FINAL PROGRAM REPORT

Of the project

Integrating Remote Sensing, GIS, and Modeling for Land-Use Monitoring in the Arid/Semi-Arid Andes (DME-Sur[1])

A project financed by the Ecoregional Fund

April 30, 2000

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Duration of the Project: October 1996 – September 1999 (extended to March 2000). A six-month no-cost extension was requested to and granted by the Fund Managers.

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[1] The acronym DME stands for Desarrollo de Métodos Ecorregionales. CIP had two proposals financed by the initial round of the Fund, one executed in northern Peru and Ecuador and the one reported here, in southern Peru and Bolivia, hence the postscripts Nor and Sur, Spanish for north and south.

Executive summary

This report summarizes the activities and outputs of the project Integrating Remote Sensing (RS), Geographic Information Systems (GIS), and Modeling for Land Use Monitoring in the Arid/Semi-arid Andes (DME-Sur). The activities reported were mainly financed by the Ecoregional Fund to Support Methodological Initiatives and conducted as an approved activity of the Consortium for the Sustainable Development of the Andes (CONDESAN). The goal of the project was to develop and test methodologies to improve the predictive performance of crop, pasture, and animal production models through the inclusion of remotely sensed qualitative and quantitative data.

The main output of the research consisted of an integrated assessment system—based on remotely sensed data, GIS, and process-based models—capable of estimating crop and animal production at different spatial aggregation scales. Such a system is useful for (i) evaluating the current status of regional production, (ii) monitoring land-use changes, (iii) defining extrapolation domains, and (iv) conducting scenario analyses related to the implementation of different policies or new technologies. The integrated system developed is directly related to elements 1, 2, and 3 of the Ecoregional program, as defined by the Fund's guidelines for submitting proposals.

The innovative characteristic of this project is its direct focus on how best to use remote sensing, GIS, and modeling tools to make them useful for monitoring land use, estimating agriculture productivity, quantifying climatic and production risks, and predicting agricultural outcomes in a practical, effective, and cost-efficient manner. For ecoregional programs, access to such tools is expected to provide regional information with temporal and spatial attributes difficult to obtain by alternative methods, particularly in remote and harsh environments like the Altiplano. Also, there is simply no alternative source for much of the multitemporal and multispectral information obtained through remote sensing.

The methods and tools developed were presented at several scientific fora, and at two international conferences the papers presented were honored with the Best of Session Awards. In addition, at least three institutions are willing to invest in adapting the integrated system developed in the project for use as a decision support tool, one of them being at national level. The fine-tuning of the system to respond to decision makers' needs plus additional efforts to develop and include new tools for multi-scale analyses are the logical next steps in the future development of the program.

1. Introduction

A continuing rise in poverty levels, the inherent high risks in agriculture, and evidence that the productivity of natural resources is being degraded all point to the need to better understand the social, economic, and environmental forces at work in the Altiplano. In search of this understanding, CONDESAN partners and others have been conducting farm- and community-level studies in the region, with a primary focus on describing and quantifying decision-making processes related to risk management. Farming system research methods have been employed in such studies, but it is recognized that these methods alone are not sufficient for a truly integrated assessment of the sustainability of agriculture in the Altiplano. Innovative methods that rely on data from remote-sensing satellites and process-based simulation models have been examined separately in the Altiplano, indicating the additional analytical capabilities that such tools might offer in ecoregional approaches to research and development. The potential for linking remotely sensed data and crop growth models to estimate production over large areas has been demonstrated elsewhere (Bouman, 1995; Thornton et al., 1997), although methods for making such linkages generic and easily applicable to other ecoregions are generally lacking.

Multi-scale perspectives play a central role in ecoregional research (ER) since agricultural researchers are encouraged to do analysis across different spatial scales and agroecologies. Since most of the geographic patterns vary with scale – i.e., are scales dependent – results of estimates at multiple scales can be seriously biased. Understanding this dependency then becomes a central issue in ER. Generic tools to understand and take into consideration scale dependency are not available. This project aimed at developing a modular integrated system capable of performing multi-scale analyses. Part of the team is developing other modules for the system. This development progresses as we better understand the scale dependency in mountain agroecosystems and test the best-suited tools to assess their impact in multi-scale analysis. As explained below, there is demand for the system for planning agricultural research and development in the ecoregion where the system was developed as well as in other areas.

2. Goal and Objectives

The method developed in this project builds upon remote sensing and process-based simulation experience in the Altiplano, complemented by similar expertise in other regions, to provide generic procedures for linking remotely sensed data, geographical information systems (GIS), and crop and livestock models. The **goal** of the project is to develop and test methodologies that will improve the predictive performance of crop, pasture, and animal production models through the inclusion of remotely sensed qualitative and quantitative data that can be updated and that provide continuous spatial coverage.

The specific **objectives** of the project are: (1) To develop methods for linking remote sensing, GIS, and dynamic models to increase the accuracy in predicting agricultural production at landscape and regional levels. (2) To test the methods developed by comparing the confidence bands of simulated agricultural production with census data, remotely sensed data, and outputs of existing simulation models.

3. Program strategies

3.1. Institutional Strategies

Two strategies were outlined and implemented throughout the project's life. The first was to recognize that complementary experience and expertise, from different individuals and institutions, was required to achieve the project's goal. The process of creating the required strategic alliance to design and implement the project was greatly facilitated by CONDESAN. Researchers from local research institutions and NGOs actively participated in the field research as well as in the analysis and programming of the integrated system produced. Advanced research centers such as JPL/NASA and AB-Plant Research International (AB-PRI) were also instrumental in this.

The second strategy was to guarantee the funds needed to fully develop the integrated system and to test the products in ecoregions outside the Altiplano. Several proposals were developed and presented to secure the funding needed. The in-kind contribution of institutions such as IRD and JPL/NASA is highly valued.

3.2. Research Approach

The program's research problem was the development of robust techniques to deal with multi-scale issues that can be applied within the financial and human resources constraints typically encountered in developing countries. The research was conducted in a collaborative manner, including strong partners from within and outside the Andean region.

The nature of the problem addressed by the team in this initial phase precluded the massive participation of non-researcher users. Decision makers were consulted whenever deemed appropriate to guarantee that the final product would meet their needs.

Theoretical considerations, combined with sound field research and skillful programming, were combined to assure the delivery of the product. Face-to-face meetings, complemented with formal and informal electronic discussions, were conducted throughout the project. Ample diffusion of project findings through participation in scientific meetings, publications, and discussions with selected decision makers contributed to raising the awareness of the importance of the problem and the need for the tools developed in the project.

4. Program activities

<table>
<tr><th>Activity</th><th>Oct96-March97</th><th>April-Sep97</th><th>Oct97-March98</th><th>April-Sep98</th><th>Oct98-March99</th><th>April-Sep99</th><th>Oct99-March00</th></tr>
<tr><td>Database Development</td><td colspan="4">CIRNMA. IBTA. CIP</td><td></td><td></td><td></td></tr>
<tr><td>Ground-based measurements</td><td></td><td colspan="4">IRD/ABTEMA. IBTA. CIRNMA. CIP</td><td></td><td></td></tr>
<tr><td>Process-based simulation models</td><td></td><td colspan="5">AB-PRI. IFDC. ILRI. CIP</td><td></td></tr>
<tr><td>Remote sensing/GIS</td><td></td><td colspan="5">ABTEMA/IRD. CIP.AB-PRI. JPL/NASA</td><td></td></tr>
<tr><td>Development of the Integrated System (SIMSRIG)</td><td></td><td colspan="6">CIP</td></tr>
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4.1. Database development

An important interinstitutional database has been assembled, comprised mostly of data needed for model calibration and testing, and that needed for field and satellite data correlation studies. Specifically, the results of over 200 historical field experiments have been digitized using the GCTE reporting format. These represent the results of potato and cereal, as well as livestock-related experiments conducted during the past 30 years at Altiplano sites in both Peru and Bolivia. The more complete crop experiments were assembled using ICASA standard formats for testing with Decision Support System for Agricultural Technology Transfer (DSSAT) and LINTUL potato plant growth model models. GIS overlays have been assembled; a Food and Agriculture Organization soils database has been georeferenced on a 10 x 10 km^2 grid and a digital elevation model on a 1 km^2 grid. SENAMHI-Bolivia has furnished the project with over 30 years of daily weather data gathered at its Altiplano stations. NOAA-AVHRR scans from 1995 and 1996 were purchased together with SPOT and LANDSAT-TM images. Radar images were provided by the European Space Agency, the Canadian Centre for Remote Sensing, and NASA. Daily NOAA-AVHRR images were captured with the Project's Antenna from April 1997.

4.2. Ground-based measurements

Monthly measurements of herbage biomass were made together with gravimetric measurements of surface soil water content. These measurements are being made in the six most important natural rangeland types, i.e., Bofedales, Totorales, Pajonales, Tholares, Gramadales, and Tholar/Pajonal. At some sampling sites in Bolivia, data since 1995 permitted the study of annual trends in production. A less frequent sampling (3 times) of crop—quinoa, potato, and barley—fields has occurred. Saline areas that are covered by radar scans were sampled three times for mapping salinity/sodicity.

4.3. Process-based models

Project collaborators as well as other interested professionals participated in two one-week workshops in Peru and Bolivia. Participants were trained in the data demands and practical use of the DSSAT family of models. These workshops were part of a series conducted in the Andean region. In total, about 85 professionals from 30 different institutions have been exposed to the modeling approach using DSSAT as a teaching platform. Such workshops have facilitated the exchange of standard soil, weather, and experimental data across the region, providing relevant and valuable input for model improvement under Andean conditions.

Livestock models were re-programmed and further tested for the Altiplano conditions. Professionals from Peru and Bolivia were trained in assembling and programming the models. They are now capable of adapting the models to new settings.

4.4. Remote sensing

The study of frost and drought risks was done for the whole Altiplano, using low-resolution and low-cost satellite data captured daily by the NOAA-AVHRR receiving station in La Paz. For the estimation of native pasture and crop biomass, NOAA-AVHRR and higher-resolution radar and optical scans were used on smaller pilot sites for correlation studies. In these studies, the project has focused on the six predominant mixed native pasture systems (Bofedales, Totorales, Pajonales, Tholares, Gramadales, and Tholar/Pajonal) and the three predominant crops (quinoa, potato, and barley) found in the Altiplano. The selected sampling areas in the pilot sites are homogeneous and representative of large areas, thus allowing the generation of biomass field data that can be correlated with vegetation indexes generated from low-resolution NOAA-AVHRR satellite data (1 km pixel size), as well as with backscatter values from higher-resolution radar scans. The advantage of using NOAA-AVHRR data is its low cost of acquisition (reduced operator, storage media, and equipment maintenance), its repetitiveness, its multispectral information including thermal bands, and its regional coverage allowing the quick generation of updated regional information to drive or “steer” production models. In addition to monitoring biomass production, radar remote sensing is being used to estimate soil moisture and salinity.

4.5. Communications

Any project that has a diverse group of disciplines and institutions working together within an ecoregional context must continuously confront the challenge of maintaining an open line of communication and understanding. And it is even more of a challenge when many of the participants are not in the region and have few opportunities to meet together. To confront this challenge, and to keep all project participants operating in consensus, an electronic discussion list was maintained and used throughout the project life. This list provided a valuable means by which participants from the Netherlands, CIP (International Potato Center) - Lima, Puno, and La Paz were able to conduct active and productive discussion of project progress and future directions.

5. Program outputs

The following paragraphs summarize the contributions made to the ecoregional methodology. The summary includes both the components that can be used as stand-alone products and the multi-scale assessment system based on RS and GIS (SIMSRIG, the Spanish acronym for the system).

5.1. Process-based models

In data-scarce environments, such as the Altiplano, validated process-based simulation models provide a tool to fill the data gap. The DSSAT family of models has been adapted to the Altiplano to simulate crop production. Most of the work on crop modeling consisted of searching for historical experimental data and the reparameterization of the models. The work was led, for both DME-Sur and Nor, by Dr. Walter Bowen. A more thorough description is given in our DME-Nor final report.

Models to simulate livestock production were developed in situ, and the initiation of the process preceded the project. During the project, these models were refined, re-programmed in object-oriented language, and further validated. Main sub-routines in the models include estimation of voluntary intake for grazing animals, nutrient breakdown and utilization (energy, protein, calcium, and phosphorus) and heat exchange between the grazing animal and the environment. Simulation is performed on a daily basis. Models have been developed for dual-purpose cattle, sheep, and alpacas. Model validity tests were conducted in a wide range of experimental and on-farm conditions.

These livestock models are field-level models where the user defines the area under grazing, pasture types, the number of divisions, and the composition of the herd or flock. Pasture growth rate in kg DM day^{-1} and its digestibility characterize grazing areas. Model estimates comprise animal production, reproduction, and herd/flock growth.

Field-level simulation models, though good alternatives, present several limitations when used at larger scales. When simulation models are used on a regional scale, uncertainty and spatial variation in model parameters can result in broad bands of simulated results. To minimize these errors the complementary tools described below were added to the system.

5.2. Remote Sensing

In recent years RS has been used to derive quantitative data on land use/land cover changes and other variables such as primary production, land surface temperature, and evapotranspiration, among others. The advantages of using remote sensing in data-scarce environments include:

- Large areas might be covered by a single image,
- There are sensors capable of providing information at high resolution and in different bandwidths of the electromagnetic spectrum, and
- There are sensors that provide daily coverage of the area of interest.

Among the limitations we can mention:
- The cost of high-spatial-resolution data,
- Data availability not guaranteed due to either problems in the sensor or atmospheric problems,
- Lack of historical records (usually less than 20 years of available data), and
- Limited predictive capability.

The following discussion explains how to link models, GIS, and remote sensing, using as example livestock production, the main agricultural activity of the area. The same principles apply to crop production. The difficulty in this case is the absence of continuous coverage with high-resolution sensors, at a reasonable cost, for large areas with high concentration of small plots.

Methods to link pasture models to remote sensing data, in a GIS environment, were tested. The principal objective was to attain a more realistic estimate of available biomass in rangelands of the Altiplano than the ones obtained by any of the methods alone. More accurate estimates of the forage availability throughout a year over an entire region are needed to determine the management options that would increase profit while protecting the natural resource base.

The first step was to develop a land use/cover map. A combination of data sources including secondary information, and field and remotely sensed data were used to develop land use/cover maps for either the entire study or for benchmark areas where more-intensive field data collection were conducted.

A sequence of images – from October 1992 to September 1993 - of the Normalized Vegetation Index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRR) over the Altiplano were used. AVHRR imagery (1.1-km ground resolution) was downloaded from the USGS- Earth Resources Observation Systems (EROS) Data Center Distributed Active Archive Center (EDC DAAC) Internet site. The sequential steps followed included:

(1) Correction of geometric distortion by the use of ground points from maps (1:250,000);
(2) Unsupervised classification based on the NDVI signatures in each month and the changes throughout the year;
(3) Ground evaluation of the unsupervised classification;
(4) Enhanced unsupervised classification with 1 km^2 (approximately) digital elevation model (USGS) correcting for similar spectral characteristics in distinct ecological settings;
(5) Ground evaluation of the enhanced classification;
(6) Selection of training sites; and,
(7) Supervised classification.

The accuracy of the classification was further assessed with a classification done with imagery taken in June 1998 over a selected area with LANDSAT TM (30-m ground resolution). Both land use and cover maps were re-sampled to 100-m pixels to do the comparison. The confusion matrix was then generated to estimate the proportion of the area incorrectly classified by the AVHRR procedure. The comparison showed that the land use/cover classes as defined by AVHRR data were on average 62 % accurate. This level of accuracy is considered appropriate, showing the usefulness of utilizing AVHRR multi-temporal data on a regional scale (Figure 1).

Daily biomass availability and quality are needed for the entire target area to scale up the field-level livestock models. Several experiments were conducted to derive these two variables from remotely sensed data.

Three measures of NDVI were used to assess the herbage biomass production at the regional level (Hobbs, 1995):

1. The maximum observed NDVI value for the growth season ($NDVI_{max}$).
2. The background-adjusted maximum NDVI ($NDVI_{ba}$).
3. Using peak NDVI as the first approximation of the end of the growing season, a temporal sum of NDVI ($NDVI_{cum}$) was calculated as the cumulative difference between observed and background NDVI values for the period between the early rains and the observed peak NDVI.

These measures were compared against observed herbage biomass. Linear and nonlinear regression procedures were used to search for a mathematical model that best described the relationships between the ground-based biomass estimates and the average $NDVI_{max}$, $NDVI_{ba}$, and $NDVI_{cum}$ (Figure 2).

Within each rangeland type, temporal monitoring of biomass changes with NDVI values was attempted. Both NDVI and $NDVI_{ba}$ were used. Monitoring time changes in herbage biomass is hindered by the constant utilization of the sampling sites. The trends found are shown in Figure 3. In spite of the disturbances caused by intensive grazing to Bofedales, NDVI appears to adequately monitor those changes.

The use of remote sensing as the sole option to provide biomass data to livestock models is not satisfactory. The data are required on a daily basis and this prerequisite is seldom satisfied. Even with NOAA-AVHRR daily data there can be prolonged periods of time when a good image cannot be acquired due to cloud interference. This is especially true during the rainy season, when more accurate biomass data are needed because it is the most productive time of the year for biomass production. To circumvent this problem a pasture model was developed and tested to fill the data gap.

Ongoing research aims at determining the quality of the standing biomass with remotely sensed data. A functional relationship between the digestibility and the reflectance in the near-infrared region of the spectrum is sought. It is well documented that the molecular absorption in this region of the spectrum is primarily due to X-H bonds, where X is carbon, nitrogen, or oxygen. Major components of the secondary cell wall of plants are rich in these bonds and therefore NIR spectroscopy has been successfully used in assessing forage digestibility at field level. A relationship where NIR explained near 60% of the in situ digestibility changes was found.

To develop the functional relationships between the spectral responses (NDVI or NIR) and biomass or digestibility, the field data were divided into two sets. One set was used to develop the relationship and the second to test its validity.

5.3. Pasture model

Light-use and INterception of PASture (LINPAS) types is a dynamic simulation model for pasture growth driven by daily weather data. LINPAS is steered by source- and sink-limited production potentials. First of all, the potential crop growth by intercepted radiation and Light Use Efficiency (LUE, g DM MJ^{-1} intercepted radiation) of the green leaves is calculated, resulting in the source-limited potential crop growth. Water- and nitrogen-limited growth rates are then calculated and results are given according to the law of minimums (Figure 4).

LINPAS can be configured with differing crop data files in order to simulate the biomass production of different rangeland types with one and the same crop module. The difference between the rangelands is expressed by five crop parameters: light use efficiency, maximum rooting depth, optimal nitrogen concentration for shoots, specific leaf area, and dead dry matter fraction remaining in the crop and not entering the soil system.

To link LINPAS with RS, the leaf area index calculated by the model is used to estimate the optical reflection of the canopy. This in turn is used to estimate the NDVI. Estimated NDVI is compared to the NDVI calculated by the inversion of the remotely sensed signal. The pasture model is re-initialized if the NDVI values differ in order to get a more accurate estimate of the biomass. Through linking LINPAS with the RS data, a more accurate estimate of available forage for the grazing animal is attained. LINPAS fills in for data gaps (e.g., cloudy days) whereas RS data account not only for the variables not included in the model that affect pasture growth but also for variables that *are* included in the model. For example, if grazing has taken place, but it was estimated wrongly from the grazing model, the re-initialization of the leaf area index accounts for the amount of biomass that is actually available in a specific pixel, thus creating a desired synergism (Figure 5).

5.4. Assembling the Integrated System

The system was designed, assembled, and programmed in C^{++} Builder. SIMSRIG (Spanish acronym, version 3.0) is a user-friendly, integrated multi-scale-assessment system software package. It is composed of four subsystems: 1) image input and processing, 2) specialized functions for multi-scale analyses, 3) interface with GIS, and 4) interface with process-based models (Figure 6). The four subsystems and their respective components work interactively and dynamically with an integrated database (Figure 7). The remote sensing / geographic information subsystem combines existing capabilities of commercial software with tools to perform quantitative multi-scale analyses, as part of the subsystem 2. By combining remote sensing with process-based models the system is capable of simulating both crop and livestock production at different spatial scale levels and to generate the data needed to analyze the scaling functional relationship, if existent.

The system can be used to assess management options for grazing and crop lands. This assessment can be done at a pixel level or at larger aggregations of pixels. The model simulates crop or animal behavior, production, and reproduction for every pixel. Soil, climate, and management effects are considered at the pixel level. The production over a pre-defined area is estimated as the summation of the results of all the pixels contained within the image.

6. Dissemination, use of outputs, and impact

The project was designed to test components and to develop a prototype tool that would be useful in data-scarce environments. Dissemination at scientific meetings was given high priority. Two awards were received at scientific meetings: best poster on livestock modeling, at the Third International Symposium on Systems Approaches for Agricultural Development; and best of session award, at the second International Conference on Geospatial Information in Agriculture and Forestry, where SIMSRIG was presented. Even though formal involvement of decision makers was not included in the original project, a moderate level of dissemination among them was achieved, since we are convinced the users will have the final word.

The integrated system developed by the project makes available state-of-the-art knowledge to serve the needs of the poor inhabitants of the Altiplano and other data-scarce environments by providing local decision makers with a DSS to ex-ante assess the impact of their decisions. It can also be used to help explain the outcomes of previous decisions.

A development project in Bolivia (PDLA), under the Ministry of Agriculture, together with a dairy farmers' association (ASPROLPA), will be the first group of decision makers to put the DSS to the test. The Ministry of Agriculture of Panama is considering investing up to one million dollars to adapt and further develop SIMSRIG for use by the Panamanian Agricultural Research Institute, the Agricultural Insurance Institute, the Agricultural Bank, and the Ministry itself. CIP's Director General has already signed an Memorandum of Understanding with the government of Panama and the proposal is being presented to the country's legislators. Initial talks with the ministry of foreign affairs of Peru have taken place. It is envisioned that the system will be adapted to the needs of the binational Peru-Ecuador project.

7. Budget discussion

The funds were used as approved by The Ecoregional Fund.

INTERNATIONAL POTATO CENTER (CIP)

INTEGRATING REMOTE SENSING, GIS, and MODELING for LAND-USE

MONITORING in the ARID/SEMI-ARID ANDES - DMESUR

FINANCED BY : THE INTERNATIONAL SERVICE FOR NATIONAL AGRICULTURAL RESEARCH

STATEMENT OF ACTIVITY BY FUNDING SOURCE

FOR THE PERIOD OCTOBER 1, 1996 THROUGH DECEMBER 31, 1999

(Stated in U.S. Dollars)

		Actual		
	Budget	**oktober 1, 1996 through december 31, 1998**	**januari 1, 1999 through december 31, 1999**	**Budget Status**
INCOME :				
Prior Year Balance (Note 3)			75,772-	
Funds Received		351,070	115,380	
TOTAL		351,070	39,608	
EXPENSES :				
A. Funds Managed by CIP				
Personal Service	237,000	199,505	36,318	1,177
Travel	42,000	20,769	11,063	10,168
Overhead 20%	55,800	46,185	9,615	
Sub-total	334,800	266,459	56,995	11,345
B. Equipment and Funds Managed by Nars	**NARS**			
Services	36,000	32,461	5,303	(1,764)
Field Trial Supplies	6,000	9,849	359	(4,208)
Equipment	100,000	105,373		(5,373)
Overhead 10%	14,200	12,700	1,500	-
Sub-total	156,200	160,383	7,162	(11,345)
TOTAL	491,000	426,842	64,158	-
Funds to be received (Note 4)			**(24,550)**	

8. Related R&D grants and activities

Funds from other grants were used to complement the activities of the project, particularly for the development of the components:

- Livestock in Ecoregional Research-LAC. Joint ILRI-CIP Project funded by EMF and IDRC
- Sustainable Mountain Agriculture – SDC
- The Global Mountain Program – EU
- Climate Variability and Household Welfare in the Andes: Farmer Adaptation and Use of Weather Forecast in Decision making – Joint UMC-CIP Project funded by NOAA.
- Enhancing Livestock Productivity as a Means of Protecting Mountain Ecosystems – Joint CIP/ILRI project funded by the System-wide Livestock Program

9. Lessons learned

Managing a multidisciplinary team based in different locations, with different cultures and backgrounds – particularly in relation to experience and knowledge of modern tools and methods – is a challenging task. Open communications as well as agile data-sharing mechanisms are a must. The feasibility of data and tools sharing through virtual laboratories – Internet based – offers a cost-effective alternative for future ecoregional projects.

The involvement of decision makers in methodological initiatives should be revisited. Early involvement, except for defining the outputs, might be counterproductive (depending on the level of knowledge of the subject). In our limited experience, once the product provides useful information for decisions it is a lot easier to get their support. When the science behind the methods is being discussed it might look like “science fiction” to them.

It is difficult to get support from “typical donors” for methodology development. We had this problem in the old Farming Systems Research days and history is repeating itself with ecoregional research. Many projects and countries received the benefit of those groups that used their meager funds to develop methodologies in FSR (e.g., RIMISP and RISPAL in Latin America) and we are quite sure that the investments made by the Ecoregional Fund will pay off. The interest shown by several decision makers (see section 6) in acquiring and using SIMSRIG and the Tradeoff Model are steps in the right direction. We should not forget that there is always a lag-period for adoption of any new method, tool, or technology; we should focus, then, on ways to accelerate the process.

The validation of the integrated system at the ecoregional level was not possible due to lack of data from census and other sources. All the testing of the system was done at the component basis, e.g., pasture availability and quality, animal and crop production, etc. This situation is found in any data-scarce environment.

The unavailability of high-resolution RS-data on a regular basis made the testing of SIMSRIG for cropping areas difficult. Plot sizes were too small even for the satellites with higher ground resolution. In conjunction with a camera company in the USA, the team is designing a low-cost system capable of circumventing this limitation.

10. Follow-up

Follow-up activities are divided into two groups. The first group of activities consists of the dissemination and use of the outputs of this phase: publications in refereed journals, and training and preparation of training materials. In addition, two or three cases where the system is adapted and used by decision makers, as explained in section 6.

The second group of activities includes the continuation of basic and applied research to provide the system with newer processes and tools for multi-scale analyses. One key area is the development of cost-effective ways of monitoring small plots in cropping areas in mountain agroecosystems. We have initiated this with the design of such an RS device. We have also initiated, during the no-cost extension of the project, the incorporation of other geo-spatial analysis tools. The most important methods being considered are quadtrees, texture, fractal analysis, and other spatial aggregation routines. These new sets of tools would facilitate the analyses where topography is highly irregular, e.g., mountains and highlands.

Annexes

The following list contains the most relevant documents and papers produced during the project:

Bowen, W.T. and S. Moreau. 1998. Integrating remote sensing, GIS, and modeling for land-use monitoring in the arid/semi-arid Andes. *In* Proceedings of the ISNAR Methodological Research at the Eco-regional Level Review Workshop, April 20-22.

Hijmans, R. High resolution climate surfaces.

Hijmans, R. 1999. Estimating frost risk in potato production on the Altiplano using interpolated climate data. CIP program report 1997-98, pp. 373-380.

Hijmans, R.J. and W.T. Bowen. 1997. Scale issues of using GIS-linked potato models: A case study on drought stress in the Andes. Agronomy Abstracts.

Hijmans, R.J. 1997. Simulation models for studying limiting factors in potato production. In: Denisov, N., C. Heberlein, L. Czaran and O. Simonnet. GIS in Agricultural Research: Awareness Package. UNEP/DEI/TR.97-9. (# 38).

Ibarra, C. N. and R.A. Quiroz. 1999. SIMSRIG a Multiscale integrated modeling system based on remote sensing and GIS: I. Model description. SAAD III, Lima, Perú Nov. 7-10.

Jongschaap, R. Conversion of evapotranspiration by NOAA-AVHRR

Jongschaap, Raymond E.E.. 1999. LINPAS model: dynamic simulation of rangeland production in the Altiplano of Peru and Bolivia. . SAAD III, Lima, Perú Nov. 7-10.

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FIGURES

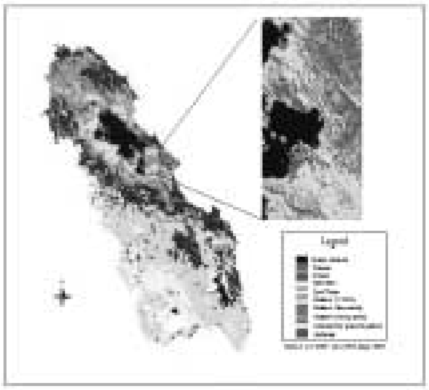

Figure 1. Land cover classification of the Altiplano Ecoregion using multi-temporal AVHRR data

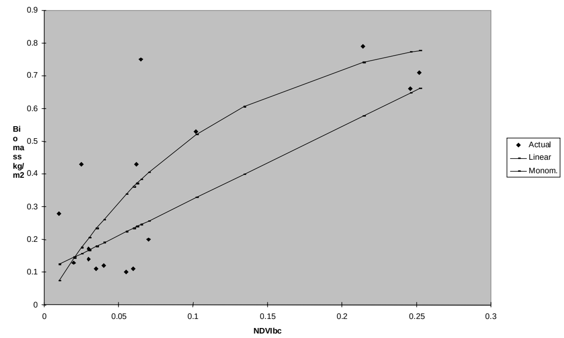

Figure 2. Relationship between vegetation index and biomass

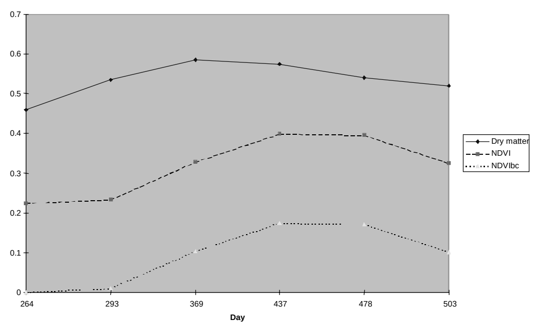

Figure 3. Time course of dry matter (Kg/m2), NDVI and NDVIbc in Bofedales

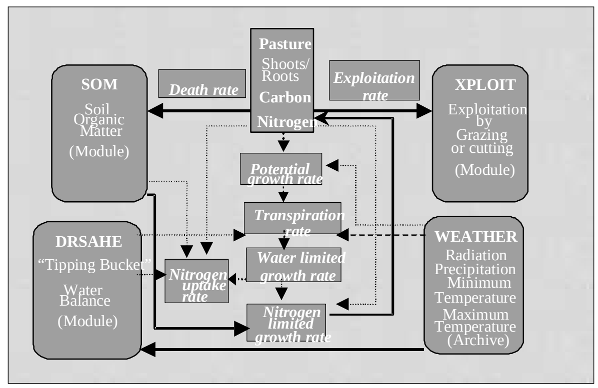

Figure 4. LINPAS simulation model

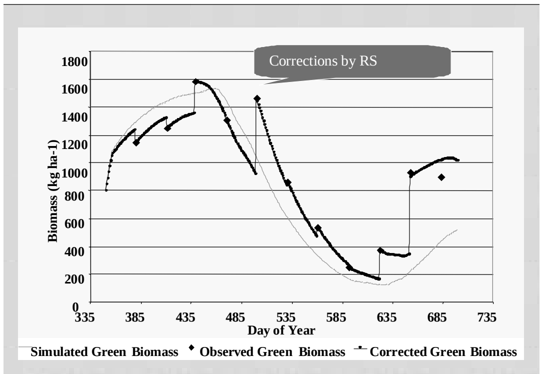

Figure 5. Model corrections by RS

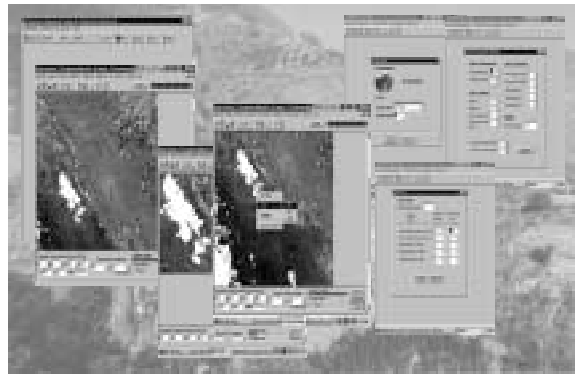

Figure 6. An integrated multiscale-assessment system software.

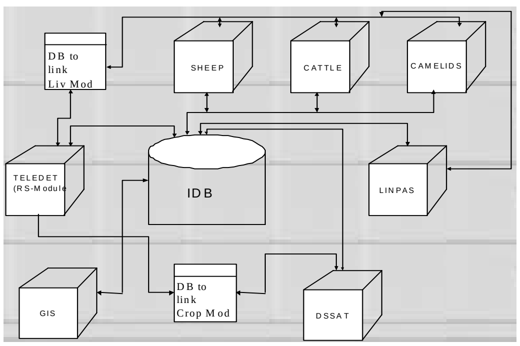

Figure 7. A diagram that shows the components of the system and their linkages.

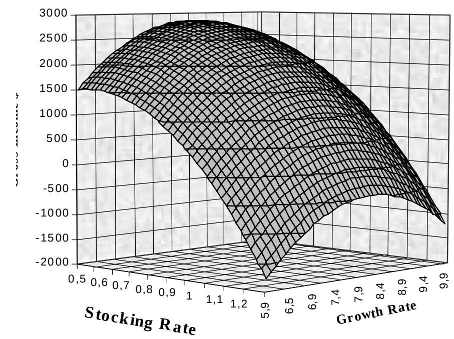

Figure 8. Response surfase describing the simulated gross income of animal production system.