10.10 North and South America forest, cropland and pasture/rangeland change. Spatial distribution of **a** forest, **b** cropland, and **c** pasture/rangeland extent (stable area) and change (gain and loss) during 1960–2019

widespread pasture was lost in North America. These land use change processes were supported and exemplified by numerous studies, e.g., agricultural land abandonment and woody encroachment of rangelands in the United States (Auken 2000; Ramankutty et al. 2010).

Global financial status also has a close relationship with the temporal dynamics of land use change. There was an abruptly slowed rate of land use change in South America since 2005. Before the financial crisis in 2005, rising demand stimulates global agricultural production, which in turn accelerates global land use change (Rajcaniova et al. 2014). The globally rising demand in the several developed countries of North America stimulates the expansion of bioenergy crop in South America (e.g., production of oil crops in Argentina, Brazil of South America). Global food price surges rapidly due to climatic extremes, biofuel policies, and export bans in 2007–2008 (Akram-Lodhi 2012) and 2010 (Bellemare 2015; D'Amour et al. 2016). In South America, land use changes are tightly associated with foreign investments and cross-border land acquisitions in agriculture (Arezki et al. 2015; Chen et al. 2017;

Krausmann and Langthaler 2019). The land use change follows a pattern of sudden increase (2000–2005), the subsequent fluctuations (during 2006–2010), and sharp decrease (after 2010), which demonstrates fluctuated developments in countries of South America, e.g., Brazil and Argentina. After the economic crisis of 2007–2009, the slowdown of land use change is mainly induced by a declined agricultural expansion, particularly in Argentina. With the end of the economic boom during the Great Recession, the reduced agricultural production has pushed higher the expansion rate of agricultural land in Argentina and Brazil.

10.3.3 Vegetation Structure/Function Changes and the Driving Factor

The natural climate and grazing are the two major factors determining drylands ecosystem structure and functioning in Americas' drylands. Increasing aridity is likely to aggravate imbalances among soil nutrient stoichiometry, and undermine Ecosystem functioning (Maestre et al. 2016). The intensified grazing and rising aridity have been widely reported to cause vegetation degradation (Eldridge et al. 2016).

Figure 10.11 shows that the overall NDVI of savannas demonstrates an increasing rate in South America. But forests mainly distributed in central South America have exhibited a significant decreasing trend. Overall, vegetation browning is observed in southern South America. North America dryland region displayed a significant greening trend on barren vegetated land, shrublands, and grasslands.

The drylands in North America experienced significant drying, where vegetation coverage has been increasing. The largest coverage increments were for croplands as a result of irrigation activities (Mueller et al. 2016) and increased SM. Grasslands in North America are also heavily irrigated. Significantly increased shrublands NDVI

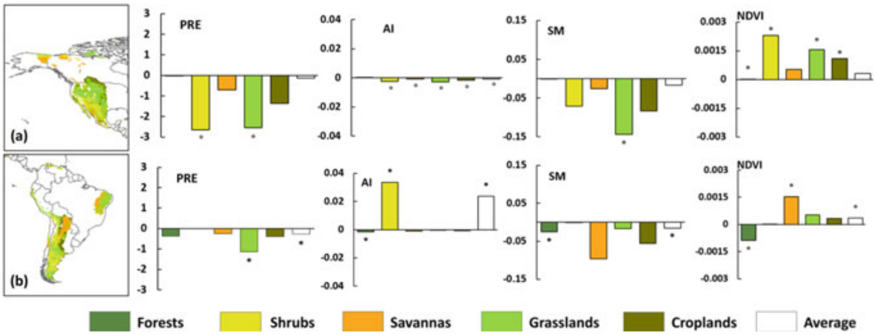

Fig. 10.11 Land cover types and the corresponding trends of PRE, AI, PRE-ET, SM, and NDVI for **a** North America and **b** South America during 1982–2020. * indicates a significant variation with P < 0.05, and ** indicates a highly significant with P < 0.01

were concentrated in the southwestern United States. Snowmelt in spring and summer is critical for vegetation growth in this area (Notaro et al. 2010), especially for shrubs that require deep soil water (Kurc and Benton 2010). The increased NDVI may be due to enriched water storage in deep soils stemmed from warming associated snowmelt. The above analysis suggests that both human activities and climate change contribute to the increased NDVI in the drylands of North America. Biological invasion has become widespread in the southwest United States (Herrick et al. 2010).

Obvious drying was observed in South America drylands forest, consequently decreasing therein vegetation growth. The drought-related NDVI reduction mainly occurs in forests, which causes ecosystem degradation. NDVI and drought indices showed a relatively high consistent trend in South America drylands. All the four drought indices point to dryness trends, but the average NDVI exhibits a weak rising, mostly caused by increased NDVI in the eastern savanna. The NDVI increasing is also observed in croplands, mostly related to irrigation practices (He et al. 2019).

The current droughts in South American are related to both El Niño and La Niña events, between which La Niña has played a more significant role. Warming atmosphere alone seems certain to make severe droughts more frequent, especially in Southwest South America (Voosen 2020).

Grazing is the most widespread land use in drylands, which provides food for a significant proportion of people worldwide (Asner et al. 2004). Grazing causes apparent effects on ecosystem structure and functioning in drylands (Hanke et al. 2014). Proper grazing rest, season-off-use, stocking rates, and subsequent management after fire are essential to restore resilient sagebrush ecosystems before they cross the breakdown threshold and become an annual grassland (Chambers et al. 2014; Miller et al. 2011).

The impacts of grazing on ecosystem are related to livestock type, grazing intensity, and some environmental factors. In North America grasslands, strengthened grazing intensity leads to a moderate expansion of bare soil soil (Augustine et al. 2012), while productivity and coverage of some grasslands can be partially increased by compensation growth, especially for grazing-resistant C_4 shortgrasses (Irisarri et al. 2016). Research shows that in Patagonian steppes (South America), sheep grazing alters the structure of plant communities. Compared to permanent grazing exclusion, moderate grazing keeps the sheep preferred plant species (Oñatibia and Aguiar 2019). At the same time, grazing impact on biodiversity is also regulated by different environmental factors. In North America, light and moderate grazing results in a decreased biodiversity in high-grassy grassland ecosystems with poor soil fertility and an increased biodiversity in high-grassy steppe with fertile soil (Fahnestock and Knapp 1994). For aboveground net primary Production (ANPP), in Argentina, ANPP based on live biomass increment is significantly higher in 4- and 15-year non-grazed sites than in 2-year grazed and 2-year non-grazed sites (Pucheta et al. 1998). Meanwhile, grazing intensity may regulate the response of ANPP to environmental factors. Studies have shown that the relationships between precipitation and ANPP are sensitive to grazing intensity (Irisarri et al. 2016). In North America, in the long-term grazed rangelands (>30 years), doubling grazing intensity in shortgrass steppe (SGS) and 175% increase in grazing intensity for northern mixed-grass prairie (NMP) reduce ANPP and precipitation-use efficiency (PUE) by approximately 24% and 33%, respectively (Irisarri et al. 2016).

Grazing also has a certain effect on livestock production in the semi-arid short grass prairies of North America. Beef production grows with increased grazing intensity in normal moisture conditions or wet years, but causes no increase in drought years (Irisarri et al. 2019). In Patagonian rangelands, compared with continuous grazing management (CGM), the weight of animals under holistic grazing management (HGM) is reduced and the body condition scores of HGM is also lower than that of GCM (Oliva et al. 2021). In addition to the above-mentioned, there are also impacts of growing grazing costs in North America. Riverbanks are the most bio-abundant zones in arid and semi-arid regions. Livestock will choose to live along riverbanks most of the time. Then the ecological risk will correspondingly escalate. Under this grazing mode, the adverse effects of grazing are amplified and need to be addressed (Fleischner 1994). Overall, to adapt to the changing climate and promote sustainable development, appropriate climate prediction tools are critical for managing rangelands. Also the quantity and quality of the current and predicted food need to be incorporated into the grazing management plan (Derner and Augustine 2016).

10.3.4 Carbon Dynamic and Nitrogen Dynamics

Gross primary production (GPP) is a key component of ecosystem carbon cycle (Fig. 10.12). The average annual GPP of North America drylands is 0.50 kg C m^{-2} yr^{-1}, which is more than double the value in South Americas (0.20 kg C m^{-2} yr^{-1}). In 2020, the mean annual GPP of forest, shrublands, savanna, grassland, and cropland in North Americas is 1.21, 0.30, 0.72, 0.46, 0.70 kg C m^{-2} yr^{-1}, respectively. The mean annual GPP of forest, shrublands, savanna, grassland, and cropland is 1.63, 0.32, 1.2, 0.84, 0.97 kg C m^{-2} yr^{-1} in South Americas, respectively. During the last two decades, nearly 87.1% of the drylands in Americas show growing vegetation GPP. The average vegetation GPP has increased from 0.17 to 0.20 kg C m^{-2} yr^{-1} and from 0.42 to 0.5 kg C m^{-2} between 2001 and 2020 in South Americas and North America, respectively. The savanna and cropland in North America show a significant ecosystem GPP growth at a rate of 5.12 g C m^{-2} yr^{-2} and 7.95 g C m^{-2} yr^{-2} during the last two decades, respectively. The average annual GPP are increased at a rate of 4.7 g C m^{-2} yr^{-2} and 1.6 g C m^{-2} yr^{-2} for drylands in North America and South America, respectively.

Climate change effects on GPP trends contain much uncertainty. Increased GPP around North and South America is mainly due to elevated atmospheric CO_2 concentration, except for some small parts of the Brazilian plateau (Sun et al. 2019). In the temperate steppe ecosystems of North America, precipitation significantly promotes vegetation growth, also GPP (Sun et al. 2019). In western North America with high water stress, the spatial continuity of GPP sensitivity to precipitation is not significant (Sun et al. 2019). GPP is more limited by water constraints through decreased SM and increased VPD in western and central United States (Madani et al. 2020).

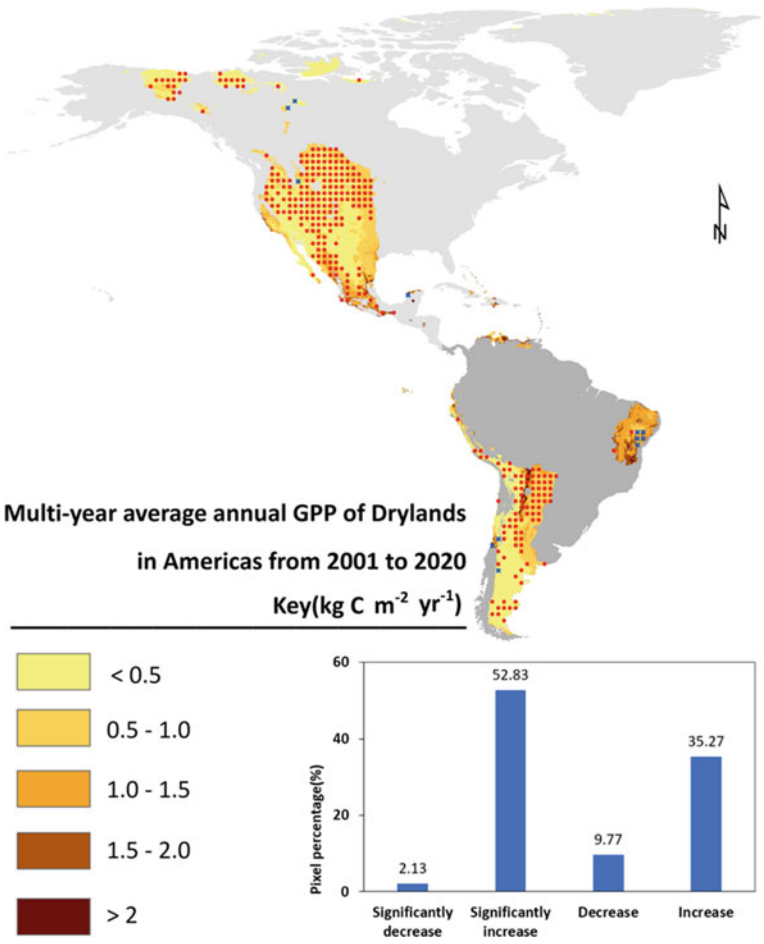

Fig. 10.12 The multi-year average GPP of drylands in Americas based on MODIS17H2 datasets. The • and X indicates the significant increased and decreased GPP area, respectively. The bottom panel shows the percentage of pixels exhibiting increasing and decreasing ecosystem GPP over the drylands in Americas

GPP increment trends are mainly regulated by increased solar radiation and temperature in humid temperate North America, and in many dry forest regions of South America, land-cover change is responsible for reduced GPP (Sun et al. 2018). Forest loss rates in temperate North America are relatively low, causing a lower impact on GPP than in South America (Sun et al. 2018). Rising temperatures play a primary role in stimulating GPP in northern high latitudes, while it suppresses ecosystem in South America (Cai and Prentice 2020).

Both soil and vegetation carbon storage in drylands contributes considerably to the terrestrial carbon storage. Soil organic matter levels in the top soil are mainly negatively correlated with mean annual temperature and positively correlated with precipitations in the Northwest agriculture systems of inland USA (Morrow et al. 2017). The land cover shifts, such as grasslands encroachment into drylands tend to boost soil organic carbon content. However, woody invasion tends to boost soil organic carbon content in semiarid and subhumid drylands while decreasing it in arid drylands in North America (Barger et al. 2011). Research has found that woody plant encroachment shifted soil organic carbon from an annual loss of 6200 g C m^{-2} to annual gains of 2700 g C m^{-2}, with an annual average accumulation of 385 g C m^{-2} in North American drylands (Barger et al. 2011).

Nitrogen availability is the second critical factor limiting dryland ecosystem primary productivity after water availability (Hooper and Johnson 1999; Yan et al. 2010). Even though the belowground parts account for more than half of the total net primary productivity in the drylands, studies across three typical dryland ecosystems in North Americas show that as compared to aboveground productivity, root productivity is less responsive to nitrogen addition (Swindon et al. 2019). Nitrogen availability is influenced by climate change and human activities. The predicted aridity exacerbation will reduce the nitrogen concentrations in the global drylands; however, it is still not clear how aridity change will impact the nitrogen content in America drylands. Legume shrubs expand markedly in the dryland crop system of the Northern Plains and the Pacific Northwest United States during the cool season. One significant reason is due to their strong capacity as soil nitrogen fixers (Arash et al. 2018). Nitrogen fixation by biocrusts, which covers a large proportion of soil surface in low-nutrient drylands, also contributes significantly to ecosystem nitrogen fixation (Baldarelli et al. 2021; Weber et al. 2015). On the other hand, nitrogen deposition in the temperate N-limited dryland ecosystem set the stage for more possible invasion by nitrophilic grasses (Vallano et al. 2012). Increasing nitrogen pollution is also found to be the primary factor causing 78 listed or candidate species as threatened or endangered in serpentine grasslands of California Bay (Hernández et al. 2016).

10.4 Managing Drylands in Americas: Challenges and Opportunities

10.4.1 Major Issues in Managing Drylands in Americas

Desertification is the most threatening ecosystem change that affects the livelihoods of local people. Due to its close linkage with land degradation, persistent desertification may further lead to the loss of human well-beings. After desertification, woody encroachment and soil erosion also pose serious threat to Americas' drylands by lowering diversity and undermining ecosystem services.

Woody encroachment, perhaps the most dramatic form of dryland vegetation cover change, continues to expand over extensive drylands of the United States and South America (Rosan et al. 2019). The invasive distribution of buffelgrass, which are highly productive in drylands, has expanded to 53% of Sonora State and

12% of semi-arid and arid ecosystems in the Sonoran Desert of Mexico (Arriaga et al. 2004). Sequentially, plant–plant and plant-soil interactions are adjusted and landscape structure and functions are modified (Franklin and Molina-Freaner 2010).

For Americas' drylands, another widespread environmental issue is the exacerbating soil erosion caused by the land cover transition from grassland to shrubland. During the second half of the nineteenth century, large-scale commercial stockbreeding quickly spread to the North and South America semiarid drylands, which caused severe ecosystem degradation on drylands and affected millions of people as happened in the other developing countries (Reynolds et al. 2007). The most recent climatic projections predict that the global dryland area will expand 11–23% by the end of this century (Huang et al. 2016b). Then soil erosion affected areas are likely to further expand under climate change and population growth (Safriel et al. 2005). Some countries in South America are faced with especially severe soil erosion issue. The national assessments conducted in 1979 revealed that soil erosion severely affected 36% of Chile's territory and the affected areas are still expanding.

The intensified land use practices and rapid land-use change pose a rapid growing threat to both plant and soil diversity (Kobayashi et al. 2019). The living organisms in the top soil layer, such as mosses, lichens and other microorganisms, are normally used to reflect the soil diversity. Soil diversity contributes significantly to vegetation growth by maintaining soil fertility, while soil erosion causes the decrease of soil diversity. Soil with lower soil diversity is incapable of supporting the mismatching high vegetation diversity, which in turn decreases soil carbon. In semi-arid grassland, adding nutrients to the soil can slow down the loss of plant diversity (Harpole et al. 2016). The high-intensity grazing can also lead to the loss of the native plant diversity, particularly in combination with extreme climatic events, such as drought (Souther et al. 2020). According to recent studies and assessments of current and anticipated climate changes in the Great Plains, it is also suggested that rural people and ecosystems are more and more sensitive to changes brought on by warming, droughts, and increased variability in precipitation (Ojima et al. 2021).

Water resource scarcity is typical for drylands in South America. Numerous rivers or catchment are fed by melting snow and glaciers, and their flows or runoff have been significantly affected by global warming. Glaciers are served as the water resource buffer for ecosystems, locking up precipitation during the rainy season and releasing water slowly during the dry season. The glacier retreat or shrinkage, and early snow melt will change the seasonal accessibility to water resources (Young et al. 2010) and exacerbate the vulnerability of the dryland ecosystems. Construction of small reservoirs that could be tapped in the dry season could just be "part of the answer". This also raises up the importance of adapting to the present land and resource management styles in the face of the unprepared changes.

10.4.2 Sustainable Managing Drylands: Conservation Agriculture, Husbandry, and National Park System

Biodiversity conservation is one of the most important goals for sustainable drylands management. The overarching government regulations are needed to guide the sustainable management in drylands by various stakeholders to gain multifunctional use of drylands. The US government has announced millions in rewards for conservation partners each year for agriculture and husbandry innovations, supporting improvements in managing land efficiency and environment protection. The natural resources conservation programs of the Natural Resources Conservation Service (NRCS) encourage reducing soil erosion, improving wildlife habitat, and providing financial supports to private rangelands and farmlands.

The stable foundations for ecosystem services for agriculture are provided by the health and fertility of the soils in the Americas. The intensification and diversity of cropping systems, on the other hand, are crucial for maximizing farming's short-term earnings, but they also constitute a serious threat to the sustainable management of the land. Thus, adopting sustainable land management practices, such as the use of Conservation Agriculture (CA) is growing in dryland agriculture (Shrestha et al. 2020). CA is characterized by minimum soil disturbance, crop rotation, and maintaining a certain degree of permanent soil cover. According to updated figures published by FAO, the U.S. is leading the list of countries with more absolute areas under CA. In South America, the adoption of CA has been especially quick. The MERCOSUR countries (Argentina, Brazil, Paraguay, and Uruguay) in South Americas are amongst the top five countries in terms of surface area protection using CA in the world (Shrestha et al. 2020).

For husbandry, many management practices try to keep the disturbance-driven heterogeneity characteristics of rangelands for maintaining forage diversity in rangelands. For example, cross-fencing and winter-patch graze are included in the conservation plans with the NRCS, proved efficient in improving soil carbon levels and ranch profitability (Buckley et al. 2021; Derner et al. 2018). To sustain wildlife and ecosystems in balance with human livelihoods, the patch-burn grazing has been extensively promoted in North American (Scasta et al. 2016). It can be an alternative management approach in fire-prone ecosystems to optimize both livestock production, ecosystem functioning, and biodiversity conservation (Ricketts and Sandercock 2016). On the other hand, the adaptive capacity of rangelands and grassland communities to support the local diversity is also highly variable. A comprehensive socio-ecological system (SES) framework, with indicators and links to key outcomes related to livelihood and ecosystem process running, is critical in improving evaluation of climate and land use effects changes on husbandry (Ojima et al. 2020), thereby facilitating management actions during husbandry.

Studies have shown that, biodiversity is substantially higher within the well-managed reserves as compared to the public lands (Gray et al. 2016). At the country level, to achieve the ultimate goal for protecting biodiversity and sustaining ecosystem services the drylands provide, American governments designate high

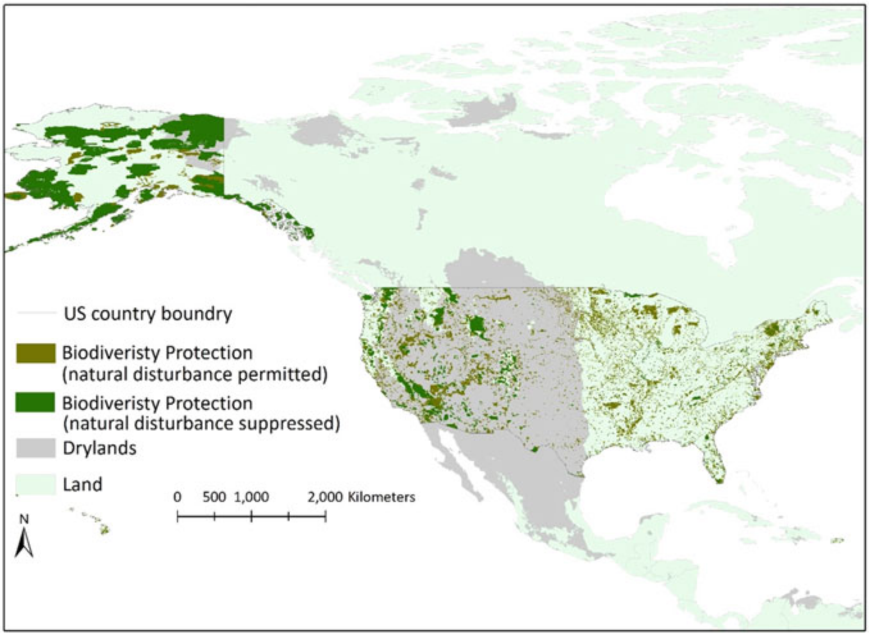

Fig. 10.13 Distribution of biodiversity protection lands in USA (US Geological Survey GAP Analysis Program)

percentage of lands as protected by national parks system. In the USA, drylands make up more than one-third of the natural disturbance permitted biodiversity protection lands, and one-fourth of the naturally disturbed biodiversity protection areas are also scattered there (Fig. 10.13). Among those protected areas, biodiversity conservation is always listed as the top priority goal. Those ecoregion-based managements provide further aid to safeguarding critical species and their diverse habitats. Research also suggests that considerable investments should be directed to private land conservation and encourage the engagement with local stakeholders, consequently increasing the success of endangered species protection (Clancy et al. 2020). As most drylands in western North America and Southern Latin America are exposed to slow climate velocity and located in high land-use instability areas, prioritizing protection, restoration and maintaining the connectivity among protected area networks will be highly beneficial as compared to other drylands such as in European Union (Asamoah et al. 2021). Therefore, policy makers and multiple stakeholder groups, such as scientists, the public, and other private sectors, should cooperate effectively to achieve the restoration and protection goals in America drylands.

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