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Holdridge Life Zone Map: Republic of Argentina

María R. Derguy, Jorge L. Frangi, Andrea A. Drozd, Marcelo F. Arturi,
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Forest Service

International Institute
of Tropical Forestry

General Technical
Report IITF-GTR-51

November
2019

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Abstract

Derguy, María R.; Frangi, Jorge L.; Drozd, Andrea A.; Arturi, Marcelo F.; Martinuzzi, Sebastián. 2019. Holdridge life zone map: Republic of Argentina. Gen. Tech. Rep. IITF-GTR-51. San Juan, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 48 p.

Ecological zonation is a fundamental tool for territorial and ecosystem management. The Holdridge model is a system of ecological zoning based on the identification of bioclimatic units (life zones) that employs the variables of biotemperature, precipitation, potential evapotranspiration (EVP), EVP/P ratio, latitude, and altitude.

Argentina displays high environmental variability. However, despite the completion of several comprehensive zonations of intrinsic scientific value, the country lacks an ecological zonation with objectively and precisely delimited units that may be repeated through time**.** The objective of this study was to identify and map the Holdridge life zones present in Argentina. Available climatic data were integrated at 1 km spatial resolution. The applied model revealed high environmental heterogeneity, with a total of 83 life zones. Of this total, 72 corresponded to life zones in the original triangular model of 120 life zones described by Holdridge, and 11 were new life zones, extending the original model to a total of 131. The model recognized five latitudinal regions, from boreal to tropical, and seven altitudinal belts, from basal to nival. Northwest Argentina contained the highest concentration of life zones. The life zones with the most geographic extent are Warm Temperate Dry Forest (15 percent of the nation) and Subtropical Dry Forest (9 percent), while Warm Temperate Alpine Wet Tundra and Subtropical Alpine Wet Tundra covered less than 0.1 percent. A wide range of biotemperatures, precipitation levels, and elevations, and their diverse combinations, explains why so many life zones are present. Several factors influence climatic systems operating in Argentina, including its geographic location and north-south latitudinal extension (from about 21° to 55° S); the presence and characteristics of different portions of the Cordillera de los Andes (which reach elevations of up to 7000 m above sea level) in the west; the eastern lowlands; and the circumpolar oceanic current and related currents in the southern Pacific and southern Atlantic Oceans. Application of the Holdridge system to Argentina resulted in an objective, detailed, and precise country bioclimatic zonation that highlights its environmental heterogeneity, which supports natural ecosystems, cultivated species, agriculture, forestry, and livestock production. This assessment can serve as a useful tool for evaluating the spatial evolution of climate change, land management and other sociocultural aspects, biodiversity conservation, and other objectives.

Keywords: Bioclimate of Argentina, Holdridge life zones, latitudinal regions, altitudinal belts, life zones richness, coverage and distribution.

Resumen

Derguy, María R.; Frangi, Jorge L.; Drozd, Andrea A.; Arturi, Marcelo F.; Martinuzzi, Sebastián. 2019. Mapa de zonas de vida de Holdridge: República Argentina. Gen. Tech. Rep. IITF-GTR-51. San Juan, PR: U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry. 48 p.

La zonificación ecológica es una herramienta fundamental para el manejo del territorio y de los ecosistemas. El modelo de Holdridge es un sistema de zonificación ecológica que identifica unidades bioclimáticas (zonas de vida) en base a las variables biotemperatura, precipitación (P), evapotranspiración potencial (EVP), cociente EVP/P, latitud, y altitud. Argentina presenta una gran variabilidad ambiental, sin embargo, y a pesar de existir de numerosas zonificaciones comprehensivas de valor científico intrínseco, el país no cuenta con una zonación ecológica detallada cuya unidades estén definidas objetiva y precisamente y pueda ser repetida en el tiempo. La finalidad de este estudio fue identificar y mapear las zonas de vida de Holdridge presentes en Argentina. Se integraron datos climáticos disponibles a una resolución espacial de 1 km. El modelo aplicado a la Argentina reveló una gran heterogeneidad ambiental, con un total de 83 zonas de vida. De ellas, 72 correspondieron a zonas de vida ya descritas por Holdridge en su modelo triangular original de 120, y 11 zonas de vida fueron nuevas extendiendo el total de ellas a 131. El modelo aplicado reconoció5 regiones latitudinales desde boreal a tropical y 7 fajas altitudinales desde basal a nival. El noroeste de Argentina mostró la mayor concentración de zonas de vida. El Bosque Seco Templado Cálido (15 por ciento del territorio del país) y el Bosque Seco Subtropical (9 porciento del territorio del país) fueron las zonas de vida de mayor extensión geográfica, mientras que la Tundra Muy Húmeda Alpina Templada Cálida, y la Tundra Húmeda Alpina Subtropical representaron menos del 0,1 por ciento del territorio. Los grandes rangos que presentan la biotemperatura, precipitación y altitud sobre el nivel del mar como sus diversas combinaciones, explican el elevado número de zonas de vida.Varios factores influencian los sistemas climáticos que operan en Argentina. Ellos incluyen su ubicación geográfica principal en latitudes medias, la gran extensión latitudinal N-S (desde casi 21° a 55° S), la presencia, al oeste, de la Cordillera de los Andes (que alcanza elevaciones de hasta casi 7000 m sobre el nivel del mar) con porciones de diferentes características así como el predominio de planicies y tierras baja al este, y el efecto de la corriente oceánica circumpolar y otras corrientes derivadas de ella que intervienen principalmente en los océanos Pacífico sur y Atlántico sur. La aplicación del modelo de Holdridge para Argentina resultó en una zonificación bioclimática objetiva, detallada y precisa del país que destaca la gran heterogeneidad ambiental del mismo para la vida espontánea, los cultivos y la producción agropecuaria y forestal, al mismo tiempo que puede emplearse como una herramienta útil para evaluar la evolución espacial de cambios climáticos, el uso de la tierra y otros aspectos socio-culturales, la conservación de la biodiversidad, y otras finalidades.

Palabras clave: Bioclima de Argentina, zonas de vida de Holdridge, regiones latitudinales, pisos altitudinales, riqueza, cobertura y distribución de zonas de vida.

Contents

Introduction

A fundamental first step in designing an ecosystem management program is the delineation and classification of ecologically homogeneous units. The basic attributes of the system being managed could be derived from existing maps or classification schemes (Lugo et al. 1999). In particular, an efficient ecological zonation should be based on quantitative variables and be sensitive to changes in environmental factors affecting the development or the spatial distribution of ecosystems. Moreover, to be applicable worldwide, it should be defined by factors that can be applied at the same scale (Céspedes and Tosi 2000).

The Holdridge Classification System

Leslie R. Holdridge (1947, 1967, 1979) developed a model based on the characterization and mapping of bioclimatic units (fig. 1). The model has an empirical and objective basis and defines the conditions for ecosystem function through its first-level ecological unit, the "life zone" (Lugo et al. 1999). The life zone concept was originally described in 1889 by Clinton H. Merriam (McColl 2005) as a way to characterize areas with similar communities of plants and animals. Merriam observed the correspondence between (1) the changes in communities that develop at a similar elevation when latitude increases and (2) these changes at certain latitudes when elevation increases. Because latitude and altitude show relationships with some climatic factors, these observations are an expression of the importance of climatic conditions in the existence of different life forms and vegetation physiognomies (McColl 2005).

According to Holdridge (1947), a life zone is a natural ensemble of associations defined by three variables that limit the development of biological processes and that can be expressed in a logarithmic scale to convey the influence of heat and water on biological responses. These variables are (1) mean annual biotemperature (MAB), (2) total mean annual precipitation (P), and (3) the ratio of potential evapotranspiration (EVP) to precipitation (EVP/P) (fig. 1).

Mean annual biotemperature is the mean of temperatures (heat) estimated to produce vegetative growth of plants in relationship with the annual period (Holdridge 1967). Total mean annual precipitation is the quantity of rain and snow falling each year per square meter. Potential evapotranspiration is the maximum quantity of water that can be annually evaporated and transpired by an ecosystem per square meter. Holdridge (1967) calculated EVP with an equation in which EVP depends on biotemperature. The EVP/P is the quotient of mean annual potential evapotranspiration to average total annual precipitation, which provides an index of ecosystem humidity conditions (Yue et al. 2001).

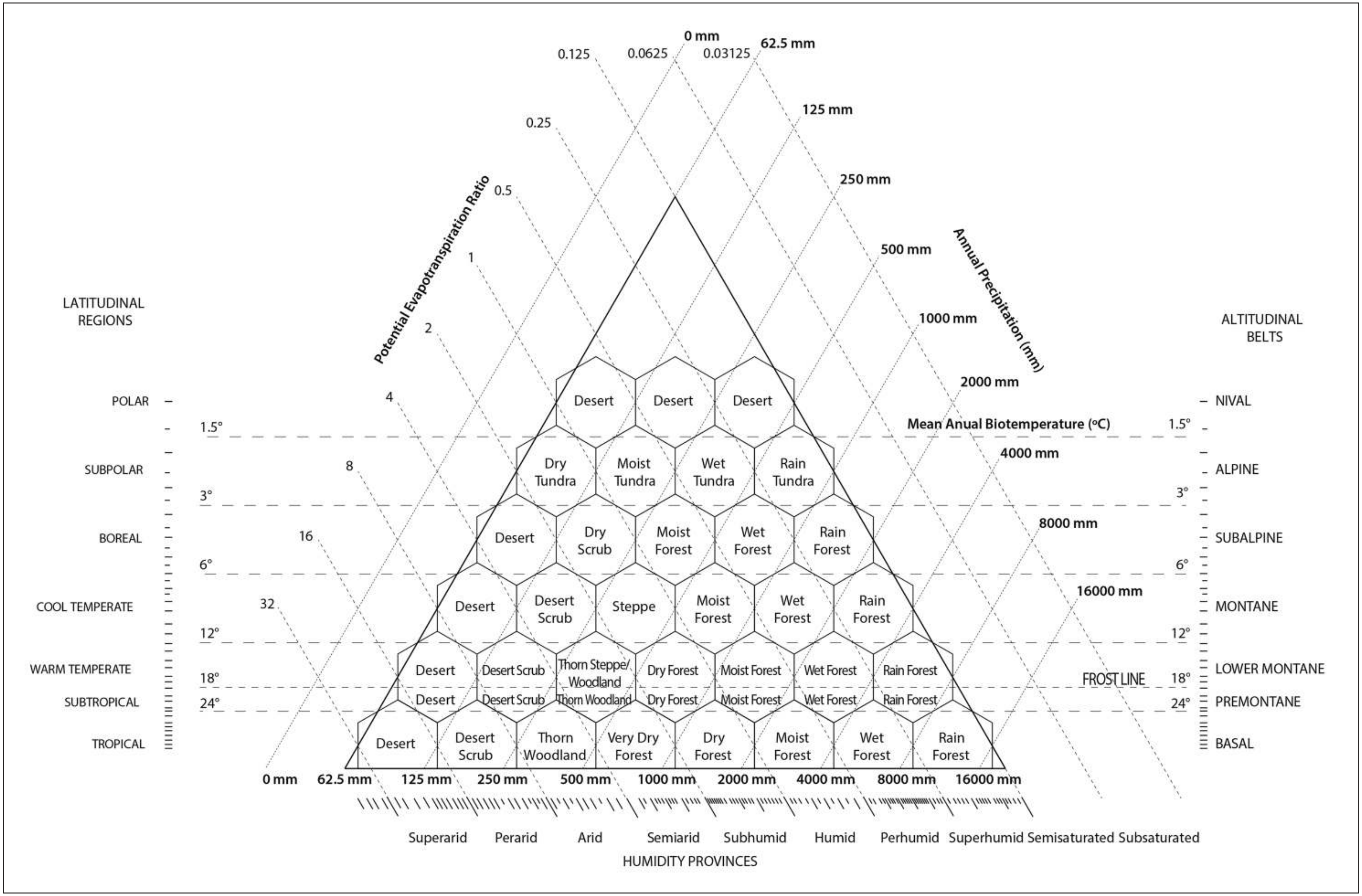

Figure 1—Holdridge life zones classification system.

These bioclimatic variables define three zonation systems: (1) **latitudinal regions** based on their heat distribution at sea level (basal biotemperature) (fig. 2), (2) **altitudinal belts** based on their heat distribution at the terrain surface (elevation level) biotemperature (fig. 2), and (3) **humidity provinces** that are a function of the EVP/P ratio (see fig. 1).

Life zones were denominated by the author with a name referring to vegetation physiognomy, and so reflecting the relationship between climate and natural vegetation observed and established by Holdridge, specially based on his research experience in the tropical mountains of the Americas. However, life zone names may not coincide or correspond to the observed vegetation cover. The life zone is the first hierarchy of environmental categories in the Holdridge model and does not include other factors affecting vegetation type such as soil, drainage, salinity, slope, aspect, strong winds or mist, and various precipitation patterns (see, for example, Jiménez-Saa 1993). These variables are considered in a second level of classification, the association, a natural unit in which vegetation, physical geography, geological formation, and soil are interrelated in a unique combination with a typical aspect or physiognomy (Holdridge 1979).

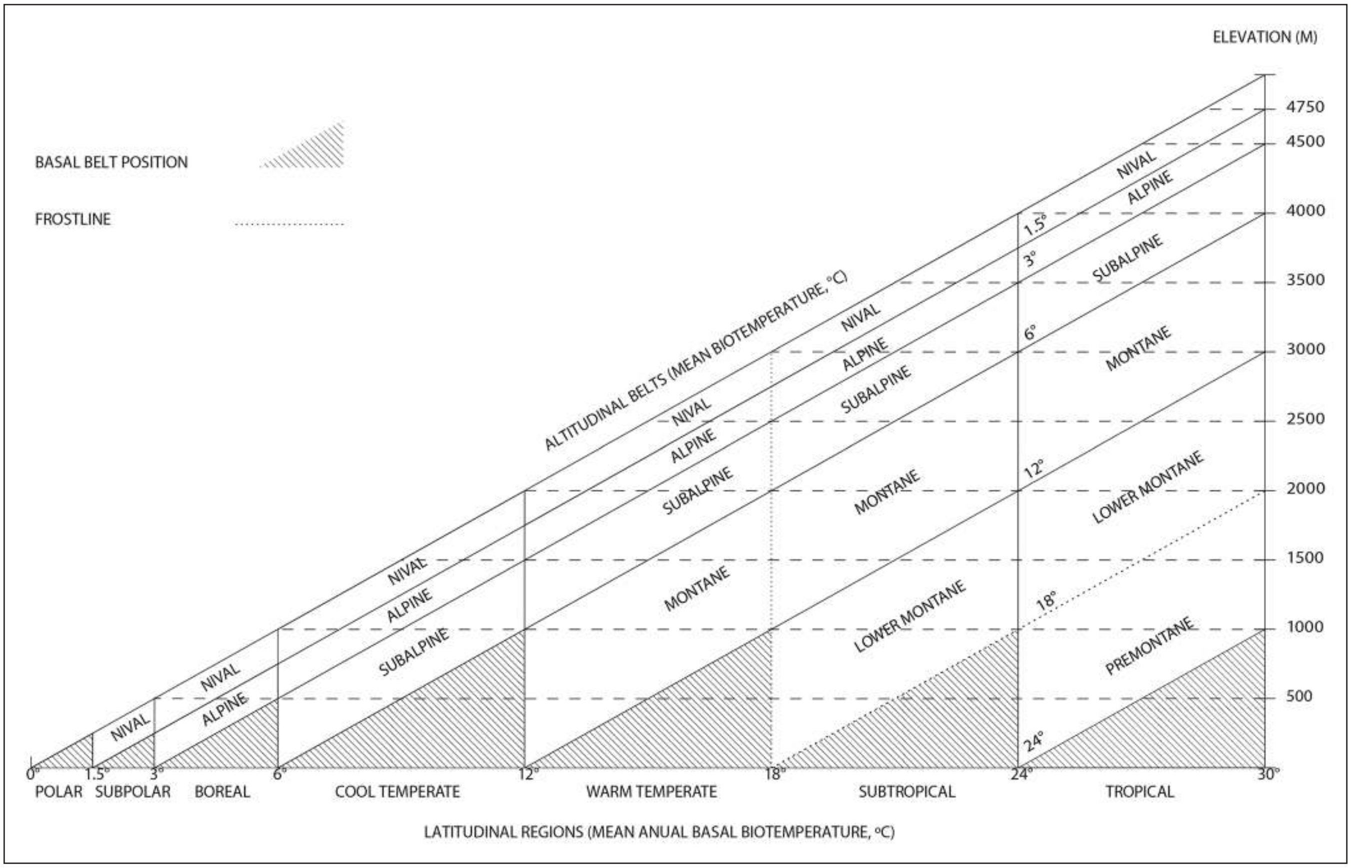

Figure 2—Latitudinal regions and altitudinal belts in the Holdridge life zone system.

Matteucci and Colma (1982) stated that the main innovations of the life zone system were the use of (1) the expression of the factor heat as biotemperature, and (2) a logarithmic progression for heat and precipitation increments. Employing them, they obtained significant changes in the natural vegetation units.

Previous Use of the Holdridge System

Holdridge's ecological model was applied mainly to the tropical and subtropical zones of the Americas: Perú (Tosi 1960), Honduras (Holdridge 1962a), Colombia (Espinal and Montenegro 1963), Venezuela (Ewel and Madriz 1968), Paraguay (Holdridge 1969), Costa Rica (Tosi 1969), Panamá (Tosi 1971), Puerto Rico (Ewel and Whitmore 1973), Bolivia (Unzueta 1975), Brasil (Tosi 1983, Tres 2016), and Nicaragua (Holdridge 1962b, Mendoza et al. 2001). It was also applied in the United States (Lugo et al. 1999), the People's Republic of China (Yue et al. 2001), Russia (Kirilenko and Salomon 1998, Krankina et al. 1997, Wieder et al. 2006), and India (Chakraborty et al. 2013). Furthermore, a low-detail worldwide map of life zones is available (IIASA 1989).

Why Apply the Holdridge System to Argentina?

Argentina has a great diversity of ecological systems that have been described in a range of biogeographical, physiognomical, and ecoregional zonation schemes and maps with different aims and scales (e.g., Brown and Pacheco 2005; Burkart et al. 1999; Cabrera 1971, 1976; Cabrera and Willink 1973; Castellanos and Pérez Moreau 1944; Dinerstein et al. 1995; Frenguelli 1941; Hueck 1972; Hueck and Seibert 1988; Morello 1986; Morello et al. 2012; Ragonese 1967). However, despite the availability of several comprehensive zonations of intrinsic scientific value, the methodological approaches employed to establish their findings are rarely explicit enough to consider them objective approaches that can be replicated by other authors or at different times. Adding this fact to the evidence of historical and regional influences on present biodiversity patterns generates the need to explore and develop integrated new ecological classification approaches (Ribichich 2002).

The territory of Argentina is particularly worthy for analysis by using the Holdridge system because of its large latitudinal range and wide altitudinal range in southern South America, which has given Argentina considerable bioclimatic heterogeneity and consequently a high richness of life zones. The main objective of this study is to apply the Holdridge life zones model to Argentina to characterize its bioclimatic environmental heterogeneity. We also present a descriptive summary of relevant information on climate, geography, geomorphology, and oceanic currents as the main drivers of bioclimatic heterogeneity and spatial distribution of life zones in Argentina.

Materials and Methods

Study Area

Argentina occupies 2 791 810 km^2 and encompasses a latitudinal range of 33° that extends from its proximity to the Tropic of Capricorn at the confluence of the Grande de San Juan and Mojinete Rivers (21°46'S), province of Jujuy, to Cape San Pío (55°03'S), Isla Grande of Tierra del Fuego (IGN 2016).

Argentina's environmental heterogeneity is considered the result of at least several factors related to its latitudinal range, such as temperature, geomorphology, and the shape and location of the country in the southern cone of South America relative to oceanic water masses, prevailing air and water currents, and the Cordillera de los Andes (Morello and Mateucci 2000). Moreover, Argentina is integrated by different geological provinces (Ramos 1999a).

Relief and Geology

Argentina presents a complex relief and geology. Thus, it is important to highlight the marked contrast between the country's western mountains and eastern lowlands (fig. 3). This contrast is mainly due to the long and elevated Andes cordillera and its association with other more ancient mountain systems affected by the Andean orogeny. This mountain complex has a continentally dominant north-south direction, along which elevations diminish toward the south, and different sectorial geomorphic features that partly reflect differences in the subduction process of the Nazca plate under the South American plate (Ramos 1999a, 1999b, 2007). The high mountain relief in western Argentina is the source of sediments deposited in the lower elevation eastern plains. The main trend of rivers in Argentina is to flow in a general west-to-east direction, except for rivers in the country's Mesopotamia region, which flow north to south (Morello and Mateucci 2000).

In the Argentinian-Chilean domain, Tassara and Yáñez (2003) recognized three cordilleran sectors:

1. **Central Andes** (22° to 33.5° S). This is the most elevated sector, with peaks that exceed 6000 m above sea level (asl). Ramos (1999a, 2007) noted that, in the most northern portion (18° to 24° S), the width west to east of the elevated intermountain land attains its maximum distance to the Chilean continental–ocean margin (about 700 km). This portion of the Central Andes includes the Western cordillera, the "altiplanicies" (high mountain plains), and "bolsones" (large geomorphic depressions without external drainage) of the Puna with a chain of active volcanoes, the folded and shifted lands of the Eastern Cordillera, and the Subandean mountains. There is another portion (28° to 33° S) in which the Principal Cordillera and the Frontal Cordillera are not associated with active volcanoes.

Figure 3—Geological provinces of Argentina. Source: Ramos 1999b.

2. **South Andes** (33.5° to 47° S). Subduction shows a Benioff angle similar to that of the north portion of the Central Andes but one that causes lesser deformation, and there are active volcanoes (e.g., Tupungato) that form a magmatic chain toward the south, with the cordilleran zone involving only the Principal Cordillera and restricted to 300 km of the western South American continental margin. The extra-Andes Region contains signs of volcanic activity in the form of large basaltic plains like those in the Payunia nature reserve.
3. **Austral Andes** (47° to 56° S). Its septentrional portion is continental and corresponds to the Patagonic Andes extending from Lanín Volcano (3376 m asl) to the Magellan Strait, with a mean altitude of about 1500 to 2000 m asl and some peaks >3300 m asl (e.g., Tronador, 3478 m asl, and Fitz Roy, 3375 m asl). This portion includes a transitional zone without volcanic activity between about 46° to 49° S, and contains magnificent continental ice fields. The second portion is more meridional and occupies the extreme south of the continent and the Fueguian archipelago, where the cordillera changes its direction from north-south to west-east, with its maximum height at Mount Darwin (2488 m asl) in the Chilean sector of the Isla Grande of Tierra del Fuego. The orientation of the Fueguian cordillera is parallel to that of the dominant western winds and to the oceanic circumpolar current watering the coasts of Isla Grande, Isla de los Estados, and other insular systems.

The plains dominate east of the Andes, where they are known as Chaco-Pampean plains and the Patagonian plateau (fig. 3). The Chaco-Pampean plain is a huge lowland extending in the east from north of the center of the country in a vast basin covered by sediments less than 2 million years old (Folguera and Zárate 2009). In its northern portion, the Pilcomayo, the Bermejo, Juramento, and Salado Rivers flow through the Chaco plains from northwest to southeast. The Paraguay and Paraná Rivers flow north to south along the eastern border of the Chaco plain, associated in Argentinian territory with their watersheds (Iriondo 1987). The Chaco component of the plains extends through the northern, central, and eastern portions of Argentina and continues farther north into southwest Paraguay and southeast Bolivia. In the western Chaco-Pampean lowlands, there are some north-south-oriented mountain systems that are elevated in a discontinuous pattern over the plains. These mountains in the Sierras Pampeanas region include the Nevados de Aconquija in the provinces of Tucumán and Catamarca (Cerro del Bolsón, 5552 m asl), the Sierras Grandes of Córdoba (Mount Champaquí, 2884 m asl), and the Sierras of San Luis in the province with the same name (Cerro Agua Hedionda, 2150 m asl). The Pampean portion of the lowlands has two mountain systems in the province of Buenos Aires oriented northwest to southeast. The lowest is the septentrional (named Tandilia, Cerro La Juanita, 524 m asl), and the tallest is the meridional system (known as Ventania, Cerro Tres Picos, 1238 m asl), which causes a zonal cooling effect (Burgos 1968). In the province of La Pampa are low mountains ("sierras") known as the Sierras Mahuidas (e.g., Lihue Calel, Choique Mahuida, and Pichi Mahuida), an old system that originated about 2.5 billion years ago from lava eruptive events located near the Chadileuvú-Curacó River system and composed of some isolated hills (ca. 600 m asl) rounded by erosion. The Pampean plains reach their border with Patagonia at approximately 39° S.

The easternmost lands of Argentinian territory, the Mesopotamia, are surrounded by major rivers. These lands include gentle landscapes and the Paraná River Delta in the province of Entre Ríos, flatlands and lowland freshwater wetlands ("esteros") dominating the province of Corrientes, and a hilly landscape in the province of Misiones, with its highest peak, Cerro Alegría (843 m asl), in northeast Misiones near the Argentina-Brazil border. These hills form a divide between the Paraná and Uruguay Rivers.

The Patagonian plateau is located south of the Huincul fault that extends from west to east at ca. 39° S (Ramos et al. 2004). In its western side bordering the Andes, there is a narrow fringe with low mountains, hills, and small plains frequently covered with wet short prairies (locally called "mallines"). In southern Patagonia, sandy deposits are commonly found at the east side of the Andean lakes protruding toward the border between Andean and extra-Andean Patagonia. However, extra-Andean Patagonia is mainly a stepped table land that descends from about 1000 m asl in the west toward the Atlantic coast in the east, where there are centripetal (endoreic) basins. There are also mountains, hills, depressions, dunes, fluvial valleys of major rivers that originate in the cordillera, steep coasts with cliffs, beaches, and tidal rivers ("rias").

The Malvinas Islands archipelago has a relief that reflects the action of glaciers until a few thousand years ago, presenting gentle hills with their maximum elevations located toward of the northern ends of both main islands: Mount Adam (on Gran Malvina Island) at 700 m asl, and Pico Alberdi (on Soledad Island) at 705 m asl (Aldiss and Edwards 1999, Otley et al. 2008).

Climate Components and Resulting Climatic Conditions in Argentina

The marked oceanicity of the Southern Hemisphere is magnified at the southern cone of South America, where the ocean has a strong regulatory effect on climate in general and of temperatures in particular (Frangi et al. 2015). The continent notably narrows at warm- and cool-temperate latitudes, where the influence of maritime currents and water masses over the mainland and islands accentuates, attenuating winter and summer extremes of temperature and resulting in low thermal amplitudes (Morello 1986). Moreover, the Andes cordillera and some other elevated orogens produce a marked effect on surface temperatures, air mass circulation, and precipitation distribution.

Different climatic components intervene in air mass circulation and in the transport, distribution, and precipitation regime in Argentina:

1. **The location and behavior of permanent anticyclones localized in the southeastern Pacific Ocean** (ca. 25–35° to 90° S) **and the southern Atlantic Ocean** (ca. 20° to 35° S) that displace toward the north in winter and the south in summer (cf. Hoffmann 1992). The southeastern Pacific anticyclone participates in the role played by permanent western winds at high latitudes, where they predominate the entire year. The southeast Pacific anticyclone is the source of cold air masses that cause winter precipitation mainly in southern Chile and the Austral Andes, as well as strongly reduced precipitation in the eastern slopes of the cordillera. This effect is produced when orography induces winds to ascend Andean western flanks to surpass the cordillera, except for those places where transversal low-elevation valleys allow humid winds to enter directly into Argentina, producing very high precipitation levels. After passing the Andes, cold wind masses cross extra-Andean Patagonia toward the east, but in part turn to the northeast, passing diagonally through the country toward lower latitudes. North of 40° S, the high elevations of the Central Andes impede the flow of polar western air masses to Argentina from the Pacific. The south Atlantic anticyclone generates humid air masses that enter the continent in an anticlockwise direction, first encountering some mountains of moderate elevation in southeast Brazil that do not impede its precipitation supply to Argentina north of 40° S, especially in eastern Argentina, where it reaches its maximum in

the province of Misiones. Precipitation distribution displays a year-round regime in northeast Argentina but gradually acquires a seasonal summer pattern of maximum precipitation with annual total rains decreasing toward the west and center of the country, where some local variability is observed owing to orographic effects. In summer, pressure differences between the mentioned oceanic anticyclones and the continental low are higher than in winter, contributing to higher summer precipitation in northern Argentina.

2. **The influence of both oceanic south Pacific and Atlantic anticyclones on the climate of northwest Argentina.** In summer, the low-pressure zone known as a "thermal low" extends in the Chaco Plain from the Llanos of La Rioja to the Chaco of Salta, coinciding with the so-called heat tongue ("lengua de calor") determined by the 48 °C isotherm of absolute maximum temperature. Northwest of this region, the tropical characteristics accentuate (Bianchi et al. 2005). These characteristics in northwestern Argentina are regulated mainly by four related systems:
    1. The **Bolivian High** (HB), a high-pressure tropospheric center located at 19°S 60°W, feeding (during the warm season in the Southern Hemisphere) heat and humidity proceeding from the latent heat released by convective activity over the Amazon basin and Central Andes (Ferreira et al. 2004).
    2. The **Chaco Low** (LCH), a low-pressure center confined to the low atmosphere of the Great Chaco in eastern Bolivia, west of Paraguay and north of Argentina. The LCH is linked to the HB. The LCH originates in surface warming resulting from radiative fluxes and latent heat and is a relatively weak low-pressure center elongated in a meridian direction from the southern portion of the Amazon basin to northwest Argentina. It is present during the rainy season, operating like an energy source (Ferreira 2008, Schwerdtfeger 1976).
    3. The **Northeast Low** (NEL) is a tropospheric low-pressure center accompanying the Bolivian High, located over the Atlantic coast between the latitudes of 0° and 10° S. The **Argentinian Northwest Depression** ("La Depresión del Noroeste Argentino" or DNOA), with its center located at 30°S 66°W near the meteorological station La Rioja (National Meteorological Service, SMN) in proximity to the mountain eastern slope, is immersed in the cyclonic system LCH and is sometimes positioned at latitudes of about 40° S (Ferreira 2008, Ferreira et al. 2010, Lichtenstein, 1980). The DNOA is present year-round with a similar high seasonal wind frequency and a more intense intermittent behavior in winter as well as more intense and longer events in summer

(Ferreira 2008, Ferreira et al. 2010). At the end of November, the LCH intensifies, generating an increase in the pressure gradient between the center of South America and the northeast Sahara in Africa. As a result, the intensity of northeastern trade winds increases, producing a positive anomalous flux of humidity toward the South American continent. The winds penetrating from northeast Brazil are channeled to the south of the continent by the Andes, forming the South American Low Level Jet (SALLJ), whose manifestation is an input of warm tropical air toward southern Brazil and northwest Argentina, mainly in summer (Lenters and Cook 1997, Marengo et al. 2002). These low-level winds incorporate humid air, resulting in precipitation along the South Atlantic Convergence Zone (SACZ) (Lenters and Cook 1997, Marengo et al. 2002, Saulo et al. 2010). According to Ferreira et al. (2010), the DNOA is a low-pressure system that became important because of its role together with the Chaco Low and the SALLJ in the exchange of air masses among the tropics and extra-tropics, modulating the transport of heat and humidity to southern South America (Saulo et al. 2004, Seluchi and Marengo 2000, Vera et al. 2006).

4. Other components involved in the Argentinian climate are the location of **marine and continental low- and high-pressure centers** that emerge under certain particular synoptic conditions, such as those leading to southeastern winds (locally “sudestadas”), Zonda wind (similar to Foehn), north winds, and the advance of cold fronts (Lamas and Maio 2011).

Temperatures in Argentina decrease from north to south and toward higher elevations in the mountains. Some data exemplify these trends. Mean annual temperature at low elevations in the north is ca. 23 °C and in Ushuaia is ca. 5.8 °C. Owing to the altitude of the highest mountains in the country (>6500 m), mean temperatures at their peaks are lower than 0 °C. At a latitude below 35° S, both the cooling mountain effect with elevation increase and at the foot of the mountains and the Atlantic oceanic water buffering effect near the coast are noticeable as indicated by the mean annual isotherms running from the northwest to the southeast. Between 35 and 27° S, isotherms present a different gently undulated pattern, indicating a mountain cooling effect (at the same latitude) to the immediate east side of elevated systems. After that, higher temperatures are generated to the west and east of the center of the country. At latitudes north of 27° S, outside the piedmont zone, the north zone of the Chaco plain presents more or less constant temperatures at the same latitude.

The Andes and other elevated mountain systems produce a prominent effect on surface temperatures, wind circulation, and precipitation distribution. North of latitude 40° S, the beginning of the precipitation season is preceded by the migration to the south of trade winds and the Intertropical Convergence Zone (ITCZ) (Kousky 1988, Liebmann and Marengo 2001) through the interaction between HB, NEL, LCH, and DNOA, previously described. Warm fronts in Argentina, generally proceeding from the northwest, do not sufficiently progress to the south; inversely, nor do southwestern cold fronts in their advance toward the north and northeast. Cold masses are the main cause of precipitation in central and northwest Argentina, when they meet warm and humid fronts (Kousky and Gan 1981, Woelken 1954). In central and northwest Argentina, precipitation decreases from the east to the sub-Andean Sierras and the Oriental Cordillera in the west, where wind rise is orographic and produces an increase of precipitation up to an elevation where precipitation begins to decrease with the increase in altitude. Finally, in the Puna, on the altiplano, precipitation ranges from about 400 mm in La Quiaca to almost zero at the Argentina-Chile border (Atacama Desert). In northwest Argentina, however, there is a great heterogeneity in climatic conditions as revealed by the presence of very different vegetation types (Bianchi et al. 2005; Buitrago 1999; Cabrera 1971, 1976) such as different forests, grasslands, Prepuna vegetation, and Puna vegetation *sensu lato*. For example, the Puna is an arid, isolated, and highly elevated surface, where nearly all net radiation is available to heat land because heat consumed by evaporation is not significant owing to the near absence of precipitation, and where strong currents of warm air rise upward, compensated by colder air from the free atmosphere to the east of the altiplano and from pronounced valleys descending from the eastern border of the Puna toward the lower region (Buitrago 1999). Moreover, in the province of Jujuy, the zonal wind known as Norte develops, and, like the Zonda in Cuyo, carries very hot, drying air into the valleys. Bobba and Minetti (2010) considered the types of anomalies in South American atmospheric circulation and their influence on the droughts in northwest Argentina in different seasons. South of the previously mentioned desertic zone, at ca. 27° to 31° S, the slopes of the Cordillera have somewhat higher winter precipitation. Between latitudes 31° and 33° S, precipitation reaches about 400 mm, and between 35° and 36° S, it is around 1000 mm (Matteucci 2012). The other northern extreme in northeast Argentina shows an annual precipitation regime, but toward the west and southwest, precipitation is gradually concentrated in the warm period with a marked monsoon regime in northwest Argentina. The decrease in precipitation toward the southwest reaches a transitional zone near the Yellow Pampa Region ("Región de la Pampa Amarilla") from 34° to 42° S and 70° to 61° W) limiting with north of Patagonia, where interesting zonal changes have been observed in the last 50 to 60 years. One of them appears to be associated with changes in the surface temperature of the central-equatorial Pacific Ocean that produced a humid phase with higher summer precipitation, reduced winter rains in the center-north of the province of La Pampa, and a significant reduction in the center-southwest (Russián et al. 2015).

Permanent western winds predominate at 40° to 60° S. In continental territory, western winds face the southern portion of the Andes Cordillera, surpassing that relatively low barrier by climbing over it and showing a Foehn effect, in such a way that the main precipitation occurs on the windward western slopes (in Chile), reaching 5000 to 10 000 mm per year. In the province of Santa Cruz, from the Deseado River basin and Lakes Buenos Aires and Pueyrredón to the Gallegos and Chico Rivers basins, precipitation decreases sharply at the lee side and over extra-Andean Patagonia, and near the Atlantic coast precipitation is very scarce. Precipitation in Patagonia has a winter regime. Western or southwestern winds blowing from Patagonia generally produce cold fronts advancing toward the northeast of the country. In summer, cold fronts frequently stop and become stationary fronts north of Buenos Aires and Entre Ríos, but sometimes continue advancing too far north into warm areas. In winter, cold fronts penetrate lower latitudes at the north of the country and precipitation is mainly associated with them. Sporadically, winter cold fronts advance into Bolivia, Perú, and Brazil affecting lowlands up to around 3000 m asl even at latitudes ca. 10° S. Over the Austral Andes in the continent, low elevations produce 1000 to 5000 mm of precipitation on mountain slopes. In the continent, southern extreme and in Tierra del Fuego, at a latitude ca. >52° S, western winds blow parallel to the Fueguian Cordillera. Circumpolar western winds and extreme high latitude oceanic conditions are the cause of low temperatures, low thermal amplitudes, and a year-round precipitation regime. Moreover, in Tierra del Fuego, temperatures diminish and annual precipitation increases with elevation, whiles now is seen in mountain peaks even in January (summer) (Frangi et al. 2004, Iturraspe et al. 1989).

Finally, oceanic currents contribute to determining the climates of Argentina, particularly the oceanic circulation of the southern cone of South America (Bastida et al. 2007, De Haro 2012, FCMAP 2008, Piola 2008, Piola and Matanó 2001). A current with unique characteristics on Earth is the cold circumpolar sub-Antarctic water current that encircles the planet at latitudes 40° to 60° S, driven by the belt of permanent western winds in the Southern Hemisphere. This circulation is facilitated by an oceanic circumpolar corridor only partially interrupted by the southernmost territories of South America, which end at about 56° S without forming a complete barrier. There are two consequences to mention. On one hand, the Austral archipelago is surrounded by cold waters with a very low thermal amplitude (e.g., the ocean temperature at Ushuaia: annual mean 7 °C, January 9 °C, July 6 °C) defining an extreme oceanic climate. On the other hand, the partial interruption is the appearance of several currents to the south of the South American continent. In the South Pacific Ocean, the northern fringe of the sub-Antarctic circumpolar ocean current, as it approaches the southern coasts of South America, gives rise to two more or less parallel branches (one oceanic and the other coastal) of the Humboldt current that carries cold water from the south of Chile to Peru and Ecuador in the north. Both branches of cold waters are separated by a wedge of warm water of the countercurrent of Peru that goes from north to south. Part of the southern fringe of the Sub-Antarctic circumpolar current, it finds the Chilean austral coasts at latitude close to Puerto Montt (40° S), and heads south with the name of Cape Horn current, where it meets again the circumpolar current to watering the most austral coasts of the continent before entering the Atlantic Ocean and forming the Patagonic current moving north to northeast near the shore. But a major branch of the circumpolar current moves both superficially and at great depth, where its trajectory is affected by the submarine relief. Once it has traversed the Drake Passage, the major branch then moves northeast as the Malvinas Current, bringing very cold water to the Malvinas Islands archipelago.

Sources of Climatic Data

The climatic data used to estimate life zones were obtained from the Digital Climatic Atlas of Argentina (Bianchi and Cravero 2010b). The Atlas of the National Agricultural Technology Institute (INTA) provides climate information at a national scale with a spatial resolution of 1 km. In this study, we employed total annual mean precipitation and monthly mean temperatures. INTA climate data is historical information that covers different time periods. In particular, the precipitation map is derived from a map of precipitation isolines based on data on the 1921 to 1961 period, using spatial interpolation procedures and corrections by local experts (Bianchi, pers. comm.). Monthly temperatures were obtained through a linear model that used altitude, latitude, and precipitation, adjusted with temperature data from the 1986–2000 period, the layer of total mean annual precipitation, and a digital elevation model (Bianchi and Cravero 2010a).

Because the objective of this study was to determine life zones under the recent decade's climatic conditions, we established the relation between data from the INTA Climatic Atlas and available daily temperature and precipitation data from the period 1981–2010 as registered at 80 meteorological stations around the country and provided by the National Meteorological Service of Argentina. Both datasets for the 80 locations were compared with the Pearson correlation coefficient.

Calculation of Life Zone Variables

Biotemperature—

Biotemperature is a parameter related to the main physiological processes of vegetation. Mean temperatures lower than 0 °C and higher than 30 °C provoke a decrease in physiological processes. In the Holdridge temperature model, values outside this range (<0 °C to >30 °C) are considered equal to 0 °C when calculating biotemperature (Holdridge 1967).

In the present study, we observed that, in the Chaco Region, using such temperature limits gave some unconvincing results (lower than expected) in biotemperature calculation for a few particular, isolated locations with some summer temperatures above 30° C. Accordingly, we decided to replace all values >30°C with 30 °C, not with 0 °C. We observed that results were then similar in neighboring sites with the previously unconvincing and expected responses. In this way, based on mean monthly temperatures (MMT), we estimated mean monthly biotemperatures (MMB) by replacing values <0 °C with 0 °C and values >30°C with 30 °C. After that, we used MMB to calculate annual mean biotemperature (MAB) (equation 1).

$$\mathrm{MMB} = [(\mathrm{MMT} \leq 0) \times 0 + (\mathrm{MMT} > 0) \times \mathrm{MMT}] + [(\mathrm{MMT} \leq 30) \times \mathrm{MMT} + (\mathrm{MMT}>30) \times 30]$$

$$\mathrm{MAB} = \Sigma_{x=1}^{12}\ \mathrm{MMB}_{x/12} \qquad (1)$$

Precipitation—

We used the total annual precipitation mean expressed in mm (P).

Potential evapotranspiration ratio—

The potential evapotranspiration ratio (EVP/P) was obtained by fitting the MAB and P layers, according to Holdridge (1959) (equation 2).

$$(\mathrm{EVP/P}) = \mathrm{MAB} \times 58.93/\mathrm{P} \qquad (2)$$

As previously mentioned, this ratio is considered an effective index of ecosystem humidity conditions (Yue et al. 2001).

Setting Latitudinal Regions, Altitudinal Belts, and Humidity Provinces

The limits of latitudinal regions were established using the mean annual basal biotemperature (e.g., biotemperature at sea level) (Holdridge 1959). To change biotemperature values calculated at the surface elevation of field grid points into their equivalent values at 0 m (sea level), we used the mean lapse rate of -6.0 °C/km indicated by Holdridge (1967). This lapse rate was applied at each mean monthly temperature (MMT) by using altitude data (in meters) derived from a digital elevation model from the Shuttle Radar Topography Mission (SRTM–USGS, https://www.earthexplorer.usgs.gov) (equation 3). The resultant layers of mean monthly basal temperature (MMBT) were again adjusted to the range 0 to 30 °C to change them into mean monthly basal biotemperature (MMBB) (equation 4), and finally a mean of them was calculated to obtain the mean annual basal biotemperature (MABB) (equation 5).

$$\mathrm{MMBT} = (\mathrm{DEM} \times 0.006) + \mathrm{MMT} \tag{3}$$

$$\begin{aligned} \mathrm{MMBB} = {} & [(\mathrm{MMBT} \leq 0) \times 0 + (\mathrm{MMBT} > 0) \leq \mathrm{MMBT}] \\ & + [(\mathrm{MMBT} \leq 30) \leq \mathrm{MMBT} + (\mathrm{MMBT} > 30) \leq 30] \end{aligned} \tag{4}$$

$$\mathrm{MABB} = \Sigma_{x=1}^{12} \ \mathrm{MMBB}_{x/12} \tag{5}$$

MABB values that Holdridge established as limits among contiguous regions/belts were selected to draw isolines, with the following exception. The limit between the Warm Temperate and Subtropical Latitudinal regions is given by the frost line, the maximum biotemperature at which frosts are still registered. This value of biotemperature was proposed to be 18 °C, the mean value of the 12 to 24 °C biotemperature range in the model (Holdridge 1967). According to Lugo et al. (1999), a frost zone can be defined in practical terms as the area where temperatures equal or lower than 0 °C are registered at least once a year during 20 consecutive years.

Because the temperature data in the INTA Climatic Atlas are mean values estimated by a model, it was not possible to verify with them according to the criteria established by Lugo et al. (1999). So, we used the daily data of the SMN for the period 1980–2010. Specifically, we verified the criteria of 20 consecutive years with at least one frost per year at meteorological stations with a mean annual biotemperature >18 °C located at altitudes <1000 m asl. Once the stations were spatially located, we used the MABB to estimate a new value for the frost line. It was calculated as the mean of the MABB values of those meteorological stations. Confidence limits of the new frost line value were also calculated. By using this new biotemperature value, we could then place the frost line on the map.

The altitudinal belts were defined according to Holdridge (1967) considering the relation between MAB and MABB for each altitudinal belt (fig. 2).

Finally, humidity provinces where established based on logarithmic ranges for the EVP/P ratio (Holdridge 1967) (fig. 1).

Life Zone Determination

The calculated bioclimatic variables (MAB, P, EVP/P, and MABB) were categorized according to the logarithmic ranges established in the Holdridge classification (fig. 1). They also were combined to define life zones that consider the pertinent latitudinal region and altitudinal belts.

Neighboring life zone hexagons show transitional or ecotonal zones (fig. 4). In applying the model, the points for territory sites that result localized in the transitional zones are assigned to the nearest life zone by estimating the distance between the point and the centroid of the hexagon representing a life zone (Holdridge 1967). In this study, the transitional zones were assigned to a life zone employing a supervised classification procedure, by using the three variables in the Holdridge model (biotemperature, precipitation, and EVT/P ratio) applying the algorithm of minimum distances (Chakraborty et al. 2013).

During life zone determination, we observed that some points had fallen outside the limits of the Holdridge life zones diagram. The new life zone hexagons containing those points were located externally to life zones in the original triangular diagram. The new life zones needed to be defined and denominated attending the new combinations of variable ranges in the Holdridge system assigning also region and belt. Finally, we employed denominations of the humidity provinces to which new life zones pertained to complete their name. Note that Holdridge (1979: 10) warned about the presence of other local conditions in the world not represented in his diagram, which indicates the existence of other life zones that represent extensions of his diagram. This is what we found in Argentina.

The final product of the analysis is a life zone map of 1 km resolution printed at 1:4,000,000 scale.

The analyses were done with ArcGIS™ version 10.1, QGIS version 2.14.11, and R software.[1]

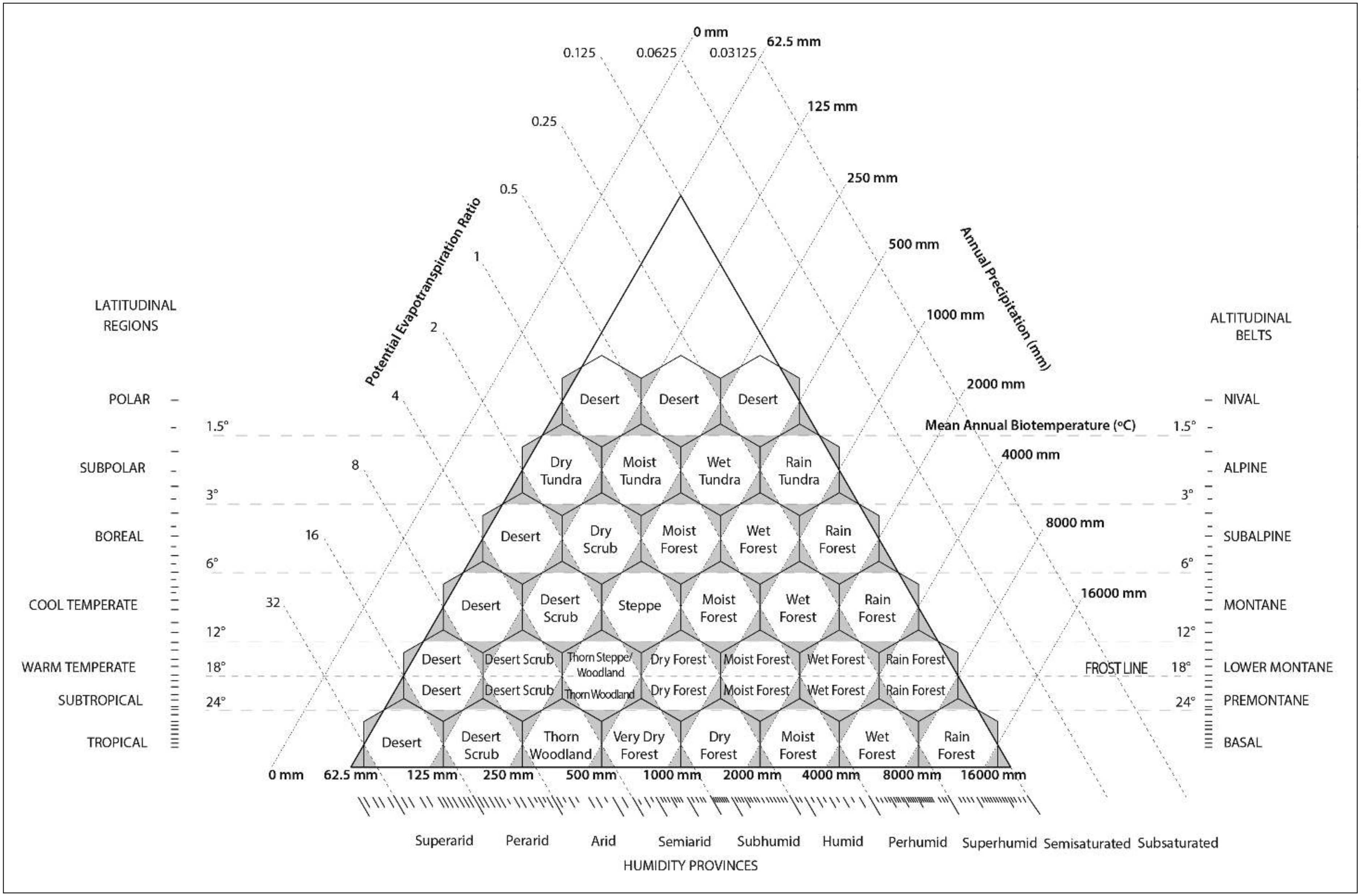

Figure 4—Contact zones among hexagons or transitional/ecotonal zones (grey). Modified from Holdridge (1967).

Results

Climatic Data Adequacy

The statistical comparison of mean annual temperature and mean annual precipitation in the datasets for 80 locations supplied by the SMN and obtained from INTA Atlas resulted in significant correlations for temperature ($r^2 = 0.96$, $P < 0.0000$) and precipitation ($r^2 = 0.99$, $P < 0.0000$) (fig. 5). Consequently, we deemed the complete dataset in the INTA Atlas to be adequate for determining life zones in Argentina.

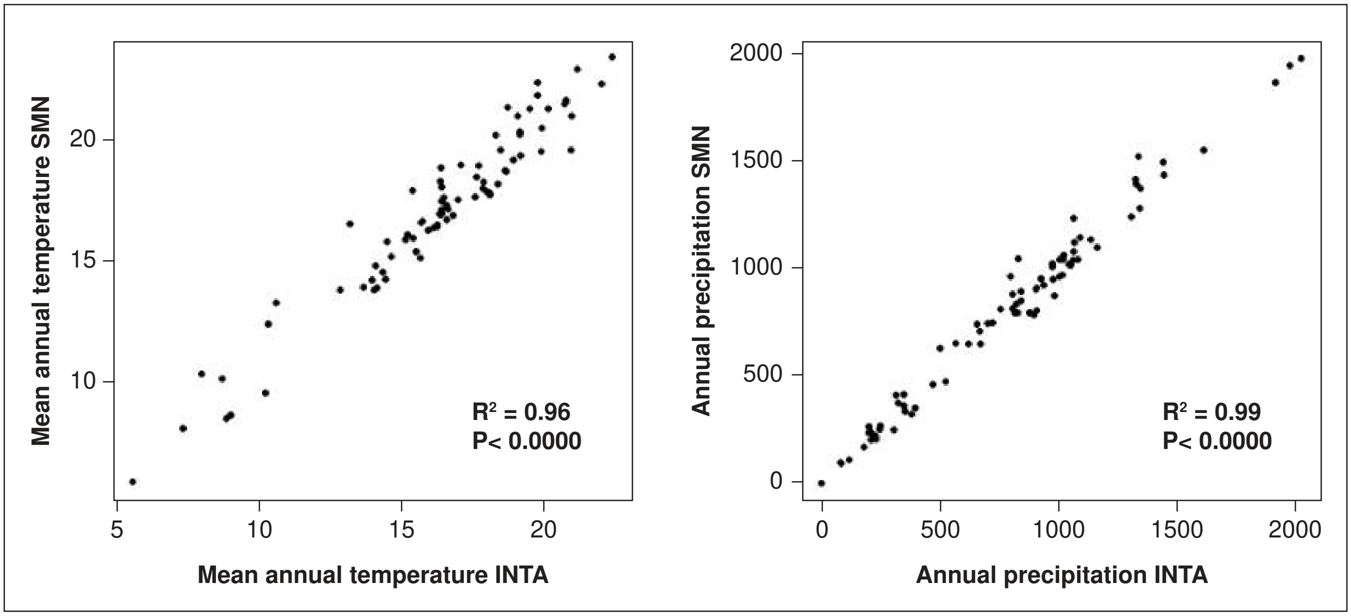

Figure 5—Air mean annual temperature and annual precipitation correlations obtained among data reported by National Meteorological Service (SMN) in 80 meteorological stations (1981–2010) (*y* axis) and data provided by the National Agricultureal Technology Institute (INTA) Digital Climatic Atlas (*x* axis) for the same stations.

Maps of Bioclimatic Variables

Figure 6 contains individual maps of Argentina with different bioclimatic variables: mean annual biotemperature at surface elevation, mean annual basal biotemperature at 0 m asl, total precipitation annual mean, potential evapotranspiration, and humidity provinces. These variables were calculated and categorized according to Holdridge's logarithmic ranges.

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

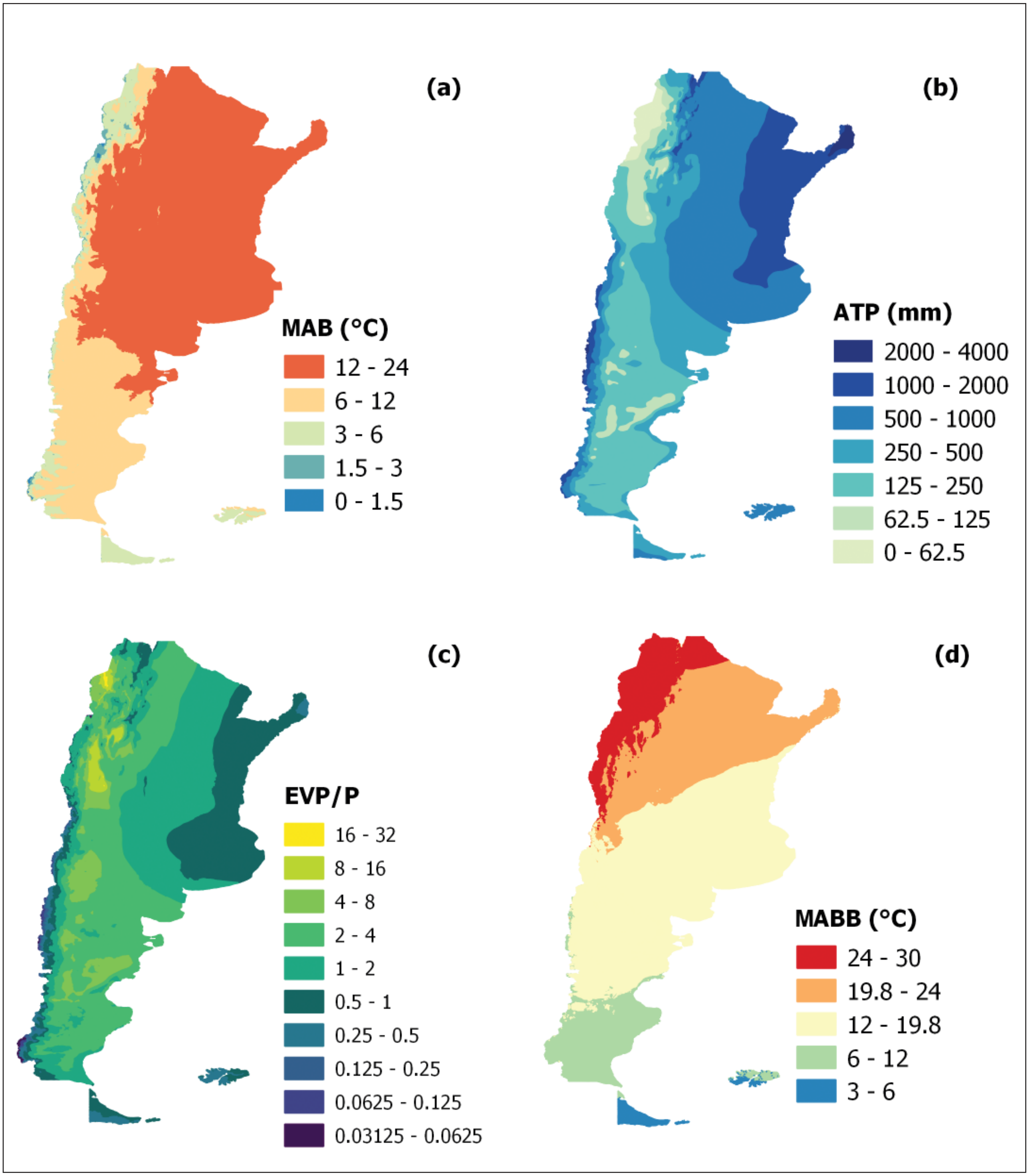

Figure 6—Bioclimatic variables categorized by logarithmic ranges (Holdridge 1967). References: MAB = mean annual biotemperature at surface elevation; ATP = accumulated annual (total) precipitation; EVP/P = evapotranspiration/precipitation ratio; MABB (°C) = mean annual basal biotemperature.

Frost Line (or Critical Line)

The value determined to be the frost line for Argentina was 19.8 °C (), with a standard deviation (S) of 1.27 °C and 95 percent upper and lower confidence limits of 20.5 °C ((), +($t_{13,0.95}$ × S)) and 19 °C(() – ($t_{13,0.95}$ × S)), respectively.

The most noticeable geographical difference between employing as frost line the value of 18 °C suggested by Holdridge or the 19.8 °C value calculated in this study was observed to the east of Argentina (fig. 7).

Latitudinal Regions, Altitudinal Belts, and Humidity Provinces

Five latitudinal regions and seven altitudinal belts were recognized in Argentinian territory. The five latitudinal regions defined ranged from tropical to boreal, showed spatial limits distributed in a northeast to southwest pattern, which accentuates from south to north (fig. 8). The most extended latitudinal region was the Warm Temperate (45 percent of the territory) in the center and partly in the south of Argentina, followed by the Subtropical Region (33 percent) mainly in the north and northeast of the country. The smallest was the Boreal region (<1 percent) at the south (table 1; fig. 8). The Tropical and Subtropical regions include the higher number of life zones (24 to 25), decreasing in both the Temperate (15 to 16) and Boreal regions (3) (table 1).

The seven altitudinal belts ranging from Basal to Nival showed a heterogeneous spatial distribution (table 2; fig. 9). The most extended is the Basal Belt (59 percent of the territory) reflecting the dominance of lowlands with elevations below 1500 m asl (table 2; fig. 9) highly represented in each latitudinal region with the exception of the Tropical region in Argentina, where we did not find a basal belt (table 3). The smallest belt was the Nival, which encompassed less than 1 percent of the territory (table 2). The Premontane Belt lower biotemperature limit was the frost line temperature of 19.8 °C, which was a higher biotemperature than that indicated by Holdridge (1967). Two of the consequences of the new value of the frost line were that (1) the upper altitudinal limit was at lower elevations than that resulting from applying a frost line of 18 °C, and (2) the Premontane Belt resulted in a smaller surface area than the one that could be obtained employing the original frost line of the model.

Humidity Provinces

Life zone distribution ranged from Superarid to Subsaturated provinces. The most extended humidity provinces were the Semiarid (978 000 km^2) and Subhumid (875 565 km^2), which implies that about 63 percent of Argentinian territory showed EVP values two to four times higher that of P. Meanwhile, 604 224 km^2 included in the Humid province showed similar values of EVP and P. A surface of 95 109 km^2, representing 3.4 percent of the country's area, showed a positive water balance with less EVP than P. An 11.1 percent area of the country ranged from Arid to Superarid with an EVP/P ratio >4 to 32 (table 4; fig. 10).

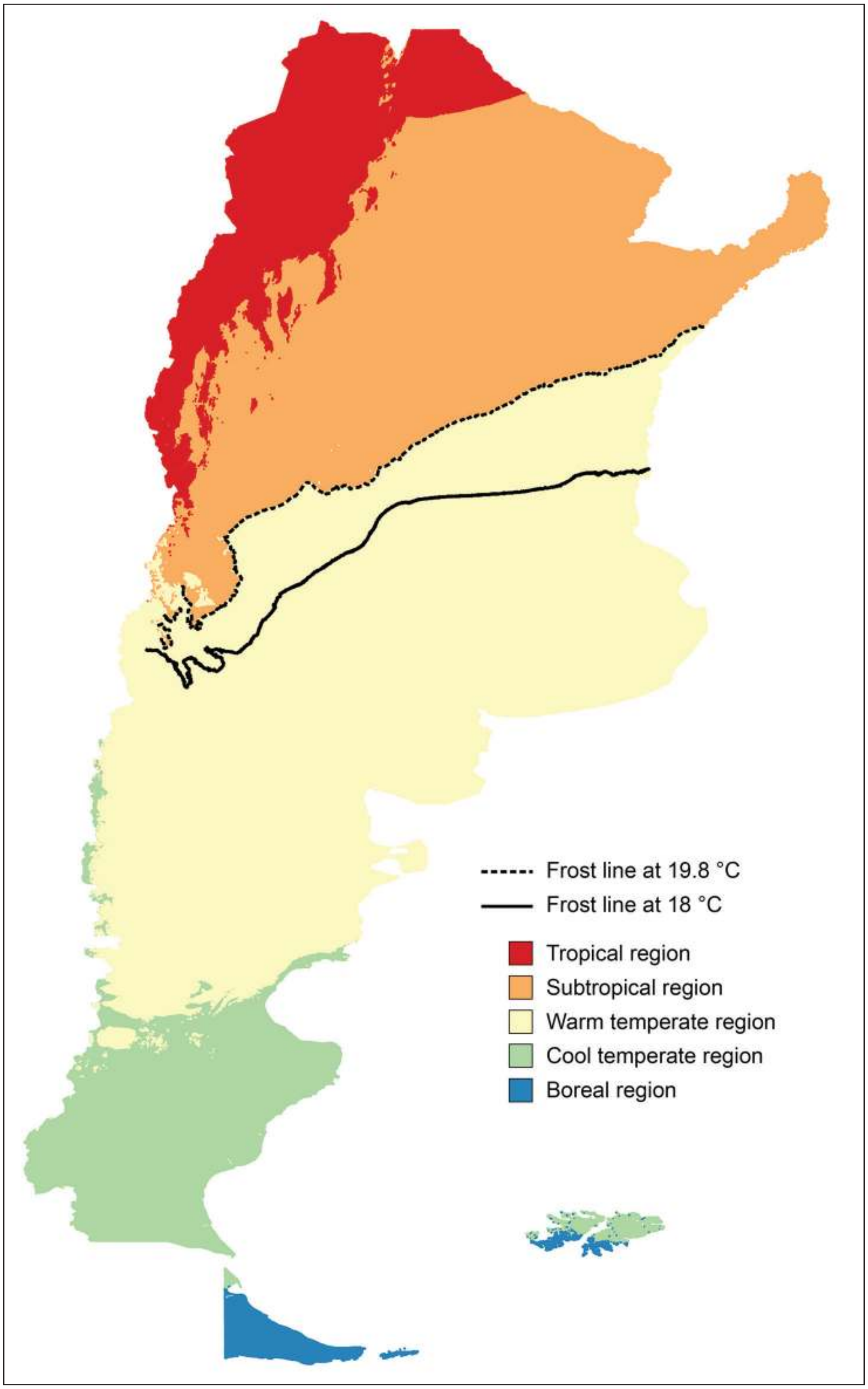

Figure 7—Frost line for Argentina, 18 °C (according to Holdridge 1967) and 19.8 °C as calculated in this study.

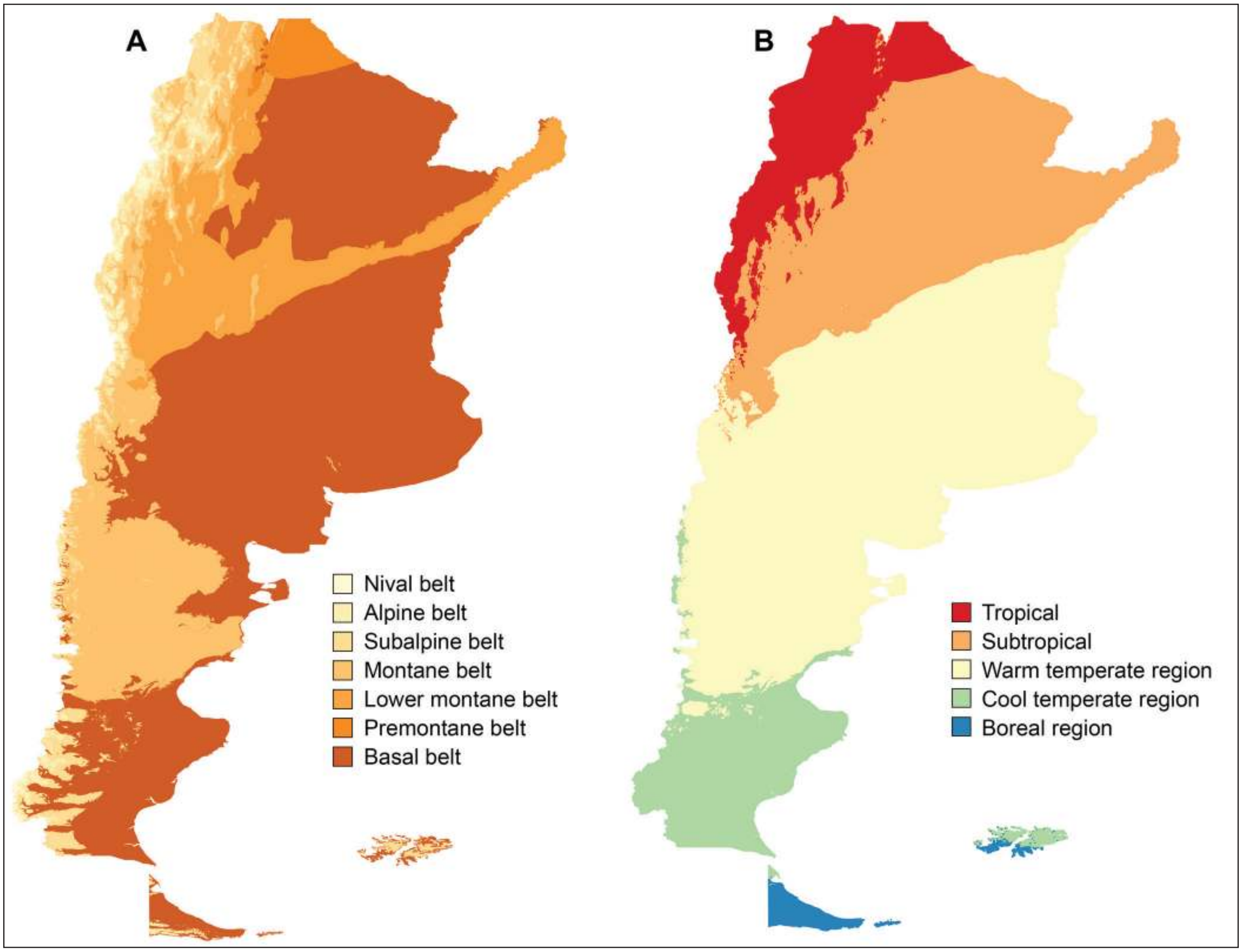

Figure 8—Latitudinal regions and altitudinal belts in Argentina.

Table 1— Distribution of life zones according to latitudinal region

Latitudinal region	Life zones	Area
	Number (percent)	*Percentage of total*
Tropical	25 (30.1)	11
Subtropical	24 (28.9)	33
Warm temperate	16 (19.3)	45.5
Cool temperate	15 (18.1)	9.4
Boreal	3 (3.6)	0.8
Total Argentina	83 (100)	100

Note: Total area of Argentina = 2 797 333 km^2.

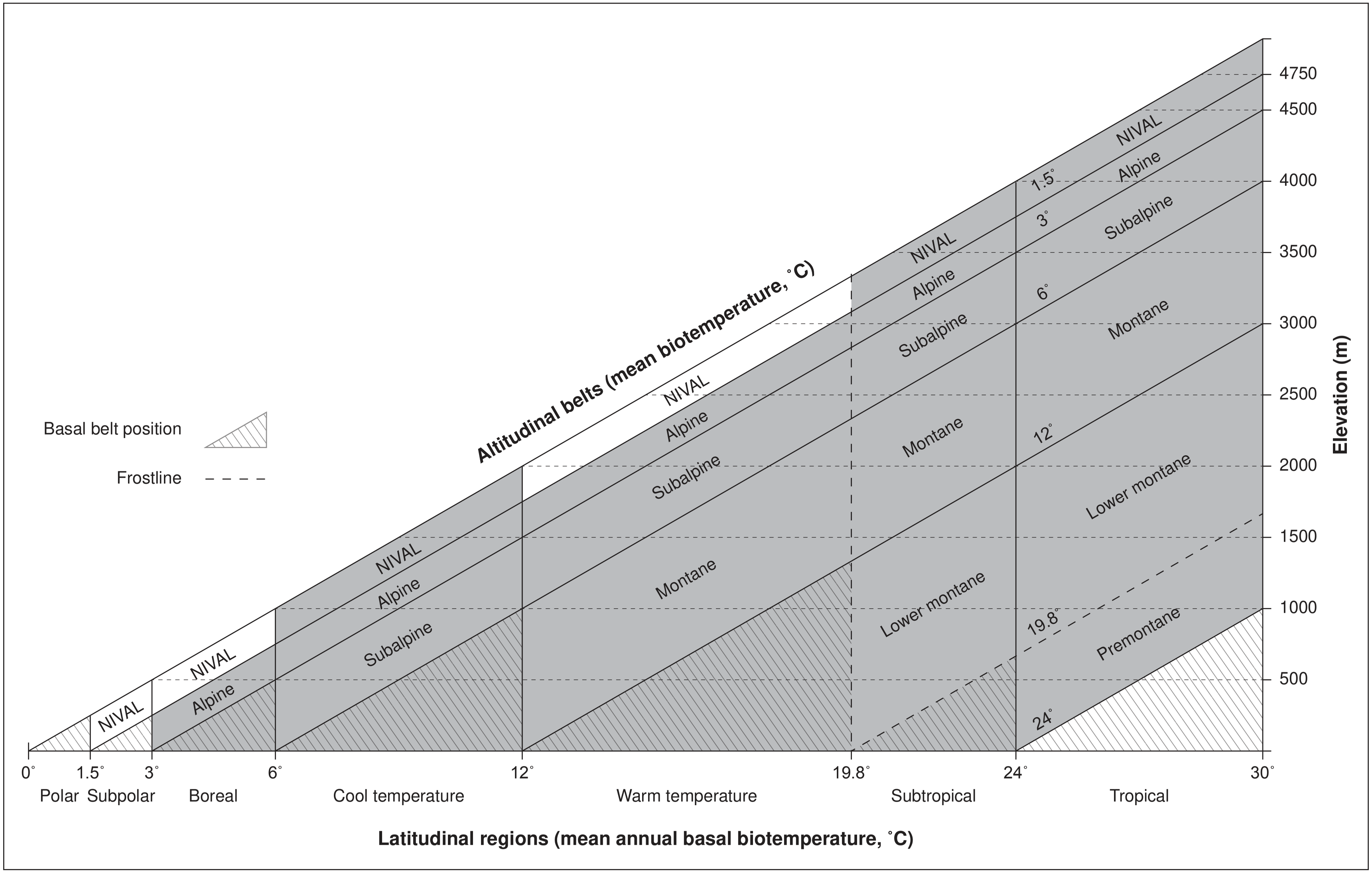

Figure 9—Diagram of Holdridge with altitudinal belts in Argentina (in gray) distributed according to latitudinal region. Modified from Holdridge (1967).

Table 2—Distribution of life zones according to altitudinal belts

Altitudinal belts	Life zones	Area
	Number (percent)	*Percentage of total*
Nival	3 (3.6)	0.6
Alpine	17 (20.5)	1.8
Subalpine	17 (20.5)	6.4
Montane	15 (18.1)	15.8
Lower montane	13 (15.7)	14.6
Premontane	2 (2.4)	1.9
Basal	16 (19.3)	58.9
Total Argentina	83 (100)	100

Note: Total area of Argentina = 2 797 333 km2.

Table 3—Area of the basal belt in each latitudinal region of Argentinain square kilometers and as a percentage of the total basal belt area in

Region	Area of basal belt	Total area of region
	Square kilometers (percent)	*Percent*
Tropical	0 (0)	0
Subtropical	490 115 (29.72)	52.68
Warm temperate	937 506 (56.86)	73.63
Cool temperate	201 558 (12.22)	76.57
Boreal	19 759 (1.20)	90.78
Total Argentina	1 648 938 (100)	

Table 4—Distribution of life zones in humidity provinces

Humidity provinces	Life zones	Area of humidity provinces
	Number (percent)	*Percentage of total*
Superarid	1 (1.2)	0.17
Perarid	2 (2.4)	2.03
Arid	10 (12. 0)	8.91
Semiarid	12 (14.6)	32.60
Subhumid	13 (15.7)	31.30
Humid	16 (19.3)	21.59
Perhumid	15 (18.1)	2.42
Superhumid	7 (8.4)	0.66
Semisaturated	5 (6.0)	0.24
Subsaturated	2 (2.4)	0.07
Total Argentina	83 (100)	100.00

Note: Total area of Argentina = 2 797 333 km^2.

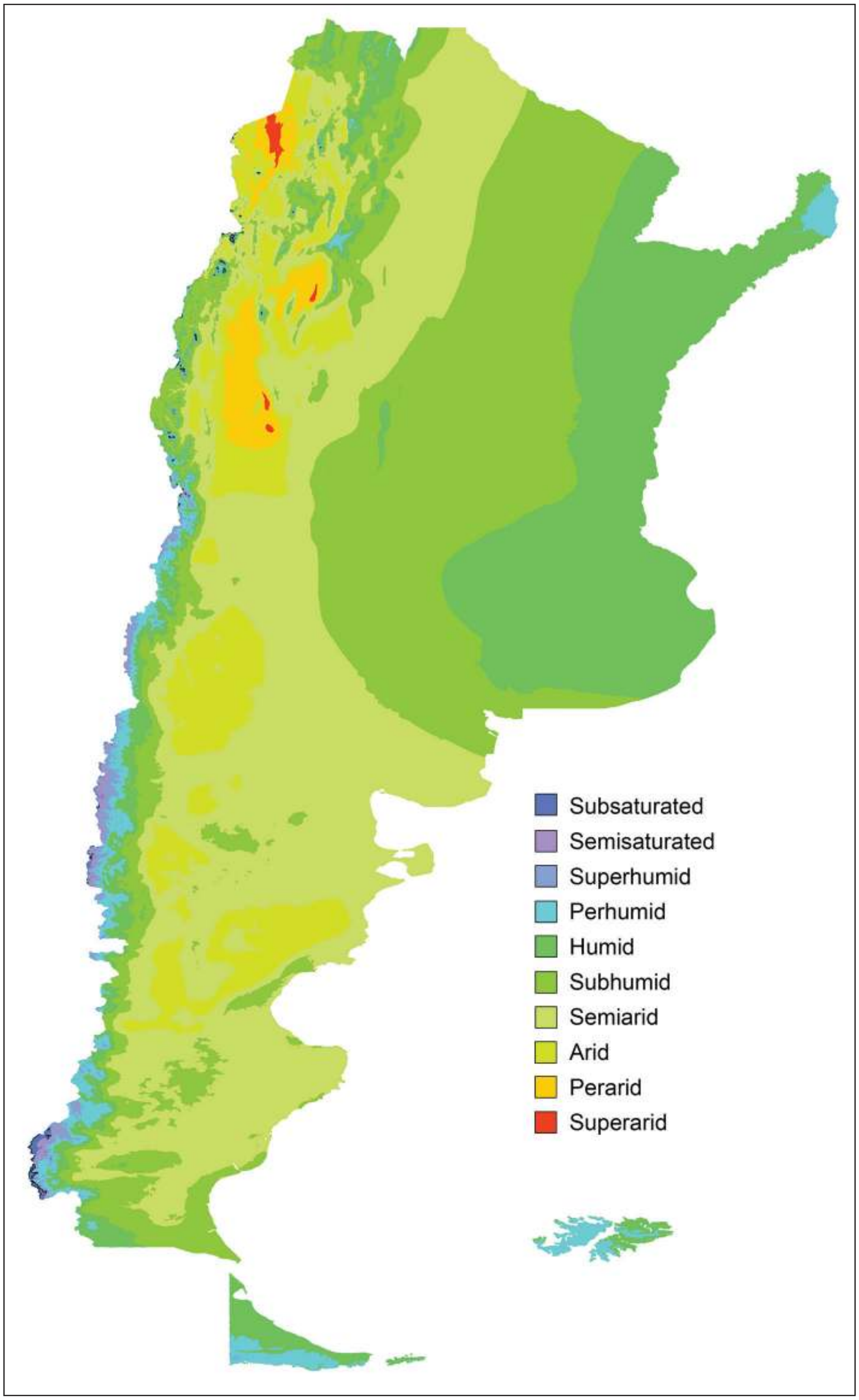

Figure 10—Humidity provinces in Argentina according to Holdridge (1967).

Life Zones

A total of 83 life zones were determined (table 5; fig. 11). The most geographically extended life zones pertained to the Subtropical and Warm Temperate regions. These are Warm Temperate Dry Forest (433 600 km^2 or 15 percent), Subtropical Dry Forest (276 300 km^2 or 9 percent), Warm Temperate Thorn Steppe (227 900 km^2 or 8 percent), and Warm Temperate Montane Desert Scrub (192 614 km^2 or 7 percent). Those of smaller extension included Tropical Lower Montane Wet Forest (170 km^2), Warm Temperate Alpine Wet Tundra (183 km^2), and Subtropical Alpine Humid Tundra (234 km^2). Eleven life zones were found to exceed the limits of the original triangular diagram (table 6; fig. 12).

The total of 83 life zones found in Argentina are listed in table 5.

Table 5—List of Holdridge life zones in Argentina grouped by latitudinal region

Holdridge life zones in Argentina

Tropical premontane dry forest
Tropical premontane humid forest
Tropical lower montane desert
Tropical lower montane desert scrub
Tropical lower montane thorn steppe
Tropical lower montane dry forest
Tropical lower montane humid forest
Tropical lower montane wet forest
Tropical montane perarid desert
Tropical montane desert
Tropical montane desert scrub
Tropical montane steppe
Tropical montane humid forest
Tropical montane wet forest
Tropical subalpinearid desert
Tropical subalpinedesert
Tropical subalpine dry scrub
Tropical subalpine moist forest (puna)
Tropical subalpine wet forest (paramo)
Tropical alpine semiarid tundra
Tropical alpine dry tundra
Subtropical desert scrub
Subtropical thorn woodland
Subtropical dry forest
Subtropical moist forest
Subtropical wet forest
Subtropical lower montane superarid desert
Subtropical lower montanedesert
Subtropical lower montane desert scrub
Subtropical lower montane thorn steppe
Subtropical lower montane dry forest
Subtropical lower montane moist forest
Subtropical lower montane wet forest
Subtropical montane desert
Subtropical montane desert scrub
Subtropical montane steppe
Subtropical montane moist forest
Subtropical subalpine dry scrub
Subtropical subalpine moist forest
Subtropical subalpine wet forest
Subtropical alpine moist tundra
Subtropical alpine wet tundra

Table 5—List of Holdridge life zones in Argentina grouped by latitudinal region (continued)

Holdridge life zones in Argentina	
Tropical alpine moist tundra	Subtropical alpine rain tundra
Tropical alpine wet tundra	Subtropical alpinesemisaturated tundra
Tropical alpine rain tundra	Subtropical nival semisaturated desert
Tropical nival perhumid desert	
Warm temperate desert scrub	
Warm temperate thorn steppe	Cool temperate desert
Warm temperate dry forest	Cool temperate desert scrub
Warm temperate moist forest	Cool temperate steppe
Warm temperate montane desert	Cool temperate moist forest
Warm temperate montane desert scrub	Cool temperate wet forest
Warm temperate montane stepee	Cool temperate subalpine dry scrub
Warm temperate montanemoist forest	Cool temperate subalpine moist forest
Warm temperate montane wet forest	Cool temperate subalpine wet forest
Warm temperate subalpine dry scrub	Cool temperate subalpinerain forest
Warm temperate subalpine moist forest	Cool temperate subalpine semisaturated forest
Warm temperate subalpine wet forest	Cool temperate alpine wet tundra
Warm temperate subalpine rain forest	Cool temperate alpine rain tundra
Warm temperate alpine wet tundra	Cool temperate alpine semisaturated tundra
Warm temperate alpine rain tundra	Cool temperate alpine subsaturated tundra
Warm temperate alpine semisaturated tundra	Cool temperate nival subsaturated desert
	Boreal moist forest
	Boreal wet forest
	Boreal alpine rain tundra

Table 6—Life zones in Argentina, located outside the original triangular diagram of Holdridge, grouped by their distribution in humidity provinces

Humidity province	Life zone
Superarid	Subtropical Lower Montane Superarid Desert (DSAMBS)
Perarid	Tropical Montane Perarid Desert (DPAMT)
Arid	Tropical Subalpine Arid Desert (DAST)
Semiarid	Tropical Alpine Semiarid Tundra (TSAAT)
Semisaturated	Subtropical Nival Semisaturated Desert (DSSNS)
	Subtropical Alpine Semisaturated Tundra (TSSAS)
	Warm Temperate Alpine Semisaturated Tundra (TSSATC)
	Cool Temperate Alpine Semisaturated Tundra (TSSATF)
	Cool Temperate Subalpine Semisaturated Forest (BSSSTF)
Subsaturated	Cool Temperate Nival Subsaturated Desert (DSUBSNTF)
	Cool Temperate Alpine Subsaturated Tundra (TSUBSATF)

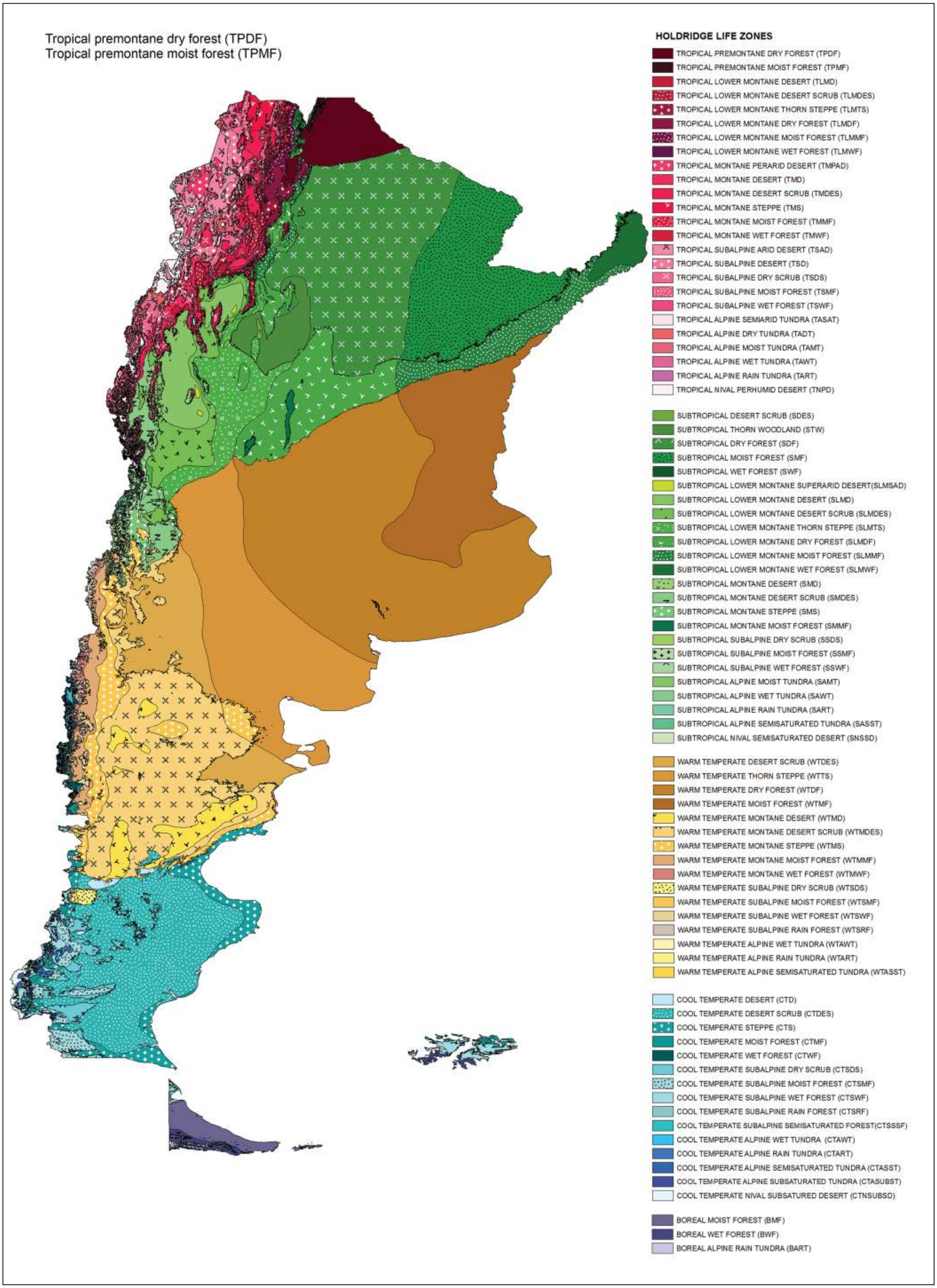

Figure 11—Life zones map of Argentina.

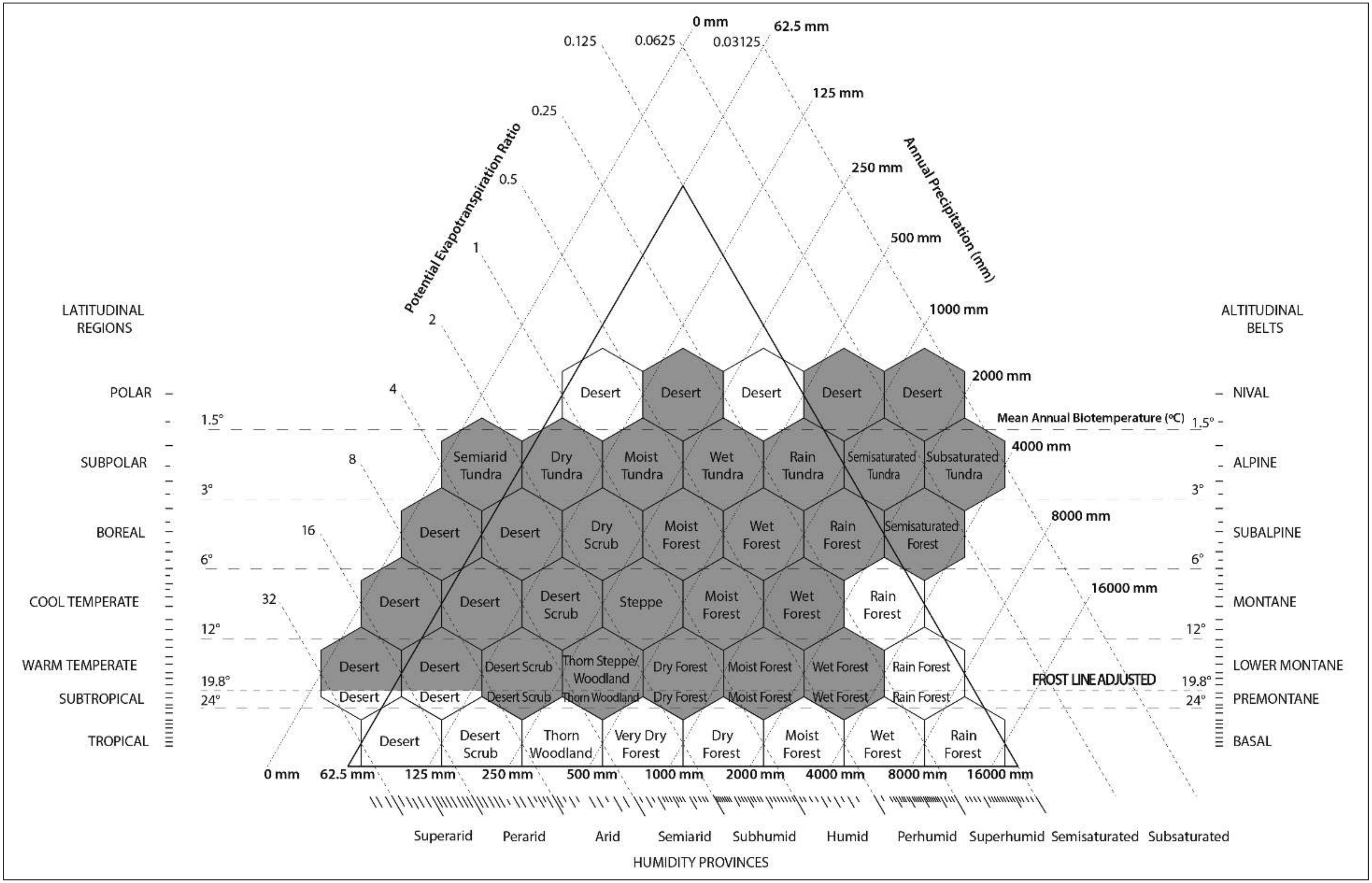

Figure 12—Holdridge life zones diagram in Argentina (in gray). Life zones in altitudinal belts may overlap with life zones in latitudinal regions. Modified from Holdridge (1967).

Discussion

The Latitudinal Regions in Argentina

Latitudinal regions and geological provinces—

This study confirms that Argentina is predominantly (across 89 percent of its land area) a **warm temperate** and **subtropical country**. Together, these two latitudinal regions totally or partially cover most Argentinian provinces of Chubut in the south through the central part of the country to Formosa and Misiones in the upper northeast, especially in the Chaco-Pampean plains, part of the Sierras Pampeanas and other low mountains and tablelands, to reach the country's western border at the Principal Cordillera and Septentrional Patagonian Cordillera. The cool temperate region covers lightly less than 10 percent of the country and includes nearly all the province of Santa Cruz (the southern Patagonian Plateau, the Deseado mass if, south of the northern Patagonian Plateau, and the Austral Patagonian Cordillera); an Atlantic coastal fringe located south of Chubut; and part of insular territories like the northern half of the Malvinas Islands and a small portion at the northern extreme of the Isla Grande of Tierra del Fuego located between Bahía San Sebastián (Saint Sebastian Bay) and the mouth of the Magellan Strait. The tropical region has a triangular shape, with its widest side at its northern border in the elevated lands of northwest Argentina provinces. This widest portion includes the Puna, Central Cordillera, northwestern sub-Andean mountains, and part of the piedmont of the provinces of Salta and Formosa. The tropical region continues over the Cordillera de los Andes, narrowing in width toward the south, where it occupies the Sierras de Famatina, sections of the Precordillera, the Frontal Cordillera, and northern portion of the Principal Cordillera. The boreal region, the smallest in size, includes the main portion of Tierra del Fuego, neighboring islands, and southern Malvinas Islands.

Latitudinal regions and applied criteria—

The strict application by Holdridge of the biothermic criteria to define latitudinal regions excludes other points of view, such as the question of the monthly low thermal amplitude, together with higher diurnal-nocturnal amplitude that characterizes tropical climates, or the geographical assignation of "tropics" to lands between the Tropics of Cancer and Capricorn. In summary, Holdridge defined biotemperature ranges as descriptors of ecological spaces to which different plants adapt. It is important to highlight that specific biotemperature isolines limits latitudinal regions but do not follow the trends of the geographic distribution patterns of the isolines belonging to the mean temperatures at surface level. This observation was previously made by Holdridge (1979), who stressed that the relationship between a latitudinal region geographically defined or employing basal biotemperature may be very irregular, and may depend on several factors such as the continental shape, oceanic currents, lakes and rivers, and mountain ranges linked to dominant winds. Biotemperature is the heat parameter employed by the model as a limiting factor in community distribution. This is a more significant parameter than heliophany (sunshine duration), because the distribution of plant communities shows more relation to heat than to geographic position itself (Holdridge 1979). Thus location of a latitudinal region as a function of basal biotemperature is considered a more precise methodological approach.

A vertical lapse rate of 6 °C/km is used to define latitudinal regions in the Holdridge model and is applied to calculate the temperature and biotemperature at 0 m asl of geographic points at certain altitudes (positive or negative with respect to 0 m). The 6 °C/km measure is an operatively accepted value because the lapse rate depends on latitude and other factors, such as the humidity saturation condition of the air parcel ascending (temperature decrease) or descending in altitude (temperature increase). The lapse rate may reach -10 °C/km in unsaturated air (DALR= dry adiabatic lapse rate) ascending from a place at sea level with 20 °C; or -6 °C/km (SALT= saturated adiabatic lapse rate) if the ascendant air is saturated (Bureau of Meteorology 1975). Moreover, the lapse rate varies with temperature and air pressure, making it extremely complex to calculate a mean value for areas with a pronounced rough relief. Buitrago (1999) concluded that -5 °C/km may be a reasonable ratio for air in northwest Argentina. Nonetheless, we preferred to use the value suggested by Holdridge.

Including the frequency of frost as a criterion for defining the frost line setting the limits between the warm temperate and subtropical regions in Argentina allowed us to identify a displacement toward higher biotemperatures with respect to the original 18 °C limit. In fact, if we reduce the demand of 20 consecutive years with frosts to a lesser number of years, frosts occur practically throughout the country (cf. Murphy 2008).

The use of the term “boreal” (= “northern” or “from north”) to designate a latitudinal region is contradictory in the Southern Hemisphere because temperatures diminish toward the South Pole; we could have employed “austral” for the same biotemperature range. However, we have used the more conventional name.

Latitudinal regions: latitude, oceanicity, relief, and climate—
In the very oceanic southern extreme of Argentina, the **Boreal** region is located in all of Tierra del Fuego (except for the northern area near Bahía San Sebastián), Isla de los Estados, and the southern sector of the Malvinas Islands. The climate of this region is influenced mainly by circumpolar and derived currents with constantly cold waters.

As described for the study area, from the extreme south to 40° S, the cordillera's elevation is low and in continental territory allows western winds to cross mountains. After leaving most of its humidity precipitated in the cordillera, wind continues blowing toward extra-Andean Patagonia and the Malvinas Islands in the Atlantic Ocean. Added is the cooling effect on the Atlantic coast of cold waters from upwelling and oceanic currents moving to the north on the continental platform. Even in the low cordillera, the Föhn influence of western winds appears to give place to a piedmont area with higher biotemperatures, indicated by the presence of a narrow and discontinuous belt in the cool temperate region in contact with the warm temperate region in the province of Chubut. In the province of Santa Cruz, which almost belongs to the **Cool Temperate** region, the oceanic cooling effect is shown at its northern border by the 12°C biotemperature diagonal line oriented from southeast to northwest and reentering Chubut, where it encompasses a narrow coastal fringe of emerged lands reaching to north of the San Jorge Gulf.

The **Warm Temperate** region is a broad strip of land oriented from southwest to northeast. It is located north of Patagonia and includes part of central Argentina, the Pampean plains, the province of Entre Ríos, and the area east of Corrientes Province. This territory receives from the south the permanent influence of western and southwestern winds. These winds produce frequent cold fronts moving toward the northeast. The region also receives the influence of warm winds from the north and northeast. The surface circulation coincides with the orientation of the frost line that sets the northern limit of the warm temperate region. The transition zone between the winter regime, with scarce precipitation characterizing extra-Andean Patagonia in the south, and the summer rains regime in the north, with reduced rains in the center of the country, gives shape to an arid diagonal crossing the warm temperate region from northwest to southeast.

At latitudes north of 40° S to the northern border of the country, oceanic effects are reduced. The high cordillera prevents western winds from going through the Andes, which reduces the influence of the Pacific Ocean. The effects of the Atlantic Ocean are mitigated to the west of Argentina by the broader longitudinal amplitude of South America toward the tropics. The continental effect is greater in northwest Argentina, particularly near the foot of the eastern cordillera.

The geographic distribution pattern of the boreal, cool temperate, and warm temperate latitudinal regions appear to be linked not only to latitude and topography but also to the way that climatic components working at the surface are associated with the presence of cold and warm fronts during the year and to the air masses of different geographic origin going behind them.

The **Tropical and Subtropical** regions are located at latitudes north of about 37° S. Mainly in northwest Argentina and, consequently, in the Argentinian tropical region, the Pacific and Atlantic anticyclones coincide with the high-pressure belt at near 30° S latitude, where winds blow toward the continent. As previously mentioned, the Pacific southeast anticyclone has scarce influence because of the high elevation of the Cordillera de los Andes, whose crests are above 4000 m asl, impeding most atmospheric processes of climatic importance that develop below that elevation. The **Tropical** region in Argentina coincides mainly with the high Cordillera and Puna systems that show geological, climatic, and biogeographic characteristics that are similar to those in the Bolivian and Peruvian Altiplano (high plateau) that is near the low-pressure zone known as “lengua de calor” (heat tongue) determined by the 48 °C isoline of maximum absolute temperature extending through the Chaco plains from Llanos de La Rioja to the Chaco of Salta province (Bianchi et al. 2005). This area has a triangular shape that narrows toward northern Mendoza province. Furthermore, it is on rough mountainous topography and slopes in the northeast Salta, northwest Chaco, and Formosa provinces, together with the distribution of warm air masses from tropical zones of Amazonia through the integration of LCH, DNOA, and HB systems. A discontinuous strip of the subtropical region extends from the southern border of Tarija province in Bolivia, occupying valleys in Salta and Jujuy provinces (Argentina) between Santa Victoria in northwest Salta, and Calilegua and San Pedro at Jujuy. This subtropical strip is interposed between both zones described in the tropical region. This subtropical ingression coincides with the development of different vegetation types in a stronger precipitation gradient than in the drier tropical vicinity (Murphy 2008). The places with more precipitation inside that fringe make it possible to transfer more radiative heat to the evaporation process, and, consequently, to decrease the temperature of the region (Burgos and Vidal 1951). Moreover, this process appears to contribute to displacement toward the north of biotemperatures east of the Chaco-Pampean plains as shown by the orientation of the frost line as suggested by Burgos (1968) for northeast Buenos Aires province.

With respect to the absent basal belt in the tropical region, it is important to highlight that this absence is not indicative of the absence of low-elevation lands in the region, because the upper (higher MAB) limit of the Premontane Belt (24 °C) may occur at low elevation (from sea level to about 1000 m asl) as observed in the piedmont and more gentle zone east and northeast of the tropical region in Argentina (see map).

The **Subtropical** region extends from east of the tropical region to the other extreme, where the frost line is located in the border with the warm temperate region. The Subtropical region is influenced by warm winds from the north facing cold air masses penetrating from the Pacific through the low Andes Cordillera south of 40° S (Eidt 1969). Cold winds move in a northeasterly direction and can occasionally provoke snowfall in the Misiones plateau. This cold air influx toward the northeast that periodically collides with warm air masses could explain why the frost line and the border with the tropical region follow a southwest to northeast orientation (fig. 11). In the arid zone of the Subtropical region between the eastern border of the tropical region and the western slopes of the Pampean Mountains is located the DNOA that, as mentioned, plays a significant role in the climate of Argentina by attracting air masses during the summer rainy season. This zone of the Subtropical region contrasts with the constantly humid extreme in the province of Misiones, where it rains year-round with only a certain higher concentration in summer.

In summary, the large latitudinal extension of Argentina explains the wide range of biotemperatures and the existence of five latitudinal regions. Simultaneously, the ensemble of the described climatic systems appears to allow understanding of the diagonal pattern showed by latitudinal regions.

The recognition of a particular value for the country frost line was decisive because this estimation under a precise definition as that of Lugo et al. (1999) provides evidence that the subtropics may be affected occasionally by frosts—that in the Argentina case and in other areas of the South American southern cone are verified by the sporadic input of polar air masses behind intense cold fronts that can reach even more sporadically very low latitudes into Amazonia. In that sense, changes in the criterion used to establish the frost line may give place to noticeable changes in the area assigned to the Subtropical region.

Life Zones in Argentina

The Holdridge system (1979), considered in its three dimensions, defines 120 life zones. However, the world contains other combinations of local climatic conditions that are not represented by the diagram, thus the existence of other life zones represent extensions of the diagram. This is why the incorporation of 11 new life zones reported for Argentina into the original diagram increased the total number to 131. In Argentina, we found 72 life zones in Holdridge's original diagram and 11 new ones, totaling 83 life zones that could be mapped at the scale used. They represent 63 percent of the 131 total life zones. In Argentina, the high bioclimatic heterogeneity is associated with the different combinations of ranges in biotemperature, precipitation, and EVP/P ratio resulting from the country's geographic (latitudinal) location, topography (from sea level to the highest summits in the Western Hemisphere), and oceanic currents operating in climate components. Life zones have a size and space arrangement of individual polygons that change located in mountainous or flat lands. In northwest Argentina, the Andes, and Puna, smaller polygonal units predominate and show arrangements with temperature and low precipitation gradients in a generally rough topographic environment. The Andes in Patagonia shows a very sharp precipitation gradient notably marked by large lakes appearing in several life zones. The plains to the east of the high mountains are characterized by large polygon seven along precipitation gradients with only few mountainous systems of higher relative elevation in each region showing a distinct life zone to those present in the surrounding plains.

Life Zones and Ecoregions in Argentina

The geographic distribution of life zones tends to coincide with the ecoregions of Argentina defined by Morello et al. (2012). The humid forests of the ecoregions Paranaense (northeast Argentina), Chaco Húmedo (Humid Chaco), and Yungas (northwest Argentina cloud forests) were clearly identified as different life zones. Regarding dry forests, those areas pertaining to the Bosques del Chaco Seco (Chaco Dry Forests) are differentiated from those of the Espinal (Thorn Dry Forests) and from the Monte. Moreover, both ecoregions of Monte, the Monte de sierras y bolsones (Monte of low mountains and closed depressions) and the Monte de llanuras y Mesetas (Monte of plains and plateaus) corresponded to two different life zones. In Patagonia, the Sub Antarctic or Patagonic Forest was differentiated from the Patagonic Steppe.

Areas with a broad climatic variability associated with topographic gradients show a marked differentiation of life zones inside the same ecoregion, such as Yungas, Puna, High Andes, and even the forest-steppe transitional area in Patagonia. This differentiation indicates a greater environmental resolution in life zones than in ecoregions. Conversely, in at least two cases we observed the opposite absence of differentiation among ecosystems in life zones. One of them is the ecoregion Esteros del Iberá (Iberá wetlands), where a particular topography and hydrology determine the occurrence of a vast lentic system in place of humid forests. This example is in fact a case that can be explained at a more detailed level: an association of Holdridge. The other case is the Pampa ecoregion, which is not differentiated from the Espinal ecoregion on the life zone map. The absence of forests in the Pampa plains is an issue that has been debated for many years. It is probable that, as observed in the ecoregion Esteros del Iberá, local factors that are not fully understood may explain the differences between real vegetation and potential vegetation at the level of life zones suggested only by bioclimatic variables. Several authors have observed that relief and soil may be related to the absence of forests in the

Humid Pampa (Parodi 1942, Vervoorst 1967), but others have suggested that local environmental causes may have interacted with biogeographic-historical causes in vegetation establishment (Arturi and Goya 2004, Chaneton et al. 2013). Apart from this, the life zone model has shown in the Pampa the thermic effect of the Sierras Australes (Ventania) mentioned by Burgos (1968), a fact highlighted by a montane belt life zone detected in those mountains of >1000 m asl. Kristensen and Frangi (1995) anticipated through mesoclimatic observations the presence of a montane belt located above the basal belt. The montane life zone in the province of Buenos Aires is exclusive of Ventania and was also confirmed by phytosociological studies (Frangi and Bottino 1995).

Conclusions

This study confirms that Argentina includes a large number of life zones and, consequently, features great bioclimatic heterogeneity. These attributes are associated with (1) the location of the country in the southern cone of America and its large latitudinal range; (2) the presence of the Cordillera de los Andes to the west, containing the most elevated peaks of the American continent, a mountainous axis that changes its geomorphic characteristics from north to south and intervenes in the biothermal expression and the distribution of precipitation and air masses with different characteristics; (3) the domain of plains to the east of the more important mountain systems in the country; (4) the activity of high- and low-pressure semi-permanent continental and oceanic centers determining different atmospheric circulation north and south of 40° S; (5) the development of particular atmospheric conditions participating in the seasonal expression of climates; and (6) the influence of ocean currents.

The map of life zones is the geographic representation of such heterogeneity, showing correspondence with biogeographical units and ecoregions.

This objective classification of life zones based on the climate of recent decades is dynamic and should be reevaluated periodically. It is a powerful tool that can be used for different purposes, for example: (1) to plan and monitor the use of land, vegetation, and other resources; (2) to localize, evaluate, select, and make compatible productive systems with systems with other land use objectives; (3) to assess environmental impacts and evaluate changes in productive conditions; and (4) to select habitats, study taxa distribution, and design conservation strategies for all kinds of biodiversity categories. The dynamic character of climatic variables allows its use in analyzing the effects of climate change on the interactions among different land uses, the structure of ecosystems, and their future trends.

Acknowledgments

We thank Néstor Barrionuevo, Instituto Nacional de Clima y Agua (INTA), for providing the climatic digital atlas data and for several suggestions; Argentina's National Meteorological Service (SMN) for providing their digitalized 1981–2010 period dataset; and especially SMN Department of Climatology chief María de los Milagros Skansi, who kindly responded to our inquiries. We also thank Alberto Bianchi and Silvia Cravero for additional information, comments, and generous advice on the study of their own "Atlas climático digital de la República Argentina," as well as Francisco Nemiña, Gabriela Yañez, Isabel Andrade (professor of physical geography), Luis Couyoupetrou, and Rodrigo Gabiassi for their contribution and collaboration with different topics that improved the present study. We greatly appreciate the cooperation of the USDA Forest Service's International Institute of Tropical Forestry (IITF), San Juan, Puerto Rico, where María R. Derguy and Andrea A. Drozd have been in a fruitful residency of academic consultation and scientific training. We are particularly in debt to IITF Director Ariel E. Lugo for his permanent support, inspiration, and encouragement; to Olga Ramos for sharing her expertise and useful comments about geographic information systems; and to A. Henreh for his suggestions about how to apply the Holdridge model. We are grateful to Horacio Sarochar (School of Astronomy and Geophysics, National University of La Plata), for attending our doubts, helping with references, suggesting important articles, and reviewing this article. Finally, thanks to Eliana Ruppel, who carefully reviewed the English manuscript.

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