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A land-use change model to study climate change adaptation strategies in the Mekong Delta

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Abstract—The rice-shrimp farming system is considered as a sustainable and beneficial model for the environment. However, the area of rice-shrimp was increasingly narrowed due to the trend of converting from rice to aquaculture by economic reasons. This paper aims to propose a medium scale land use change model for understanding the land use decision of farmers in adaptation to the environment and climate change. The model integrates a land-use decision making process based on multi-criteria selection where the main factors are land suitability, land convertibility, land use situation of neighbors, and profitability of land use patterns. Concerning the land use data, we used historical land use map in 2005, 2015 and 2019. Shrimp cultivation regions was completed by Landsat satellite image processing. The model has been calibrated by rice-shrimp map in 2015 and has been verified with the rice – shrimp map in 2019 of the My Xuyen district, Soc Trang province, Vietnam. The simulated results show that the rice-shrimp area was increasingly narrowed and has been converted to aquaculture land. In addition, the model tends to show that in a scenario of sea level rise of 15 cm in 2030, the share of rice-shrimp and shrimp tends to rise sharply, which is an important lesson for developing complex adaptive strategies of farmers.

Index Terms—Land use change model, climate change, adaptation strategies, Mekong Delta

I. INTRODUCTION

Selection of agricultural land use in brackish water regions (such as it is the case in a significant part of the Mekong Delta) where there are six months of fresh water in the rainy season and six months of brackish water in the dry season is always a hard question for the farmers and decision makers. Since the 1990s, a so called rice-shrimp farming system have been promoted for farmers to convert from one rice season per year: a rice crop during the rainy season and shrimp (tiger shrimp) in the brackish water of the dry season. This farming model is considered as environment-friendly and particularly well-adapted to climate change conditions [1], [2]. However, the

high profitability of shrimp farming has led to the conversion from rice-shrimp to shrimp. This choice can greatly increase farmers' income, but the lack of technology, the huge money investment required and unusual weather phenomena (heavy rain, drought) make it a highly risky choice [3].

The purpose of this study is to build a simulation model of farmers' decisions in terms of production choice and to test adaptive solutions when weather conditions and saline intrusion change. The model is an agent-based model based on a multi-criteria analysis to choose the appropriate usage types. The model is presented on a medium-scale area (the My Xuyen District of the Soc Trang province, Vietnam) but has been designed to be applied on the whole Mekong Delta.

The paper is organized as follows. Section II presents an overview of related works. Section III describes the proposed model and Section IV the experiments and results from simulations. Finally Section V concludes the paper.

II. RELATED WORKS

Land resource management currently lacks dedicated decision-making tools, such as tools to simulate dynamic changes in land use status. Nevertheless, in recent years, several attempts have been proposed to study land cover and land use changes [4].

Concerning the specific case of agricultural territories and land usage by farmers, [5] propose a review of farmer models dedicated to the simulation of crop rotation, forage and/or breeding. A major distinction they propose concerns the objective of the models. The first type of models, called *normative*, aims at identifying an optimal operating mode considering a set of objectives and production constraints; the second type, called *positive*, tries to represent the observed behavior of farmers. [6] identify in addition the scale at which the models are applied, as a model categorization criterion: models are

indeed applied at different scales from the farm level to the territory one.

As pointed out by [7], the farm level is a key factor as the rules for crop allocation are important drivers for the agricultural landscape changes and dynamics [8]–[10]. Several works have shown that the choice of allocation depends on the farming system characteristics and on the production objectives within a given economical context [11], [12].

Some models propose to integrate both the definition of the objectives and of the crop allocation in the same process. For example, [13] propose to formulate the choice of crop rotation as a multi-criteria decision problem: for each plot, the farmer chooses a crop rotation, according to an evaluation at the farm level of several criteria (financial risks, expected incomes, workload and farmer habits). Other works focus only on the crop allocation problem. For example, [14] propose to formalize the problem as a Constraint Satisfaction Problem integrating agronomic constraints and crop distribution constraints. Similarly, [7] considers the crop allocation problem as an optimization problem and solve it by computing the maximal flow of the possible transition graph.

For the case of Vietnam, land use change models have been applied in the northern mountainous regions of Vietnam [15] and in the central mountainous areas [16]. In the Mekong Delta, [17] shown the interest of using an agent-based model to study the land-use change in a small scale area at village level.

In this paper, the challenge is to simulate the behavior of the actors (positive approach) and not to find an optimal configuration, we thus chose to take inspiration from the work of [17], but, in order to be able to run simulation at a medium-scale, we used for the choice of crops a multi-criteria decision approach as presented in [13].

Concerning the issue of strategies in selection farming systems to adapt impact of climate change in the coastal region, some works [1], [2] encouraged the rice-shrimp as potential adaptive strategy for farmer likelihood, but there is a lack of tools for testing these strategies.

III. MODEL DESCRIPTION

A. Agents

In this model, and contrarily to what has been done in [13], [17], an important choice has been made not to take the plots as spatial unit, but to divide the space into uniform cells. This choice results from two strong constraints: the absence of precise data on the plots and the computation time. Indeed, our final objective is to be able to apply this model to the entire Mekong Delta region in Vietnam where data are lacking and for which the number of plots is very large, which makes it impossible to use a model such as [17].

Figure 1 shows the class diagram of the model. The main agents are the *cells*. Each cell has a land use type and belongs to a land unit, within or outside the dyke. Each cell has also a list of neighbor cells. The main activity of cells is to select a land usage through a multi-criteria analysis process.

The *world* agent provides environmental variables and global actions to the model.

The *Landunit* agents provide information on soil type, water condition, flood, salinity, intrusion length, etc. Land units are linked to land use patterns for providing land suitability levels. At last, *Landuse* agents provide the benefit and cost of implementation of each land-use type.

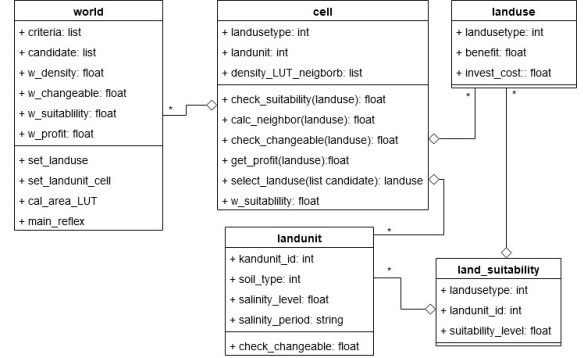


Fig. 1. Class diagram of main agent types in the model

B. Multi-criteria decision process

At each simulation step (1 simulation step representing 1 year), each cell will have the possibility to change its land-use type. To this purpose, each cell will first evaluate the benefits to convert to each existing land-use types using a weighted means of the 4 criteria (see Equation 1) and then select the land-use type that maximizes it. Because there are lot of cells that could change at the same time, only some of them are randomly chosen given a conversion rate parameter.

$$Convertibility(i, l) = \frac{\sum_{c \in C} W_c \times C_c(i, l)}{\sum_{c \in C} W_c} \quad (1)$$

Where:

- C : the set of criteria: Land suitability(LS), Ability to convert (AC), Neighbor cells (NC), Profit (P) (*cf.* description below),
- W_c the weight of the criteria c ,
- $C_c(i, l)$ the value of the criteria c for the land-use type l and the cell i .

We have defined for the cell selection of land-use type 4 criteria:

- *Land suitability*: This criterion represents the adaptation of a land-use type to a specific environment. When environmental conditions change, the adaptation level of land-use types also changes. The suitability evaluation is performed according to the FAO work [18]. Land suitability levels are based on characteristics of soil, water, topography, and current land cover situation and are classified into 4 levels: S1: Highly suitable; S2: suitable; S3: Lightly suitable and N: Not suitable.
- *Ability to convert*: This criterion measures how convenient it is to switch from the current land-use to another

one. In the farming systems, the transition from one type to another one depends on conditions where new farming type can be established. In some cases, some switches (e.g. from shrimp to fruit trees) will be very difficult whereas a switch from deep shrimp ponds in intensive shrimp farming to rice cultivation will not be possible.

- *Neighbor cells*: A large proportion of the surrounding land use types influence the choice of a farmer in deciding which type to choose.
- *Profit*: The profitability of land use types is one of the reasons leading to land use conversion. This factor is an economic adaptation when people try to find a suitable farming model to improve their lives.

The Land suitability (LS) criteria is based on the suitable level of the cells, we mapped 4 suitable levels with numeric values: S1 = 1, S2 = 0.67, S3 = 0.33 and Non suitable = 0.0 (cf. Table I).

The Ability to convert (AC) was coded as 5 levels (0, 0.25, 0.5, 0.75, 1) where value 0 is not able to convert and 1 is very easy to convert (cf. Table II).

The Neighbor cells (NC) value is computed based on the 8-cell Moore topology for each land-use type. For each cell, the value of each land-use type was calculated by proportion of that type of neighbor cells.

The Profit (P) of each land use type has been normalized. The profit was based on results from household survey for 6 land-use types in [19]: the profit of Shrimp was the highest one (389 million VND/ha), followed by Fruit trees (294 million VND/ha), Vegetables (180 million VND/ha), Rice-vegetable (64 million VND/ha), and Rice-shrimp (84 million/ha). The Double Rice gave lowest profit with 34 million VND/ha.

C. Model implementation

In order to facilitate the implementation of the model and communication with domain experts and stakeholders, we build the model with the GAMA Platform [20]. Indeed, GAMA provides many powerful tools to support the development of agent-based models, in particular the ability to integrate complex GIS data and to graphically define models [21].

IV. EXPERIMENTS

A. The case study

In this paper, we apply the model presented above on the My Xuyen District of the Soc Trang province, Vietnam. The Figure 2 illustrates the land use map of the district. The study area is a mixed region between salt and fresh water separated by dikes and sluices gate systems. The simulation is initialized with spatial data of land types and land uses, and data to compute criteria (land use profits, difficulty to switch between land use, suitability between land use and land type ...).

Figure 3 shows the evolution of the areas of shrimp and rice-shrimp in the My Xuyen district between 2005 and 2019. In 2005, the areas of shrimp and rice-shrimp were balance with around 10000 ha each. However, in 2015, the shrimp farming area had increased sharply to 19784 ha. It could be

due to the high profit of the shrimp production. Similarly, in 2019, the shrimp area increased to 21635ha while rice-shrimp area has continuously decreased to 678 ha.

This figure of agricultural activities shows that main behaviors in this region during that period were affected by the profit of the farming systems.

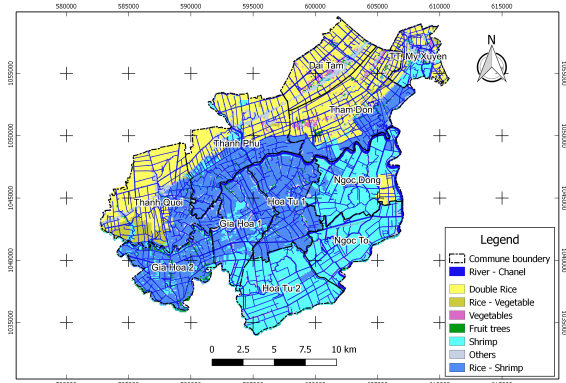


Fig. 2. The land use map of My Xuyen District in 2005

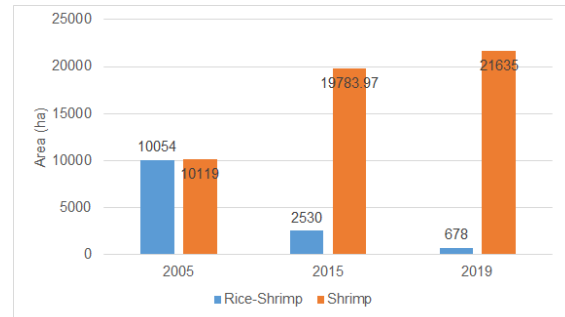


Fig. 3. Land use of My Xuyen District in the period 2005-2019

The land-unit map of My Xuyen district was built as in Figure 4. Each land unit provides the properties of soil, salinity level and salinity intrusion time. The main soil type in My Xuyen is potential acid sulfate soil. This district is clearly split by two main regions inside and outside of the dike. Land units 1, 2, 5, 6 (labeling on the map) are well protected by the dike system, whereas the other units are located outside of the dike and are thus impacted by saline water during 6 months a year. This map was used for land use evaluation based on the FAO guide [18].

In the land use model, we focus on the six main agricultural land use patterns that are the most susceptible to change: Double rice crops, Rice - Vegetable rotation, Vegetables, Rice-Shrimp rotation, Shrimp and Fruit trees. The land suitability of land use types are evaluated as in the Table I.

To compute the "Ability to convert" criteria, we gather in Table II data about the convenience to switch between land types. These data have been collected from the agriculture experts.

TABLE I
LAND SUITABILITY OF THE LAND USE TYPES.

Land unit	Property	Double Rice	Rice-Vegetable	Rice-Shrimp	Shrimp	Vegetables	Fruit trees
1	Arenosols, 3 months saline	0.00	0.33	0.00	0.00	1.00	0.67
2	Fluvisols, 3 months saline	1.00	0.67	0.00	0.00	0.33	0.33
3	Fluvisols-Potential ASS <0.5m, 6 months saline	0.00	0.00	1.00	0.67	0.00	0.00
4	Fluvisols-Potential ASS >0.5m, 6months saline	0.00	0.00	0.00	0.00	0.67	1.00
5	Fluvisols-Potential ASS <0.5m, 3 months saline	1.00	0.67	0.00	0.00	0.33	0.33
6	Fluvisols-Potential ASS >0.5m, 4 months saline	0.00	0.00	0.00	0.00	0.67	0.67
7	Fluvisols-Potential ASS <0.5m, >6 months saline	0.00	0.00	0.67	0.00	0.00	0.67

TABLE II
CONVENIENCE OF CHANGE BETWEEN LAND USE TYPES.

Changeable	Double Rice	Rice-vegetable	Vegetables	Shrimp	Fruit trees	Rice-Shrimp
Double Rice	1.00	1.00	0.75	0.00	0.50	0.00
Rice-Vegetable	1.00	1.00	0.50	0.00	1.00	0.00
Vegetables	0.00	0.50	1.00	0.00	0.50	0.00
Fruit trees	0.00	0.00	0.00	0.25	1.00	0.00
Shrimp	0.00	0.00	0.00	1.00	0.00	1.00

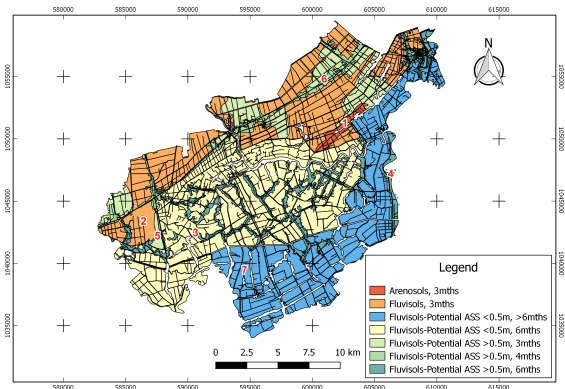


Fig. 4. Land unit map of My Xuyen District

B. Calibration and validation of the model

To calibrate the model, we use a genetic algorithm (the one provided by the GAMA platform) to find the best combination of parameters (W_{LS} , W_{AC} , W_{NC} , W_P , and the switch probability) *i.e.* the combination that maximizes the classical Kappa indicator [22], computing the similarity between the simulated map of land uses and the observed one (the land use map at the year 2015). Each parameter value can vary from 0.1 to 1 and with a step of 0.1.

The result of the calibration shows that the set of parameters for the criteria Land suitability, Ability to convert, Neighbor cells, and Profit are 0.6, 0.8, 0.8, 0.2 respectively. As far as the switch probability parameter is concerned, the best value is 0.12. The best Kappa coefficient was 0.67.

C. Validation of the model

After the calibration of the model parameters thanks on the data of year 2015, we try to evaluate the quality of the simulation by comparing the simulation results with real data in 2019.

Figure 5 shows a simulated land use map of My Xuyen district in 2019. The cultivated area of fruit trees had no impact due to land inadequacy. The map shows that almost all the rice-shrimp farming area has been converted to shrimp cultivation. The conversion from rice-shrimp to shrimp due to the dominant shrimp when considering multi-criteria selection with high suitability, high percentage of shrimp farming households in neighboring, the ability to convert and ultimately shrimp profitable.

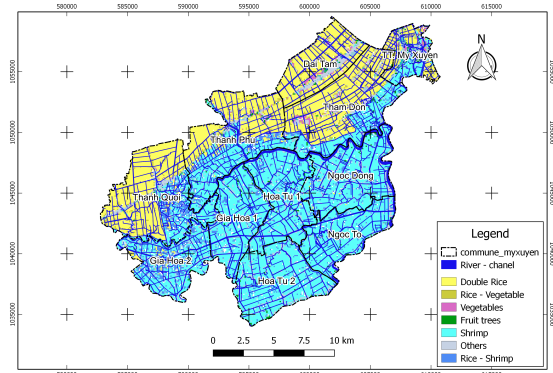


Fig. 5. Land-use simulated in 2019

Figure 6 shows that the simulated areas are very similar with the real data ones in 2019 with a Kappa value of 0.68. The simulated rice area is 88 ha higher than the actual rice area while the simulated rice-vegetable area is 151ha lower. In fact, the conversion rate from Double rice crops to Rice-vegetable in reality is higher than the simulated one. In contrast, the simulated Rice-shrimp area was 210 ha lower than the actual area while the Shrimp area in the two cases are similar. This error may be due to the fact that the criteria defined in the model are not sufficient to fully represent the actual conversion behaviors of farmers.

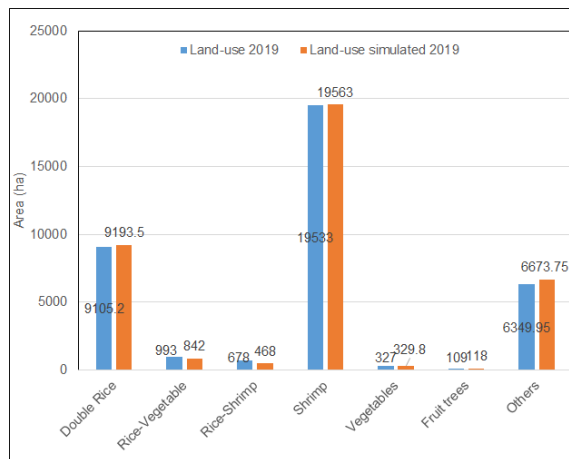


Fig. 6. Validated result of the model

D. Land use adaptation with a scenario of sea level rise

After verification of the results in the previous section, the model is now launched until 2030, to explore the adaptation to effects of climate change (and in particular of the sea level rise). We thus use as additional input a scenario of saline intrusion due to a sea level rise (SLR) of 15cm in 2030 [23], as presented in Figure 7. In the case of My Xuyen, under the hypothesis that the sluice system and the dykes still work as it is now, the salinity will increase but the intrusion length will not change much. The part of saline intrusion approaching the dyke forms two areas of different salinity.

The results of simulating the land use change are displayed in Figure 8, in which the area of rice and shrimp land have almost disappeared, everything have been converted to shrimp cultivation.

However, considering the rice-shrimp rotation farming system as a climate change adaptation model, we have tested to decrease the frequency of the selection process by modifying the parameter of flip function to prevent the conversion directly from rice-shrimp to shrimp. The result in this case is displayed in Figure 9: it shows that, when applying the adaptation selection behavior and reducing the risk, the area of rice and shrimp in the climate change adaptation scenario increases.

V. CONCLUSION

In this paper, we present an agent-based model of land use change at the level of the My Xuyen district. The conversion mechanism is based on a multi-criteria decision-making process including the land suitability, the impact of neighboring land cells, the conversion ability and the benefits of agricultural systems. The parameters have been calibrated with land use data in 2015 and simulation results have been verified with data of 2019. We have then simulated the conversion until 2030, taken into account a scenario of 15cm SLR in 2030. We found that the profitability of the land use type has a significant impact on the change of land uses of the farmers, especially when they are cultivating rice-shrimp crops.

In addition, land use type conversion investment is an important factor influencing the policy of managing spontaneous land use changes by farmers. For example, through investments to encourage or limit conversion. This adjustment has not been studied and it would be added by a complex decision in our next study.

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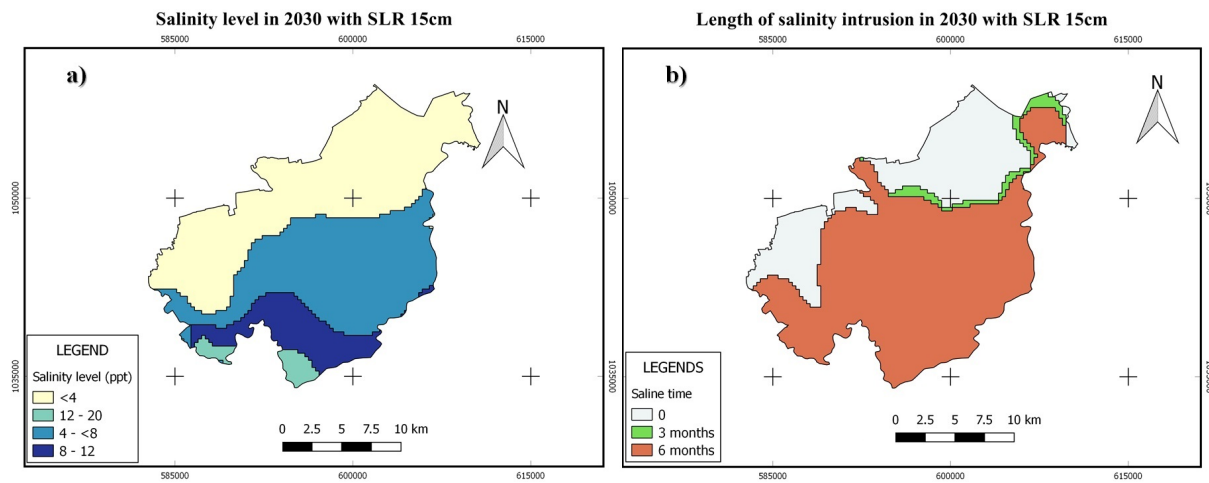


Fig. 7. Salinity intrusion in 2030 with SLR 15cm [23]. a) Salinity level b) Length of intrusion

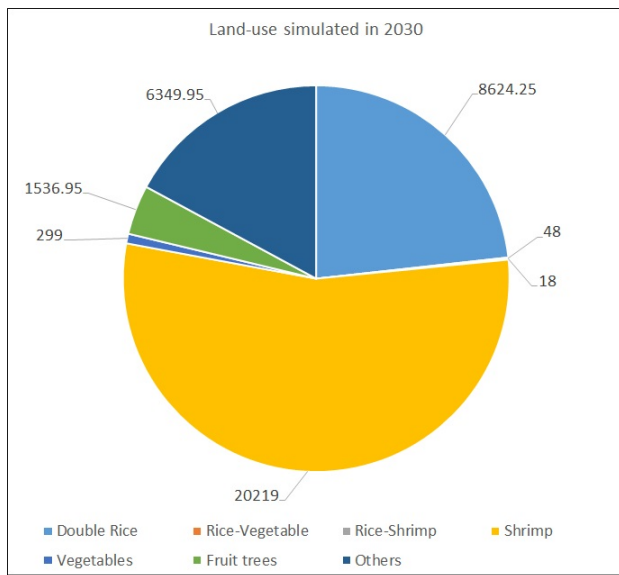


Fig. 8. Land use under impact of SLR 15cm in 2030

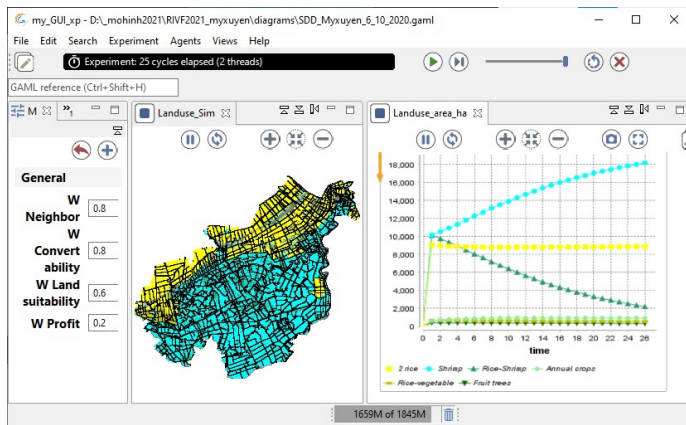


Fig. 9. Land use under impact of SLR 15cm in 2030 limiting the conversion

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