USE OF DIVA-GIS TO DETERMINE POTENTIAL CULTIVATION AREAS OF BOLIVIAN PASSION FRUITS (*PASSIFLORA* SPP.)

Marleen Delanoy and Patrick Van Damme
Laboratory for Tropical and Subtropical Agriculture and Ethnobotany
Ghent University
Coupure links 653, 9000 Ghent, Belgium
Tel.: +32 9 264 60 93
Fax: +32 9 264 62 41
mdelanoy@yahoo.com

Xavier Scheldeman
Regional Office for the Americas
International Plant Genetic Resources Institute (IPGRI)
Apartado Aéreo 6713, Cali, Colombia

Stephan, Beck
Herbario Nacional de Bolivia
Universidad Mayor de San Andrés
Casilla 10077, La Paz, Bolivia

Abstract

Passiflora mollissima (Kunth) L.H.Bailey, *Passiflora tricuspis* Mast. and *Passiflora nov* sp. are three little-known passion fruit species occurring in the *Yungas* of the department La Paz, Bolivia. These species are used as a fresh fruit and *Passiflora mollissima* and *Passiflora nov* sp. are prepared in juices as well. For crop development, it is necessary to identify potential cultivation areas. Climate plays a key role in determining the aptitude of a site for a plant species. Within the DIVA-GIS software, the BIOCLIM tool uses information on species´ collection sites in combination with detailed climatic data to model the climate-based potential distribution of the species. During field trips, 61 *Passiflora mollissima*, 234 *Passiflora tricuspis* and 87 *Passiflora nov* sp. collection sites were described and used to determine climate-based potential distribution areas within the study area. Additional coordinates of Bolivian collection sites from herbaria (LPB and NYBG) and the W^3 TROPICOS database, were used to identify climate-based potential distribution areas at national level. Additional data on vegetation and land use were used to determine overall potential distribution. Only a small zone in the study area was found to be highly suitable for *Passiflora mollissima* cultivation. Climate-based potential distribution areas of *Passiflora nov* sp. and *Passiflora tricuspis* appeared to be larger but suitability was generally lower. At national level, zones with high climate-based potential for *Passiflora mollissima* were extended over the eastern slopes of the Andes. Large parts of Bolivia showed low to medium suitability for *Passiflora tricuspis* cultivation whereas climate-based potential of *Passiflora nov* sp. cultivation seemed limited to neighbouring provinces. Only small differences were found between climate-based potential and overall potential distribution.

1. Introduction

It is generally accepted that a rapid and large loss of plant diversity is occurring worldwide. Conservation of biodiversity, especially of those species important for human nutrition and crop improvement, is therefore an urgent task (FAO, 1996; Jarvis *et al.*, 2003). Bolivia is among the 15 countries in de world with the highest biodiversity. An important Bolivian centre of diversity is situated in the *Yungas* (Ibisch and Mérida, 2003), located on the eastern slopes of the Andes (Ibisch *et al.*, 2003).

Passiflora is the largest genus in the Passifloraceae family and comprises over 450 species (Vanderplank, 1996). It contains different species with present and potential importance for agriculture (Mazzani *et al.*, 1999). Seventy *Passiflora* species have been recorded in Bolivia of which 20 are endemic (Ibisch and Beck, 2003). *Passiflora mollissima* (Kunth) L.H. Bailey, *Passiflora tricuspis* Mast. and *Passiflora nov* sp. are three underutilized species present and consumed in the *Yungas* of the department La Paz in Bolivia. *Passiflora mollissima* and *Passiflora nov* sp. are cultivated in this area. According to literature references, *Passiflora mollissima* and *Passiflora tricuspis* are promising and the latter is also widespread in the *Yungas*. *Passiflora mollissima* is native to the Andean highlands from Venezuela to Bolivia and is used as a fresh fruit, in juices or desserts (Cárdenas, 1989; Espinosa, 1992; Vanderplank, 1996). *Passiflora tricuspis* is widespread over tropical and subtropical America and used for fresh consumption (Vásquez and Coimbra, 2002). *Passiflora nov* sp. is a new species confined to the *Yungas* where it is used either fresh or in juice.

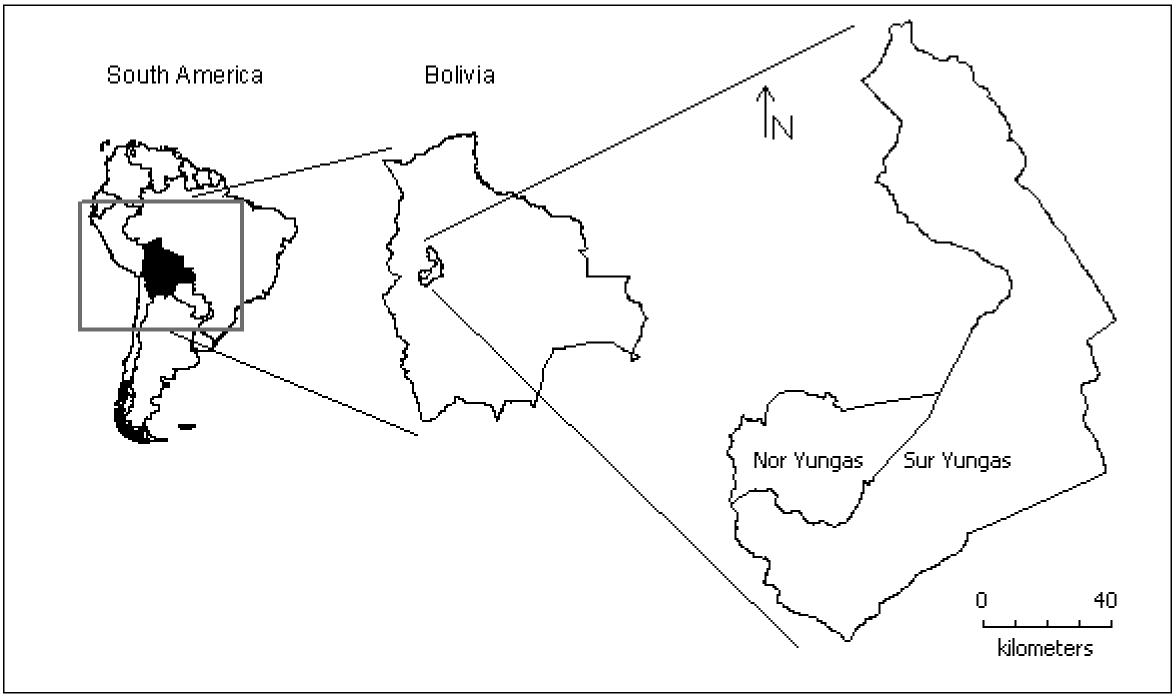
For crop domestication and development, and in order to increase cultivation areas of underutilized species, it is necessary to have information on species ecology and define potential growing zones. The present study developed this information using spatial analyses. Spatial analyses based on specimen occurrence data combined with environmental information are a powerful tool to generate valuable information in species diversity studies (Segura *et al.*, 1999; Scheldeman *et al.*, 2006) and to map potential species distribution (Stockwell and Peterson, 2002; Vargas *et al.*, 2004).

The main objectives of the present study were to define and map for each of the three species studied: (1) present distribution and population density; (2) climate-based potential distribution to define potential cultivation areas using climate data; and (3) overall potential distribution, which is the modified climate-based potential distribution using non-climatic environmental factors.

1.1 Study Area

Research was carried out within the parts of the provinces Nor Yungas and Sur Yungas that belong to the *Yungas* of the department La Paz (Ibisch *et al.*, 2003). Nor Yungas and Sur Yungas cover 2,290 and 5,770 km², respectively (INE, 2004) and are situated between 14°54’ - 16°44’S and 67°58’ - 66°49’W (see Figure I).

Figure I: Map of study area indicating its location in Bolivia and South America



The *Yungas* are defined in slightly different ways according to specific authors. We combined definitions following Killeen *et al.* (1993), CIMAR (1994) and Ibisch *et al.* (2003). The *Yungas* can be divided in two zones:

- humid montane forest: from about 400 - 1000 masl up to about 2500 - 2800 masl

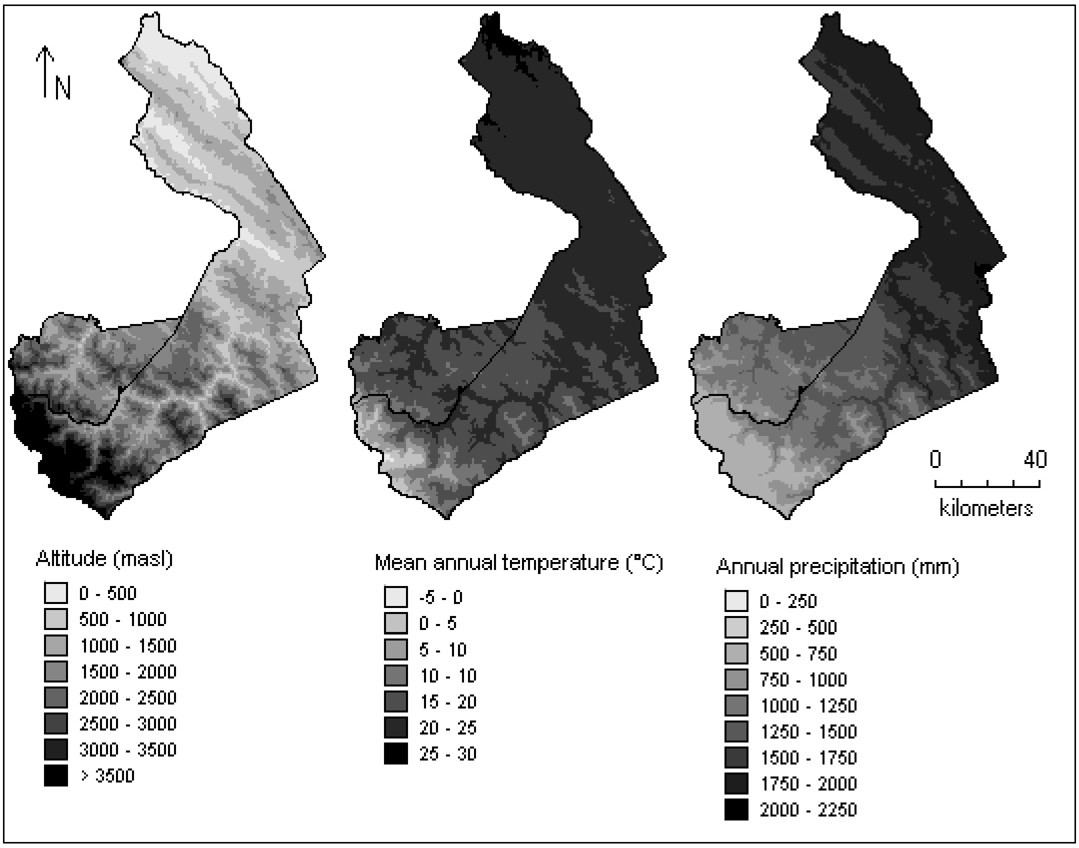
Zone characterized by highly diverse, evergreen forest that can be subdivided in three altitudinal levels. In the lowest level, forest is structurally similar to the Amazon forest. In the following level, trees are evergreen and canopy varies between 15 to 25 m while emerging trees reach 40 m. This level is situated on steep slopes with shallow, stony soils. The highest level consists of cloud forest with canopy barely closed and several lower dense layers. Forest is characterized by presence of fog during most of the year.

- Upper montane forest: between about 2500 – 2800 masl up to about 3200 - 3500 masl:

Zone characterized by evergreen cloud forest, whose diversity declines with altitude. Trees are low to medium high and have coriaceous leaves. Relief is more pronounced with steep slopes and mountain ridges.

Figure II shows altitude, mean annual temperature and annual precipitation in Nor Yungas and Sur Yungas. Altitude varies from 300 up to peaks of 6000 masl. Mean annual temperature varies between –5 and 27 °C whereas annual precipitation ranges between 500 and 2100 mm. Lower areas have highest mean annual temperature and precipitation.

Figure II: Altitude, mean annual temperature and annual precipitation in Nor Yungas and Sur Yungas



2. Materials and methods

2.1 Data Collection

During field trips, collection sites of *Passiflora mollissima*, *Passiflora tricuspis* and *Passiflora nov* sp. sites were described. Exact location and altitude were determined using a GPS (Magellan®TM SporTrak) and an altimeter (SUUNTO vector; ± 5 m). Additional coordinates from herbarium specimens obtained from the Herbario Nacional de Bolivia (LPB), the New York Botanical Garden (NYBG) and the W^3 TROPICOS database of the Missouri Botanical Garden (MO) (http://mobot.mobot.org/W3T/Search/vast.html) were obtained for Bolivian collection sites of *Passiflora mollissima* and *Passiflora tricuspis*.

DIVA-GIS 5.2., a free Geographic Information System (http://www.diva-gis.org/) was used for spatial analyses and for producing all maps in the present paper. This program can import databases of collection sites (Hijmans *et al.*, 2001). Georeferenced data were checked for inconsistencies by overlaying collection site database and the administrative boundaries database of DIVA-GIS. For each collection site, name of department and province should be the same. If names are different, this reflects an error and collection site should be removed (Hijmans *et al.*, 1999).

2.2 Present Distribution and Population Density of the Three *Passiflora* spp.

Using DIVA-GIS, a dot map was made of the collection sites for each species based on data obtained during field work. Dot maps are a simple but accurate way of visualizing distribution patterns (Skov, 2000). Present distribution and population density at collection sites were determined for each species using three methods. Firstly, we mapped population density, using the point-to-grid richness analysis tool in DIVA-GIS. We used a 5 minutes grid (corresponding to about 9 × 9 km at the equator). We applied the circular neighbourhood option with a 10 minute radius which produces a smoother surface and eliminates border effects caused by the assignation of the grid origin (Hijmans *et al.*, 2001). Secondly, we determined area of distribution by calculating average distance and maximum distance between all possible pairs of collection sites. Thirdly, area of occupancy was determined, defined as the "area within its 'extent of occurrence' which is occupied by a species, excluding cases of vagrancy" (IUCN, 2006). IUCN recommends using a 2 × 2 km grid to define this parameter. We used a Lambert equal-area-azimuthal projection, with -67.4 as the central meridian and -15.8 as the reference latitude to superpose a 2 × 2 km grid on Bolivia. The histogram tool in DIVA-GIS allowed determination of number of grid cells containing collection sites and thus the area occupied.

Altitudinal range was determined using descriptions of collection sites. Climate information was obtained using data of the 'WorldClim' database (http://www.worldclim.org), which contains 19 climate variables on temperature and precipitation. The finest resolution available was 30 arc seconds (often referred to as 1-km spatial resolution) (Hijmans *et al.*, 2005). Data were processed in SPSS 12.0. A Kruskall-Wallis test was applied to compare average altitude, mean annual temperature and precipitation between species.

We also defined vegetation and land use in collection sites by using digital maps from the "*Centro digital de recursos naturales de Bolivia*" (http://rangeland.tamu.edu/bolivia).

2.3 Climate-based Potential Distribution of the Three *Passiflora* spp.

Climate plays a key role in determining the aptitude of a site as a habitat suitable for a specific plant species (Woodward, 1987; Skov, 2000; Rafiqpoor *et al.*, 2003). Climate-based potential distribution, defined as the distribution of locations where all climatic indices fall within the extreme values derived from characterizing the collection sites was calculated. We used the BIOCLIM tool within DIVA-GIS that combines geographic coordinates of a species' collection sites with detailed climate data. Climate-based potential cultivation areas were delineated within the study area using coordinates of collection sites taken during field work. To identify climate-based potential cultivation areas at national level, all historical collection sites (collection sites taken during field work and additional coordinates of Bolivian collection sites from herbarium data) were used. As the source of these additional data is not always clear, the model's percentile was set to 95 %, thus removing the upper and lower 2.5 % of the values, to exclude possible errors from outliers. We determined range of altitude, mean annual temperature and annual precipitation for the grid cells that appeared to be suitable for cultivation.

2.4 Overall Potential Distribution of the Three *Passiflora* spp.

Climate-based potential distribution merely represents the potential area where an organism could exist based on suitable climate. While the climate-based potential for a species may be geographically large, in many cases the current distribution is much more limited (Jarvis *et al.*, 2003; Graham and Hijmans, 2006). Different factors such as vegetation, geology or soils constrain distribution. Overall potential distribution is the modified climate-based potential distribution determined by these constraints (Skov, 2000). For this study, detailed data were only available for vegetation type and land use. Climate-based potential distribution range was limited to vegetation types and land uses found in collection sites to obtain the overall potential distribution. We determined range of altitude, mean annual temperature and annual precipitation for grid cells where overall potential distribution had been determined.

3. Results

3.1 Present Distribution and Population Density of the Three *Passiflora* spp.

Geographical distribution and population density for each of the three species are shown in Figure III. *Passiflora mollissima* was only found in Sur Yungas whereas the other two species occurred in both provinces. Highest population density for *Passiflora mollissima* was found in an area bordering Nor Yungas and Sur Yungas. For *Passiflora tricuspis* and *Passiflora nov* sp., highest population density was found in central Nor Yungas. *Passiflora tricuspis* and *Passiflora nov* sp. were mainly observed in the same areas although distribution of *Passiflora tricuspis* was larger.

Figure III: Geographical distribution and population density of the three *Passiflora* species in the study area (°: collection site; □: population density with darker areas indicating higher population density)

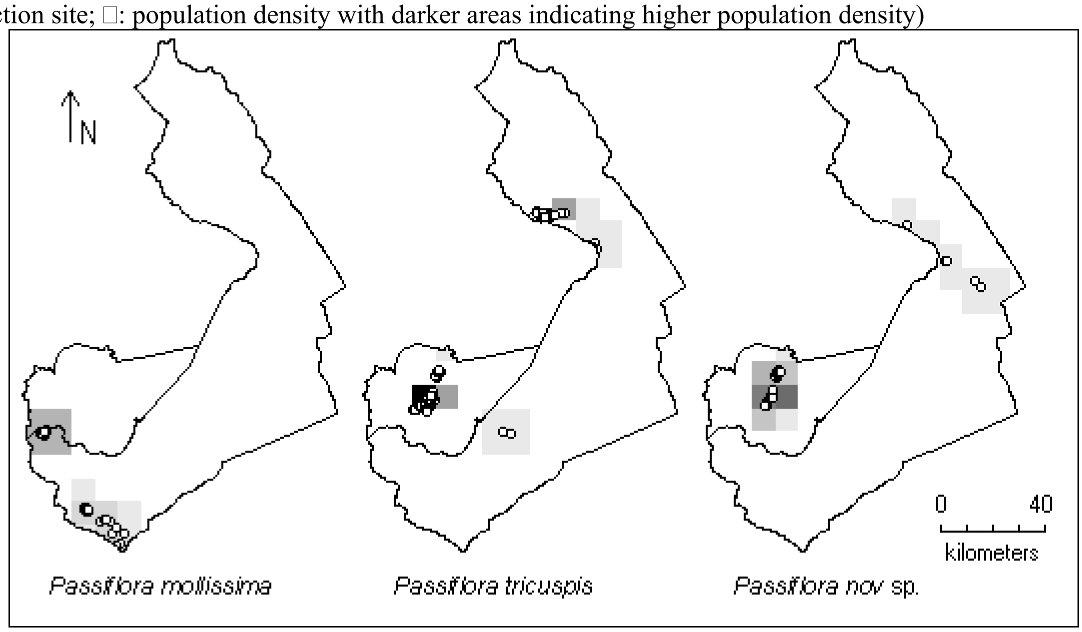


Table I shows calculated distribution and density indicators per species. Average distance between collection sites was highest for *Passiflora tricuspis* and lowest for *Passiflora nov* sp. However, maximum distance between collection sites was similar for both species. *Passiflora mollissima* had lowest area of occupation and maximum distance between collection sites but had a higher average distance between collection sites than *Passiflora nov* sp. Maximum distance increased with number of collection sites. *Passiflora tricuspis* had highest maximum number of collection sites per grid cell.

Table I: Number of collection sites (N), average distance (AD) and maximum distance (MaD) between collection sites, area of occupation (AOO) and maximum number of collection sites per grid (Max N/grid) per species

	N	AD (km)	MaD (km)	AOO (km^2)	Max N/ grid (/km^2)
Passiflora mollissima	61	20	54	26	16
Passiflora tricuspis	234	43	97	58	32
Passiflora nov sp.	87	13	95	32	28

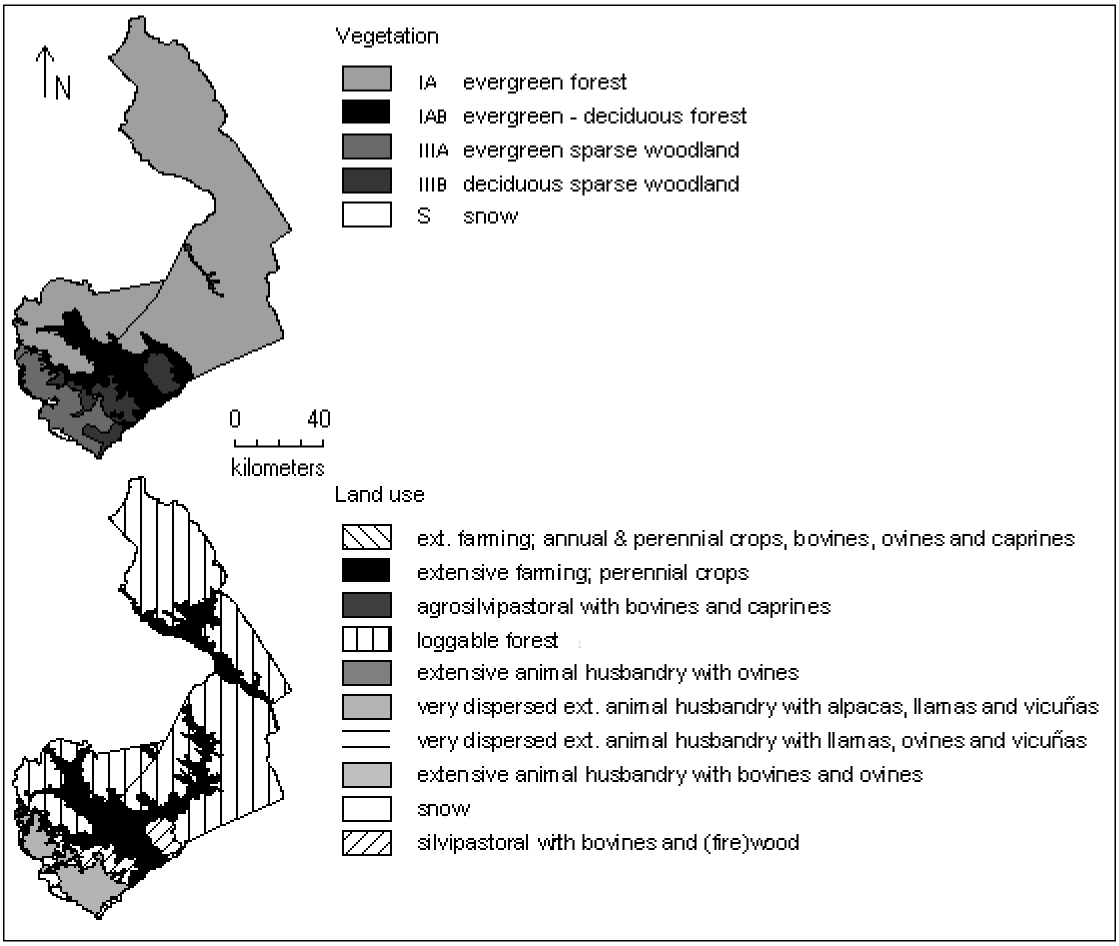
Table II shows altitude, mean annual temperature and precipitation for the collection sites for each of the three species. *Passiflora mollissima* collection sites were significantly higher located and had significant lower annual mean temperature and precipitation values than the other two species' collection sites ($p << 0.01$). No significant differences were found between *Passiflora tricuspis* and *Passiflora nov* sp.

Table II: Altitude, mean annual temperature and precipitation for collection sites from fieldwork and potential distribution locations (based on collection sites found during in field work and on additional information from herbarium databases) for each species

	Altitude (masl)		Mean annual temperature (°C)		Annual precipitation (mm)	
	Mean	Range	Mean	Range	Mean	Range
Passiflora mollissima						
Collection sites	2900	2600 – 3500	13	9 - 16	700	600 - 900
Potential distribution		2400 - 4100		7 - 16		500 - 1000
Passiflora tricuspis						
Collection sites	1100	400 - 1800	22	19 - 25	1400	1100 - 1900
Potential distribution		100 - 1800		17 - 26		600 - 1900
Passiflora nov sp.						
Observed	1200	400 - 1600	22	20 - 25	1300	1200 - 2000
Potential distribution		500 - 1600		20 - 25		1200 - 2000

Fig IV shows vegetation and land use in Nor Yungas and Sur Yungas. *Passiflora mollissima* collection sites mainly occurred in evergreen sparse woodland, deciduous sparse woodland and in evergreen forest.

Figure IV: Vegetation and land use in Nor Yungas and Sur Yungas



These areas are characterized by very dispersed extensive animal husbandry with alpacas, llamas and vicuñas. In other parts, silvopastoralism with bovines and (fire)wood is predominant. *Passiflora tricuspis* and *Passiflora nov* sp. were found in areas with evergreen forest and evergreen-deciduous forest. Land use in these areas consisted of extensive farming with perennial crops.

3.2 Climate-based Potential Distribution of the Three *Passiflora* spp.

Fig V shows results of BIOCLIM analysis for the three species in the study area. Only a small zone in the study area was found to be highly suitable for *Passiflora mollissima* cultivation. Climate-based potential distribution of *Passiflora nov* sp. and *Passiflora tricuspis* appeared to be larger but suitability was often low, especially in Sur Yungas.

Figure V: Climate-based potential distribution of the three *Passiflora* species within the study area

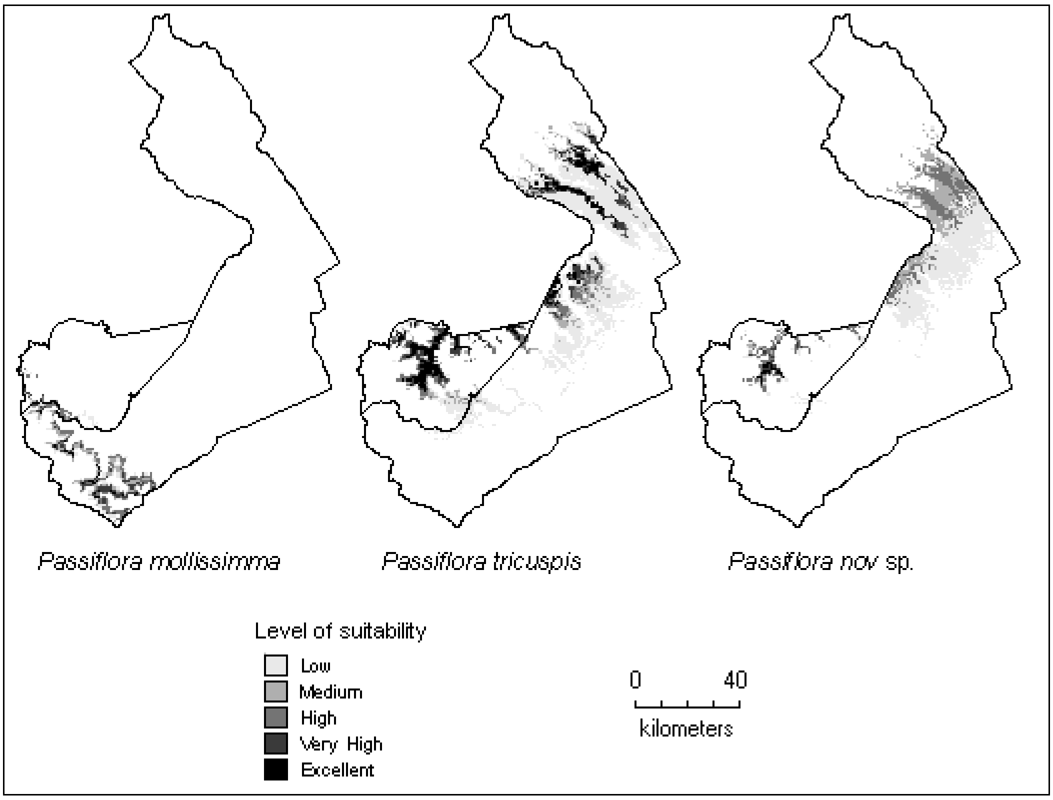
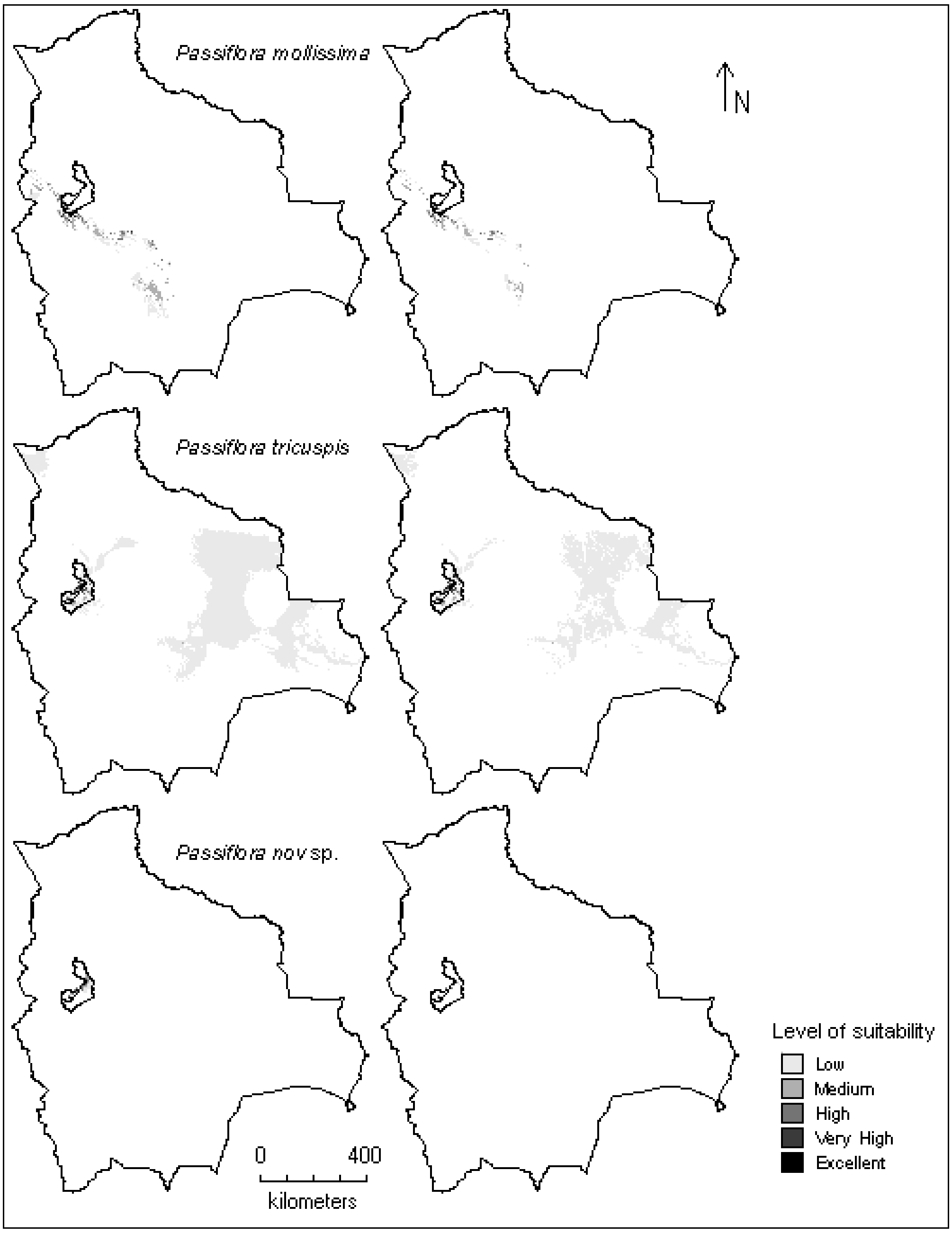


Figure VI shows climate-based potential distribution for the three species at national level. Table II indicates range of altitude, annual temperature and precipitation of suitable grid cells. Results show that *Passiflora mollissima* could be cultivated in a larger area on the eastern slopes of the Andes in Bolivia and many locations showed high to excellent suitability. For the different climate variables, areas within climate-based potential distribution have larger ranges than the ranges of climate variables found following collection sites during our field work. However, these differences are small.

Passiflora tricuspis had a much larger area suitable for cultivation than *Passiflora mollissima,* but the majority of grid cells showed only low to medium suitability. Climate parameter ranges were slightly different compared to results from our collection sites. However, minimum altitude and annual precipitation were lower than in the collection sites.

Passiflora nov sp. showed only limited distribution outside the study area. As no extra collection sites were added, range of altitude, mean annual temperature and annual precipitation are the same as for our observed collection sites.

Figure VI: Climate-based potential (left) and overall potential distribution (right) of the three *Passiflora* species in Bolivia



3.3 Overall Potential Distribution of the Three *Passiflora* spp.

Eliminating all grid cells from the climate-based potential distribution maps with different types of vegetation and/or land use than those found in any of the collection sites, we obtained overall potential distribution patterns as shown in Figure VI. Limited differences were found within Bolivia. Mainly, grid cells with low suitability were removed although also high suitable grid cells were eliminated. We compared minimum and maximum altitude, annual temperature and precipitation between climate-based potential and overall potential distributions and no differences were found.

4. Discussion

4.1 Present Distribution and Population Density of the Three *Passiflora* spp.

Passiflora mollissima had a smaller area of occupancy but a larger average distance between collection sites than *Passiflora nov* sp. This indicates that, compared to *Passiflora mollissima, Passiflora nov* sp. occurred more commonly in one region but was more rarely found outside this region. This is also shown by the fact that the maximum distance between collection sites of *Passiflora nov* sp. and *Passiflora tricuspis* was about the same although the latter had been collected from more locations. Because *Passiflora tricuspis* was more collected, one would expect that this species has the highest area of occupancy and maximum number of collection sites per grid and this was confirmed by the results.

Resolution of the grid cells affects the results and the number of collection sites per grid cell will increase with size grid cell. We used a 9 × 9 km grid (and a circular neighbourhood with a radius of 18 km) to strike a balance between the desire for high resolution and limiting geographic sampling bias (Hijmans *et al.*, 2000; Graham and Hijmans, 2006).

Graham and Hijmans (2006) found that correlation between maps created by point-to-grid and by distribution models increased with decreasing resolutions. We used relatively high resolutions and comparing results from population density mapping (created by point-to-grid) (see Figure III) and climate-based potential distribution (created by distribution models) (see Figure V), and found differences for each species. For *Passiflora mollissima*, there seems to be a collection gap between two main areas with high population density. Some of those areas showed very high suitability and are interesting for future plant collection. For *Passiflora tricuspis*, areas with high suitability were mostly covered by field trips. Some areas with low suitability however, were not yet explored. The same conclusion could be drawn for *Passiflora nov* sp. that showed even less discrepancy between population density and climate-based potential distribution.

Literature information on climate requirements was only available for *Passiflora mollissima*. According to Espinosa (1992), *Passiflora mollissima* requires between 1200 and 1500 mm of rainfall spread during the year whereas in this study lower levels of precipitation were found. Different altitudinal range data were found: according to Green (1994), *Passiflora mollissima* is a montane plant and is found in the Andes at altitudes between 2000 and 3200 masl. In Colombia ranges are from 2200 and 3200 masl according to Romero (1956), and 1800 up to 3600 masl according to Espinosa (1992). In the present study, altitudinal ranges for collection sites and climate-based potential distribution were larger.

4.2 Climate-based Potential Distribution of the Three *Passiflora* spp.

Ranges of altitude, annual mean temperature and precipitation between collection sites from our field work and climate-based potential distribution based on all historical collection sites, were similar (see Table II). Only maximum altitude of *Passiflora mollissima* and minimum altitude of *Passiflora tricuspis* collection sites characterized during field work were lower and higher, respectively than those of historical collection sites. This can be explained by the fact that field work was carried out only in the *Yungas,* which ranges from 400 up to 3500 masl.

Stockwell and Peterson (2002) found that ten collection points are enough to make an accurate prediction on bird distribution in Mexico. Guarino *et al.* (2002) stated that even limited information can be used to identify areas where a species has not been previously recorded but where it might still be expected to occur. In the present study, according to those criteria, we collected enough data to predict climate-based potential distribution in Bolivia. However, for *Passiflora nov* sp. it was not possible to add additional herbarium data as this is a new species. This restricts the possibilities to evaluate its distribution at national level. One can thus only reliably predict climate-based potential distribution within a certain maximum distance from the collection points. Comparing results of *Passiflora mollissima* and *Passiflora tricuspis,* it is unlikely that *Passiflora nov* sp. could only be distributed in such a small area. A possible explanation is that BIOCLIM uses too many parameters, which may lead to over-fitting the model (Beaumont *et al.*, 2005).

However, as herbarium data are not always very accurate, using the latter data is not always the solution to make predictions on a larger scale. Geographic co-ordinates of public databases can be imprecise or even wrong (Hijmans *et al.*, 1999). As stated above, validating results of climate-based potential distribution would be a solution but is difficult in an area with very limited literature information on species distribution (Sommer *et al.*, 2003).

4.3 Overall Potential Distribution of the Three *Passiflora* spp.

We found that overall potential distribution was similar to climate-based potential distribution for the three species. This confirms the fact that species distribution is explained mainly by climatic factors (Woodward, 1987; Skov, 2000; Rafiqpoor *et al.*, 2003). Luoto *et al.* (2006) stated that land cover information can give strikingly different results from those obtained through purely bioclimatic models. In the present research, differences between climate-based potential and overall potential distribution was limited as shown in Figure VI. No differences were found when comparing ranges of altitude, temperature and precipitation.

5. Conclusion

The use of geographic collection data, in combination with the relatively simple GIS software DIVA-GIS, allowed a quick estimate on distribution and population density for the three species studied. *Passiflora tricuspis* had widest climate-based potential distribution area in the study area and within Bolivia, although many grid cells showed low suitability. *Passiflora mollissima* had a smaller climate-based potential distribution in higher, colder and drier areas than *Passiflora tricuspis* but suitability was more often high to excellent. *Passiflora nov* sp. had a comparable distribution as *Passiflora tricuspis* in the study area but climate-based potential distribution at national level seemed limited. No substantial difference was found between climate-based potential and overall potential distribution.

Acknowledgements

Research financed by a Ph.D. grant of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen) and the King Léopold III Fund for Nature Exploration and Conservation.

References

Beaumont, L.J., Hughes, L. and Poulsen, M. (2005). Predicting species distributions: use of climatic parameters in BIOCLIM and its impact on predictions of species' current and future distributions. *Ecological Modelling*. 186: 250-269.

CIMAR (1994). *Comunidades, territorios indígenas y biodiversidad en Bolivia.* Centro de Investigaciones y Manejo de Recursos Naturales, Universidad Autónoma Gabriel Rene Moreno, Santa Cruz, Bolivia.

Cárdenas, M. (1989). *Manual de plantas económicas de Bolivia.* Los amigos del libro, La Paz, Bolivia.

Espinosa, T.C. (1992). The culture of curuba (*Passiflora mollissima* (H.B.K.) Bailey) in Colombia. *Acta Horticulturae*. 310: 215-231.

FAO (1996). *The state of the world's plant genetic resources for food and agriculture.* Food and agriculture Organization of the United Nations, Rome, Italy.

Graham, C.H. and Hijmans, R.J. (2006). A comparison of methods for mapping species ranges and species richness. *Global Ecology and Biogeography*. 15: 578-587.

Green, P.S. (1994). *Passiflora mollissima*. *Kew magazine*. 11 (4): 183-186.

Guarino, L., Jarvis, A., Hijmans, R.J. and Maxted, N. (2002). *Geographic information systems (GIS) and the conservation and use of plant genetic resources*. p. 387-404. In: J. M. M. Engels, R. V. Ramantha, A. H. D. Brown and M. T. Jackson (eds.) Managing plant genetic diversity, IPGRI, Rome, Italy.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. *International journal of climatology*. 25: 1965-1978.

Hijmans, R.J., Garrett, K.A., Huamán, Z., Zhang, D.P., Schreuder, M. and Bonierbale, M. (2000). Assessing the geographic representativeness of genebank collections: the case of Bolivian wild potatoes. *Conservation biology*. 14 (6): 1755-1765.

Hijmans, R.J., Guarino, L., Cruz, M. and Rojas, E. (2001). Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genetic Resources Newsletter*. 127: 15-19.

Hijmans, R.J., Schreuder, M., De la Cruz, J. and Guarino, L. (1999). Using GIS to check co-ordinates of genebank accessions. *Genetic resources and crop evolution*. 46: 291-296.

Ibisch, P.L. and Beck, S.G. (2003). *Espermatófitas*. p. 103-112. In: P. L. Ibisch and G. Mérida (eds.) Biodiversidad: la riqueza de Bolivia. Estado de conocimiento y conservación, FAN, Santa Cruz de la Sierra, Bolivia.

Ibisch, P.L., Beck, S.G., Gerkmann, B. and Carretero, A. (2003). *Ecoregiones y ecosistemas*. p. 47-88. In: P. L. Ibisch and G. Mérida (eds.) Biodiversidad: la riqueza de Bolivia. Estado de conocimiento y conservación, FAN, Santa Cruz de la Sierra, Bolivia.

Ibisch, P.L. and Mérida, G. (2003). *Biodiversidad: la riqueza de Bolivia. Estado de conocimiento y conservación.* FAN, Santa Cruz de la Sierra, Bolivia.

INE (2004). *Estadísticas e indicadores socioeconómicos del departamento de La Paz.* Instituto Nacional de Estadística, La Paz, Bolivia.

IUCN (2006). *Guidelines for using the IUCN Red List Categories and Criteria: Version 6.1.* Standards and petitions Working Group, Gland, Switzerland.

Jarvis, A., Ferguson, M.E., Williams, D.E., Guarino, L., Jones, P.G., Stalker, H.T., Valls, J.F.M., Pittman, R.N., Simpson, C.E. and Bramel, P. (2003). Biogeography of wild *Arachis*: assessing conservation status and setting future priorities. *Crop Science*. 43 (3): 1100-1108.

Killeen, T.J., Garcia, E.E. and Beck, S.G. (1993). *Guía de árboles de Bolivia.* Quipus S.R.L., La Paz, Bolivia.

Luoto, M., Virkkala, R. and Heikkinen, R.K. (2006). The role of land cover in bioclimatic models depends on spatial resolution. *Global Ecology and Biogeography*. in press.

Mazzani, E., Perez, D. and Pacheco, W. (1999). Distribution and use of species of the genus *Passiflora*

(Passifloraceae) in the highlands of Lara and Falcon States, Venezuela. *Plant Genetic Resources Newsletter*. 119: 34-32.

Rafiqpoor, D., Nowicki, C., Villarpando, R., Jarvis, A., Jones, E.P., Sommer, H. and Ibisch, P.L. (2003). *El factor abiótico que más influye en la distribución de la biodiversidad: El clima*. p. 31-46. In: P. L. Ibisch and G. Mérida (eds.) Biodiversidad: la riqueza de Bolivia. Estado de conocimiento y conservación, FAN, Santa Cruz de la Sierra, Bolivia.

Romero, C.R. (1956). Plantas de valor comercial del genero Passiflora: granadilla, curuba, badea y otras. *Agricultura tropical*. 12 (6): 403-407.

Scheldeman, X., Willemen, L., Coppens d' Eeckenbrugge, G., Romeijn-Peeters, E., Restrepo, M.T., Romero, M., Jimenez, D., Lobo, M., Medina, C.I., Rodriguez, D., Ocampo, J.A., Van Damme, P. and Goetgebeur, P. (2006). Distribution, diversity and environmental adaptation of highland papayas (*Vasconcella* spp.) in tropical and subtropical America. *Biodiversity and conservation*. in press.

Segura, S., Guarino, L., Lopez, L., Gru, M. and Coppens d' Eeckenbrugge, G. (1999). *Mapping the distribution and regions climatically suitable for four species in Passiflora subgenus Tacsonia (Passifloraceae) and P. manicata.* Poster presented at II Simposio de Recursos Genéticos para América Latina e Caribe - SIRGEALC, 21-26 November 1999, Brasília, Brasil.

Skov, F. (2000). Potential plant distribution mapping based on climatic similarity. *Taxon*. 49: 503-515.

Sommer, J.H., Nowicki, C., Rios, L., Barthlott, W. and Ibisch, P.L. (2003). Extrapolating species ranges and biodiversity in data-poor countries: The computerized model BIOM. *Revista de la Sociedad Boliviana de Botánica*. 4 (1): 171-190.

Stockwell, D.R.B. and Peterson, A.T. (2002). Effect of sample size on accuracy of species distribution models. *Ecological Modelling*. 148: 1-13.

Vanderplank, J. (1996). *Passion Flowers.* Cassel, London.

Vargas, J.H., Consiglio, T., Jørgensen, P.M. and Croat, T.B. (2004). Modelling distribution patterns in a species-rich plant genus *Anthurium* (Araceae), in Ecuador. *Diversity and distributions*. 10: 211-216.

Vásquez, R. and Coimbra, G. (2002). *Frutas silvestres comestibles de Santa Cruz.* Fundación amigos de la naturaleza, Santa Cruz, Bolivia.

Woodward, F.I. (1987). *Climate and plant distribution.* Cambridge university press, Cambridge.