Integrating remote sensing, geographic information system and fuzzy logic: an index to evaluate the natural potential for livestock ranching in the Pantanal

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Resumo: O objetivo deste estudo foi desenvolver um índice do potencial natural de produção pecuária (PNPP) para o Pantanal em nível de fazenda usando indicadores de paisagem combinados com o processo de inferência fuzzy. Quatro indicadores de paisagem relacionados com a produção de gado de corte foram selecionados por um grupo de experts. A aplicação dessa tentativa foi mostrada através de dados de uma fazenda piloto localizada na sub-região da Nhecolândia, Pantanal, MS. As técnicas de sensoriamento remoto aliadas com sistemas de informação geográfica (GIS) foram usadas para mapear os tipos de vegetação e corpos d'água (tipos de paisagens) da fazenda piloto. As métricas da composição dos tipos de paisagens foram feitas usando o ArcGis 9 e então estimados os quatro indicadores selecionados pelos experts: proporção da cobertura de floresta (CF); valor produtivo das paisagens (VPP); diversidade dos corpos d'agua (DCA) e grau de inundação (GI). Um processo de inferência fuzzy envolvendo definições de funções de pertinência, operações de conjunto fuzzy e regras de inferência foram realizados e validados com um grupo chave de tomadores de decisão. Diferentes cenários também foram simulados em lote e validados com usuários. Ambos os procedimentos foram desenvolvidos no programa Webfuzzy. O valor do índice PNPP obtido na fazenda piloto esteve dentro do esperado. Lógica fuzzy combinada com métricas de paisagens permitiu definir o potencial natural das fazendas para produzir gado de corte no Pantanal.

Palavras-chaves: análise de paisagem, indicador de sustentabilidade, aprendizado de máquina fuzzy, validação participativa.

Abstract: In this study, an index natural potential for livestock ranching (NPLR) at ranch level in the Pantanal wetland was obtained using landscape indicators combined with fuzzy inference process. Four landscape indicators related with livestock production were selected by an expertise group. The application of this approach was illustrated through a pilot ranch located in the Nhecolândia sub-region, Pantanal, MS. Remote Sensing (RS) and Geographic Information System (GIS) technologies were used to map the vegetation types and aquatic habitats (landscapes types) in this ranch. Landscape type's composition metrics were obtained using the ArcGis 9 and were used to estimate the four indicators selected by expertise: forest cover proportion (FC); landscape productive value (LPV); diversity of aquatic habitats (DAH) and flooding degree (FD). Fuzzy inference process involving definitions of membership functions, fuzzy set operations and inference rule were run and validated with the participation of core stakeholders. Different scenarios also were simulated in batch and validated with the participation of stakeholders. Both procedures were performed by Webfuzzy software. The NPLR index value found in the pilot ranch was as expected by both expertise and stakeholders. Fuzzy logic combined with landscape metric seems to be suitable for the definition of the natural potential of ranches to produce livestock in the Pantanal.

Key Words: landscape analysis, participatory validation, fuzzy machine learning, sustainability indicator, wetlands.

1. Introduction

The Pantanal is a complex and dynamic tropical wetland, flooded seasonally with a variety of vegetation formations, based on different landscapes units (physiognomies) such as forest, forested savanna, arboreal savanna, open grasslands, dirty grasslands, permanent ponds, temporary ponds, temporary canals and lowlands. Extensive livestock was established over 200 years ago in the Pantanal due to presence of abundant natural pastures areas Santos et al. (2008). Natural potential for livestock ranching depend of the capacity of an area produce forage resources. However, not all regions have appropriate areas for livestock production due to natural limitations such as intense flooding and low availability of permanent water bodies as well as inadequate landscape composition. Regardless of the region, livestock production is conducted in almost all Pantanal (about 95%) whose traditional management (low impactpractices and low inputs) has contributed with the natural resources conservation. However, in recent decades this activity is becoming less sustainable mainly in areas with environmental restrictions.

Mapping landscape types has been developed to manage the Pantanal natural pastures which constitute the base of the domestic and wild herbivores food intake (Santos et al., 2009). A sustainable ranch in the Pantanal need to attend environmental, economic and social goals, searching for equilibrium among these domains and their interactions. To achieve this level of equilibrium, the development of a tool to assess sustainability at ranch level is necessary. Sustainability indicators have been broadly used to monitor and evaluate systems, but several indicators are empirical and based on approximate data. In this situation associated with complex systems as the Pantanal, the fuzzy logic can be used because take into consideration expertise knowledge, as it is adequate to deal with uncertainties. In this system, indicators are used to support decision rules and to build modelsbased on expert knowledge to deal with uncertainties Chevrie and Guely (1998).

Fuzzy logic offers a suitable method that is easy to implement and enables knowledge transfer of complex environmental to decision makers and general public Chevrie and Guely (1998); BabaeiSemiromi et al. (2011). The fuzzy logic, introduced by Zadeh (1976), can be described as an extension of classical set theory, where each object can assume a continuous degree of membership to a set, ranging from 0 (does not belong to the set) and 1 (belongs to the set). This concept allows uncertainty treatment and aligns very well to manage nebulous concepts such as sustainability.

2. Objectives

To define landscape indicators using remote sensing and SIG to evaluate the natural potential of beef cattle ranches in the Pantanal wetland;

To propose an index to assess the natural potential for livestock ranching in the Pantanal using fuzzy logic.

3. Material and Methods

Several experts meetings were conducted to identify the main aspects related to sustainable cattle ranching in the Pantanal (e.g. social aspects, economic viability, pasture productivity and quality conservation, landscape and biodiversity conservation, water resources, livestock management and livestock ranching feasibility). In accordance to each aspect, experts groups were formed to select the indicators. The aspect focused in this paper was the natural characteristic that favours the livestock production in the region. A core set of four indicators were selected to produce a natural potential for livestock ranching (NPLR) index for ranches located in the Pantanal wetland (**Table 1**). Thresholds values were established by expert and stakeholders. Feedback sessions were conducted using the methodology 3S Cloquell-Ballester et al. (2006). The responses of the stakeholders were presented using Likert type scales (1 to 5). The respondents also were asked to list the four indicators they believed were the most important to inform natural potential livestock ranching (importance ranking). It must be demonstrated that the proposed indicator should be responsive to identified assessment questions, to provide relevant information for societal concerns and management decisions, as well as to be conceptually linked to the ecological function US EPA (2000).

Table 1. Indicators and Fuzzy set defined to classify the natural potential of livestock ranches of the Pantanal wetland

Indicators	Thresholds
Forest cover proportion (FC)	Ideal - <0,3
	Moderate – 0,3-0,6
	Critical – 0,61-0,80
	Poor – > 0,8
Landscape productive value (LPV)	Ideal – 0,41-0,70
	Moderate – 0,2-0,4
	Critical – 0,1-0,21
	Poor - <0,10
Diversity of types of Aquatic habitats(DAH)	High – 3
	Moderate - 2
	Low - 1
Flooding degree/flooding extension (FD)	High -3 (>75%)
	Moderate – 2 (25-75%)
	Low -1 (<25%)

The next step was the evaluation of the implementation feasibility which involves the sampling and measurement methods. A pilot case study was used to show the landscape indicators selected described in **Table 1**. The pilot ranch was the Nhumirim research station located in the Nhecolândia sub-region, Pantanal, MS. Landsat 5-Thematic Mapper satellite images from 2010 and 2011 were acquired from the INPE, the Brazilian space agency. Image from 2010 was chosen preferentially from the late dry season to avoid clouds and to obtain better visualization to estimate the first three indicators, while image from 2011 was one of the late wet seasons, which allowed the estimation of the fourth indicator. Data preparation and image processing were carried out utilizing ERDAS software package.All images were rectified to UTM zone 21, WGS 84. Unsupervised classification was then used to map the vegetation units in ERDAS. The 2010 Landsat image was separated into five classes (floodplain vegetation types): (1) forested savanna -FS; (2) arboreal savanna - AS; (3) grassland savanna - GS; (4) wetland – Wl and (5) water bodies – Wb. Similar procedure was conducted with the 2011 image but separated into two landscape classes: (1) dry areas and (2) water-covered areas (Figures 1a, b). Classified images were exported to ARCGIS version 9.0 (ESRI, Redlands, USA) and then, vegetation types composition metric were evaluated and generated the following indicators: forest cover proportion (FC) that refers to proportion of forested savanna (%); landscape productive value (LPV) that refers to the ration between grazing preferred vegetation classes (wetland + grassland savanna)/grazing less preferred vegetation class (arboreal savanna); diversity of aquatic habitats (DAH) was estimated by the number permanent aquatic environments and their distribution over the ranch. The 2011 thematic map was used to estimate flooding extension that contributes to determine the flooding degree (FD) indicator.

For dealing the uncertainties, the indicators were processed by fuzzy inference system. This was adopted to determine an index to evaluate the natural potential for livestock ranching (NPLR) involving the four indicators. The fuzzy inference system adopted in this paper was the proposed by Mamdani (1976), and consists of three basic steps Ying (2000): 1. Fuzzification, where the numerical value of an input variable is converted to a degree of membership to a fuzzy set (linguistic term); 2. Fuzzy inference, where the rule base expressed in terms of fuzzy sets is assessed, given the inputs and 3. Defuzzification, where the fuzzy sets found are combined to provide a numerical output. Thus, the construction process involved the following steps: definition of membership functions; definition of knowledge base in form of inference rules; model validation and correction. The fuzzy sets and their respective thresholds for the different indicators are shown in the **Figure 1**.

The trapezoidal functions at the ends of intervals, and triangular functions at intermediate portions of intervals were used as membership functions of these fuzzy sets. These linguistic terms and thresholds were validated in a participatory manner. As example of the indicator LPV (Landscape productive value) and their respective fuzzy sets can be seen in **Figure 2**. A fuzzy model was developed using the FuzzyGen Lima and Massruhá (2009) for the selected set of four indicators and 144 inference rules were generated.This rule base was evaluated and validated to reflect the knowledge of experts on the subject. As example of rule: “If FD is high and DAH is high and LPV is ideal and FC is ideal then index ismoderate”. The final index was classified into three categories: high, moderated and low productive potential. At the end of inference, the output fuzzy set is determined and defuzzified by centre of gravity method Chevrie and Guely (1998).To perform the inferences and subsequent analysis, were used the software Webfuzzy, Lima et al. (2011). A simulation process in batch using the same software was accomplished, testing the output of model to several scenarios

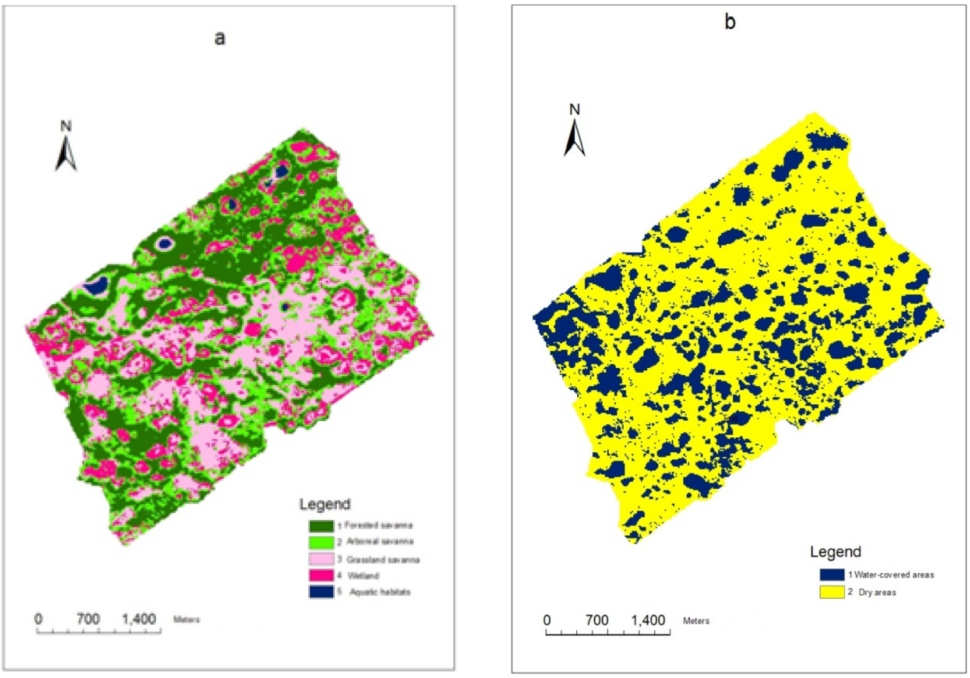

Figure 1. A five-class map (a) where 1= forested savanna; 2= arboreal savanna; 3= grassland savanna; 4= wetland; 5= aquatic habitats, and a two-class map (b) where 1= water-covered areas; 2= dry areas of the Nhumirim ranch, Nhecolândia sub-region, Pantanal, MS.

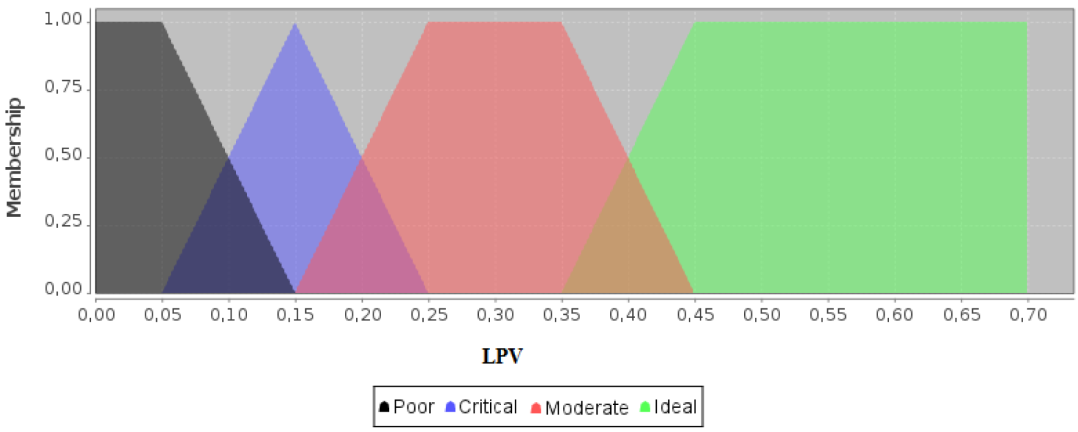

Figure 2. An example of the indicator LPV (Landscape productive value) and their respective fuzzy sets and degree of membership (pertinence).

4. Results and Discussion

The social validation of the four indicators and their respective thresholds were carried out by 12 core stakeholders. The respondents approved all indicators in terms of conceptual and operational coherence (**Figure 3**).

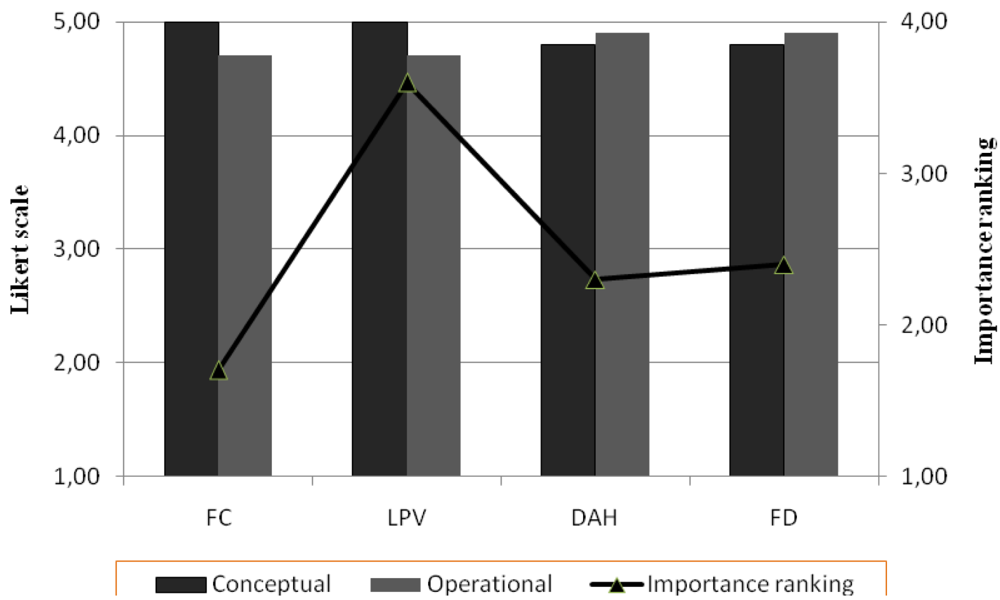

Figure 3. Mean Likert scores for conceptual and operational coherence (Likert scale: 1= totally disagree; 2= disagree; 3= neither disagree nor agree; 4= agree; 5= totally agree) and importance ranking (1=lest important to 4=most important) of the indicators evaluated by group of core stakeholders.

From experts' judgments, it can be defined that the indicator landscape productive value (LPV) is determinant to define the natural potential for livestock ranching (NPLR) index for ranches of the Pantanal. Pilot Tests and simulations in batch were conducted using the Webfuzzy software and adjusts were made on fuzzy rules. **Figure 4** shows the fuzzy output, named deffuzification using the center of gravity method (output crispy value of 9.06). This output of the model refers to Nhumirim ranch that presented values of 0.3, 0.63, 2 and 1 to FC, LPV, DAH and FD input variables, respectively. In this analysis the model made use of two rules from 144 rules.The results obtained for the pilot ranch were presented in radar graph (**Figure 5**) indicating a ranch with high potential for cattle production (NPLR index =8.2).

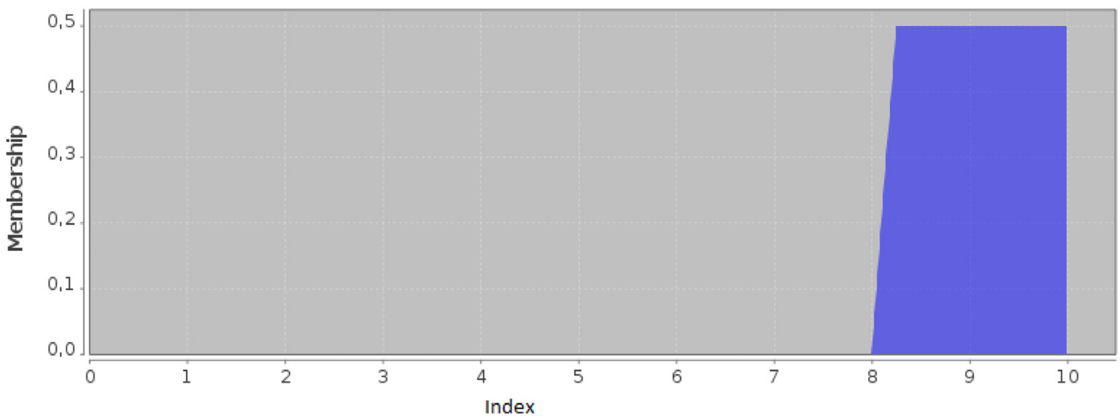

Figure 4. Center of gravity position with output crisp (9.06) of the fuzzy set to evaluate the natural potential for livestock ranching (NPLR) index to Nhumirim ranch with values of 0.3, 0.63, 2 and 1 to FC, LPV, DAH and FD, respectively.

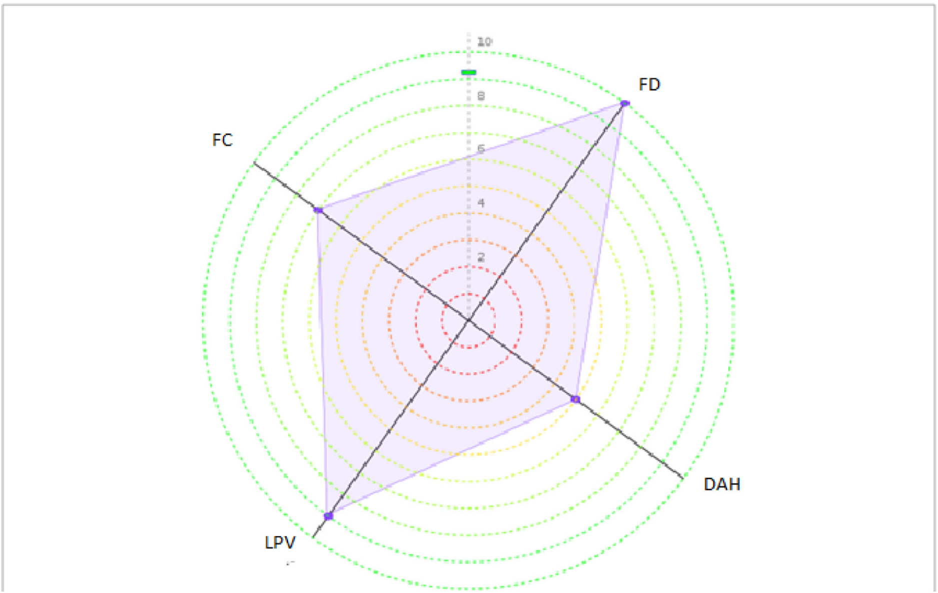

Figure 5. Indicators to assess natural potential for livestock ranching displayed in radar by the Webfuzzy software showing NPLR index of 8.2 .

The NPLR index produce aggregated information about the natural productive potential of different ranches of the Pantanal and might serve to develop a practicable evaluation approach for decision makers.

5. Conclusions and Suggestions

This methodological framework allowed assesses natural potential for livestock ranching from the selection of appropriate indicators. This tool also can be applied to others regions with selection of indicators emphasizing on a specific land use type or multifunctional use. Participative processes in the development of rules demonstrated to be efficient and flexible because sustainability is a continuous process of learning that can be updated dynamically.

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7. References

Babaei Semiromi, F.; Hassani, A.H.; Torabian, A.; Karbassi, A.R.; Hosseinzadeh Lofti, F. Water quality index development using fuzzy logic: a case study of the Karoon River of Iran. **African Journal of Biotechnology**, v.10, n.50, p. 10125-10133, 2011.

Chevrie, F.; Guely F. Fuzzy Logic: Schneider-Electri Cahier Techniques, n. 191. France: Schneider, 1998.

Cloquell-Ballester, V.A.; Cloquell-Ballester, V.A.; Monterde-Diaz, R.; Santamarina-Siurana, M.C. Indicators validation for the improvement of environmental and social impact quantitative assessment. **Environ.Impact Asses. Rev.**, n.26, p.79-105, 2006.

Lima, H.P de; Massruhá, S.M.F.S.Sistema FuzzyGen: manual do usuário. Campinas: Embrapa Informática Agropecuária, 2009.24 p.(Embrapa Informática Agropecuária. Documentos, 96).

Lima, H.P. de; Massruha, S.M.F.S.; Abreu, U.G.P. de; Santos, S.A. Webfuzzy e fuzzygen - ferramentas para modelagem fuzzy: aplicação na sustentabilidade das fazendas do Pantanal. In: CONGRESSO BRASILEIRO DE AGROINFORMÁTICA, 8., 2011, Bento Gonçalves. **Anais**... Florianópolis: UFSC; Pelotas: UFPel, 2011. Nãopaginado. SBIAgro 2011.

Mamdani, E.H. Application a fuzzy logic to approximate reasoning using linguistic synthesis. In: INTERNATIONAL SYMPOSIUM ON MULTIPLE-VALUED LOGIC, 6, 1976, Logan. **Proceedings**…. Logan, Utah, United States, p.196-202, 1976.

Santos, S.A.; Abreu, U.G.P.; Tomich, T.R.; Comastri Filho, J. A.; Crispim, S.M.A. **Pecuária no Pantanal: em busca da sustentabilidade**. In: EMBRAPA. (Org.). Agricultura tropical. 1 ed. Brasilia: EMBRAPA-SPI, 2008.

Santos, S. A.; Rodela, L. G.; Tomas, W. M.; Cunha, C. N. D. A.; Ravaglia, A.; Pellegrin, L. A. Mapeamento das unidades de paisagens, fitofisionomias e forrageiras chaves da sub-região de Poconé, Pantanal, MT. In: Simpósio de Geotecnologias no Pantanal, 2., 2009, Corumbá. **Anais**... Campinas: Embrapa Informática Agropecuária; São José dos Campos: INPE, 2009. CD ROM.

United States Environmental Protection Agency (US EPA), 2000.In: Jackson, L.E., Kurtz, J.C., Fisher, W.S. (Eds.), **Evaluation Guidelines for Ecological Indicators**. EPA/620/R-99/005, US Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

Ying, H. **Fuzzy control and modeling: analytical foundations and applications**. New York: IEEE Press, 2000. 342p.

Zadeh, L.A. **Fuzzy sets**. Information and Control, v. 8, p. 338–353, 1965.