THE MOUNTAIN FOREST TERRITORY IN TEXCOCO WITH THE COMPLEX ADAPTATIVE SYSTEMS APPROACH.
EL TERRITORIO FORESTAL DE LA MONTAÑA EN TEXCOCO A PARTIR DEL ENFOQUE DE SISTEMAS COMPLEJOS ADAPTATIVOS.

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Abstract

This paper follows the need to generate conceptual frameworks that allow an abstraction of reality that is more functional, objective and attached to the nature of events. It refers to an approach that allows a glimpse of the situation of the different actors related to the management of natural resources and ecosystems in an integral way. The objective of the work is to use the conceptual framework of socio-ecosystems as complex adaptive systems to carry out the description of the institutional structure that has the function of forest management, concepts such as *socio-ecosystems, complex adaptive systems, adaptive cycles, panarchy* and *evolutionary resilience* are treated as conceptual tools to generate inputs supporting strategic planning and decision making. The method used seeks to simplify a complex system as much as possible, first with a bibliographical review to identify the actors corresponding to each level of organization, then determining the type of interaction based on concepts of "power" and generating diagrams using the agent modelling software Vensim to visualize the system, the results allow us to describe from a first perspective the importance of an approach for the planning of natural resources that contemplates multiple levels of organization, functions of the agents that compose them, feedback mechanisms within and between these organizational levels and particularly the justification for the application of monitoring and learning processes by the actors that make up the Socio Ecological System (SES) structure.

Keywords: *Socio-ecosystems, Feedback Mechanisms, Power Interactions, Complex Adaptative Systems, Governance*

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Introduction

There are multiple elements and processes in the development of society and its territory, some obvious and others not so much. This is why contextualized, multidimensional, and multiple-scale solutions are necessary. The active participation of the population is crucial in overcoming the present problems, making these actors an integral part of the solution.

Texcoco de Mora unveils, in this sense, a heterogeneous composition, composed of both urban and rural elements and specific ecosystems such as the Ex-Lake of Texcoco, the forest area on Mount Tlaloc and peri-urban areas. Therefore, it contains a population with heterogeneous demographic groups in reference to their economic activities, consumption patterns, worldview and especially their relationship with natural resources. These factors necessarily result in complex situations when managing natural resources.

The area that includes "Monte Tlaloc" within the municipality has a "complicated" situation with respect to its management due to the presence of multiple social actors and government institutions involved, in addition to a vital and constant use by the nearby populations of the environmental services it provides. This justifies the need for a more flexible, articulated and comprehensive approach to asses coherent and beneficial management for the localities that interact directly with the ecosystem, maintaining services to the general population.

This work seeks to identify the components and interactions of the "Monte Tlaloc" forest socio-ecosystem that generates resilience through a complex adaptive systems approach, using municipal boundaries to delimit the study in such a way that it can be an initial exercise in order to use conceptual tools that allow improving strategic planning at different administrative scales and contributing to sustainable development, as well as encouraging future research on the theorization and measurement of evolutionary resilience and adaptive management in the context of forest management in Mexico.

Materials and methods

The study area includes 418.69 km2 (Figure 1). It has a population of 279,698 inhabitants as of 2020 and covers 153.44 km2 of forest area (33%).

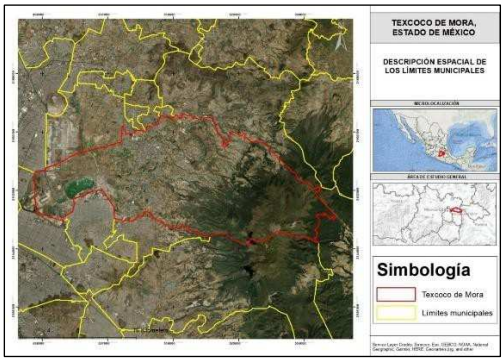

Figure 1.- Location of the study area (Own elaboration)

According to the Municipality Development Plan (PDM, 2022-2024), Texcoco has 60 localities distributed in 19 neighborhoods; these are divided into several zones: Municipal Headquarters, Lakeside, North Zone, South Zone, Conurbation Zone and Mountain Zone.
For the objectives of this work, we will concentrate on the “Mountain Zone” (Figure 2).

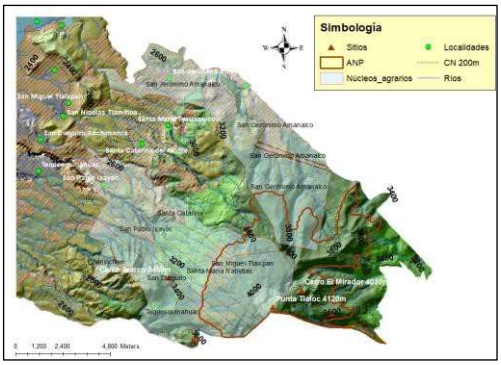

Figure 2.- Agrarian nuclei of the ejidos with the function of forest management in the municipality (own elaboration with data available in (Conabio, 2022).

Figure 2 highlights the forest area segmented by “agrarian nuclei”; these zones correspond to the area assigned to the ejidos and community within the municipality for their use, whether agricultural, livestock, or forestry activities. In this case, we analyze those ejidos and communities with their agrarian core within the forest system.

The method consisted of three stages: A) definition of internal and external actors of the ecosystem partner, B) elaboration of diagrams and C) analysis of results, described below.

A) Generate a database with the actors that make up the structure in charge of forest management

Through a bibliographic review process using the information available from the National Agrarian Registry (Geographical perimeter data of certified agrarian nuclei, by state - SHAPE format, 2023), as well as federal and state legislative frameworks, of particular importance are

the General Law of Sustainable Forest Development (2022) and the Law that Creates the Decentralized Public Body Called "Protectora de Bosques del Estado de México" (Gobierno y LEGISTEL, 2001), among others. In this way, information was obtained about the ejidos in charge of forest management within the municipality, as well as the institutions related to the same function. Through this process we identify the actors involved in the management of forest resources in the different levels of government in Mexico. The following were considered:

Federal level of organization: President of the Republic, Congress of the Union, Secretary of the Environment and Natural Resources (SEMARNAT), National Commission of Protected Natural Areas (CONANP), National Forestry Commission (CONAFOR), National Forest Council, Secretary of Development Agrarian, Territorial and Urban (SEDATU), National Institute of Indigenous Peoples (INPI), Secretary of Agriculture and Rural Development (SADER), Secretary of Welfare, Agrarian Attorney General's Office (PA), National Institute of Ecology and Climate Change (INECC), Mexican Youth Institute (IMJUVE), Trusts Established in Relation to Agriculture (FIRA), Secretariat of Finance and Public Credit (SHCP), Secretariat of Economy (SE), National Institute for Women (INMUJERES), National Development Finance Agricultural, Rural, Forestry and Fisheries (FND), Information Service Agri-Food and Fisheries (SIAP), Secretariat of National Defense (SEDENA), Secretariat of Security and Citizen Protection (SSPC), Federal Attorney for Environmental Protection (PROFEPA), Tax Administration Service (SAT), Secretariat of Tourism (SECTUR), Office of the Attorney General of the Republic (FGR), Secretariat of Public Education (SEP), National Water Commission (CONAGUA), National Coordination of Civil Protection (CNPC), National Service of Health, Safety and Agri-Food Quality (SENASICA), Secretariat of Energy (SENER) and Ministry of Roads and Transportation (SCT).

State level of organization: State Governor, State Congress, State Forestry Council, Rural and Forest Secretariat (SECAMPO).

Municipal/local organization scale: eight ejidos and one communal forest territory: San Miguel Coantlichan, San Pablo Ixayoc, Santa Catarina del Monte, San Miguel Tlaixpan, Ejido Nativitas, Tequexquinahuac, San Gerónimo Amanalco (ejidal), San Jerónimo Amanalco (communal) , San Dieguito Xochimanca, in addition, Municipal City Council and Rural Development Directorate.

B) Establish a group of concepts as a framework to describe interactions between actors

Through a bibliographic review process on studies with similar approaches, the document “Power asymmetries in social networks of governance on ecosystem services” (Améline Vallet, 2020) was identified and cited, which establishes a reference framework to abstract power relationships between related agents (Table 1) to the management of natural resources and their ways and capacity of exercising that power.

Table 1.- Ways of exercising power, table adapted from Vallet et al.(2020).

Ways of exercising power	Definition	Examples of mechanisms	Examples of actors
Reward	Ability to manage positive valences or diminish negative ones in order to change one's behavior. It requires the receiver to perceive and give importance to the reward.	Bonuses based on results, conditional subsidies	Companies, Payments for Environmental Services bodies.
Force	Physical ability of an actor to keep another doing what he wants. Ultimately it can be in violence.	Represion	Army
Coercion	Non-legitimate capacity to achieve goals with a front in resistance (govern, command, requests, etc...).	Sanctions	Dictators
Authority	Legitimate ability to get others to obey.	Tradition, charisma, legal rationality	Community leaders, religious leaders, presidency
Persuasion	Presentation of arguments, appeals, or exhortations from one actor to another, which changes their behavior, with reference to their own values and preferences.	Communication	Means of communication (newspapers, television, internet)
Manipulation	Influence of one actor over another to hide the foundations of his own action.	Political propaganda, commercial advertisements	Lobbying
Reference	Attractiveness of an actor, with whom another actor identifies and wishes to be closely associated.	Artistic promotion	Celebrities, influential people on social networks
Expert	Special knowledge or expertise of an actor that can influence behavior from another.	Technical and scientific advice	Doctors

Subsequently, an Excel table was generated by organization scale and the following variables were established: name of the actor, type of interaction, interaction code and bibliographic reference.

C) Describe the institutional structural aspect related to the socio-ecosystem's internal and external forest management through databases, interactions, and diagrams.

The Vensim program (2022) was used. It is simulation software for system dynamics and feedback mechanisms, it uses agents, components and their interactions as a reference.

Modeling can be numerical, if values and algorithms are assigned, in such a way that models can be adapted from qualitative to quantitative with relative ease using the same software.

D) Establish a group of concepts as properties of the Complex Adaptative System to use as a reference framework in order to discuss the generated diagrams.

During the process of bibliographic review and development of the theoretical framework, multiple properties established by other authors of complex adaptive systems were identified. For the analysis, the concepts established by Chan (2001) in the document "Complex Adaptive Systems" were used, supplemented with the work of Carmichael & Hadzikadic (2019). In this process, we sought to find the most "important" properties, sometimes repeated in different ways in other documents, allowing us to understand the difference between SCA and other types of systems in a simpler way.

The properties are distributed control, connectivity, coevolution, emergent order, far from equilibrium state and path dependence. Using these concepts, their implication in the established context was broken down.

Results and discussion

Three diagrams were obtained per result corresponding to the three levels of government, federal and state, and one called municipal/local.

The resulting diagrams allows to visualize the interdependence between the agents that make up the institutional structure with the forest management function, at the government' levels.

Through a bibliographic review process, 31 actors present for forest management at the federal government level were identified (Figure 3), among which there were a total of 75 interactions (Table 2).

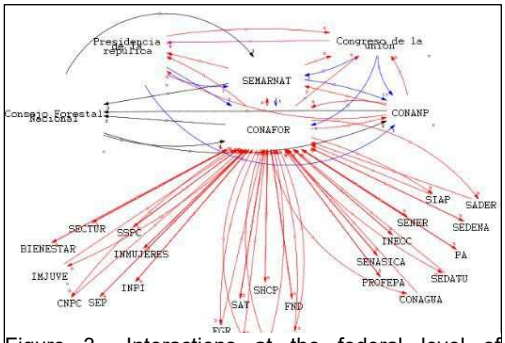

Figure 3.- Interactions at the federal level of organization

Table 2.- Interactions at federal scale

Types of interaction:		
Color	**Description**	**Quantity**
Red	Persuasion, experts	60
Black	Experts	6
Blue	Authority	8
Pink	Authority, persuasión, experts	1

The established directional relationships allow us to identify agents with greater power in the network and feedback mechanisms. At the federal level, interaction networks are observed (persuasion, experts) that indicate the integration of the objectives of different institutions to achieve forest management in a framework established as "sustainable" by the work plan of CONAFOR, which is the institution with the function of regulate the forest management at this scale and that works directly at the local scale with the ejidos. The other actors maintain the population's needs in relation to different development sectors, observing that it is necessary to have multiple other services served from a federal scale to maintain the function of forest management at an ejidal/local scale.

Regarding control, although it is "distributed", some feedback mechanisms with greater "importance" can be identified, such as the SENASICA pest control sector and the financial/administrative part, such as the Ministry of Finance and Public Credit. (SHCP), These and other actors fulfill functions that allow the CONAFOR to act at the federal level.

Through a bibliographic review process, 5 actors present for forest management at the federal government level were identified (Figure 4), among which they add up to a total of 19 interactions (Table 3).

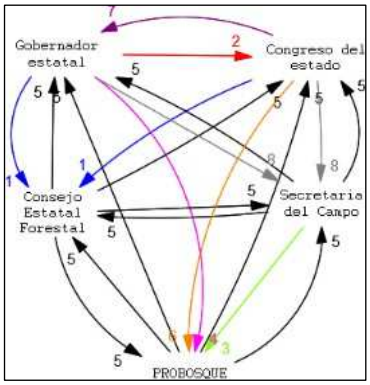

Figure 4.- Interactions at the state level of organization

Table 3.- Interactions at the state scale

Types of interaction:		
Color	**Description**	**Quantity**
Blue	Reward	2
Red	Persuasion	1
Green	Authority, reward, persuasion, experts	1
Pink	Reward, persuasion	1
Black	Experts, persuasion	10
Orange	Authority, reward	1
Purple	Authority, experts, persuasion	1
Grey	Authority, persuasion	2

At the state level, there is also an agency with forest management functions, however, in the power relations, it is observed that it depends on the Rural Secretariat to act, giving less "power" of action to the agency. Similar feedback mechanisms also arise at the federal level as the constant function of other institutional actors that support services to the population is necessary; however, these interactions linked to the Field Secretariat are not explicit here.

At both scales, relationships are observed with their respective congresses, presidency and governors. These relationships have a legislative nature, by themselves they have many interactions and feedback mechanisms, enough for an independent study when zooming in each of them, in general they fulfil the function of giving direction to forest management and others. We find in both intertwined sectors, from both functional forest management as well as financial and administrative sectors. The forest councils of both scales function as supports, providing different knowledge and perspectives, both technical and cultural, to the forest management plans at their respective scales.

The particular functions of each actor are determined by a legislative process that ends with a publication in the Official Gazette of the Federation and/or the Gazette of the State of Mexico, in these the objectives can be found and subsequently establish the interactions that arise specifically for the fulfillment of each objective of each actor, with similar products being the manuals of procedures, processes and protocols, as well as the work plans of each actor.

The properties of complex systems such as distributed control, connectivity, can then be identified down to the level of individuals working in each of the specified institutions, being necessary, for example, to fulfill administrative work such as the transfer of budgets, attention to requests, facility maintenance, among others. The other concepts are a little more difficult to locate but can be determined in co-evolution actions, emergent order, state far from equilibrium and path dependence, co-evolution refers to the fact that the actors at different scales change and in this process They influence the change of other actors, although there is a certain direction, the process of their actions is highly connected and changes as a whole. The emergent order refers to the capacity of systems at different scales to have new behaviors or possible conditions, due precisely to their own change processes and the influence of other actors, e.g.-Each actor in each scale has a group of variables corresponding to their attributes and rules of behavior, these are determined by a legislative process. In the feedback

mechanism that exists between SENASICA and CONAFOR, each one has its attributes (budget, infrastructure, human resources, etc.) and rules of action (objectives, procedure manuals, etc.), remembering that the attributes do not change. On the same scale among individuals, the individuals that make up SENASICA, which is already on another scale, are people with attributes (salary, work hours, emotional state) and rules of action (functions). Each one, when fulfilling their functions, exercises that distributed control over the system and the connectivity that exists between the condition of the forest and how someone feels on a work day in the office (note the absence of the temporal dimension in work). Regarding co-evolution, the actors are changing, thus the change in how SENASICA performs its functions will affect what CONAFOR can manage, which is the forest.

The emerging order then comes as the possible changes in these scales of the individuals in the values of these variables, and this is understood with the states far from equilibrium, since the values of these variables vary in the temporal dimension (the budget assignment, the assigned infrastructure, the human resources in quantity and quality, etc.), however these are within a domain regime, so they maintain their functions. This can alternate, if the direction of the executive changes, and influences the values of its attributes drastically together with some actors, such as a drastic change in the budget of CONAFOR, this could generate a transition in the domain regime and depending on the resilience of the institution will be able to maintain its functions. Likewise, if such a change were to occur for SENASICA, other sectors, not just forestry, would be affected if they cannot perform their functions (connectivity, co-evolution). New behaviors or values may also emerge through the emerging order. Attributes that allow the system to maintain these functions, also in this last example we see the property of path dependence, which is more related to the temporal and spatial dimension and is that the current condition of a system depends on the past condition and the actions that caused one to happen to another. So returning to the previous example, we would understand the path taken to having a sick forest system (undesired values in its attributes, such as species richness, usable forest volume, among others) due to the lack of compliance with the functions of SENASICA and CONAFOR, which in itself was a change in its attributes (budget, human resources), due to the alteration that occurred in the values of the attributes of the executive branch and congresses (moral, philosophical values, human resources, etc...)

At the municipal/local scale is where the structure that has a direct and physical impact on the forest system studied is identified (Figure 4, Table 4). In total, Vensim generated an analysis of 32,766 loops with the inputs, using 12 actors and 132 interactions as a reference.

Table 4.- Interactions at the municipal/local scale.

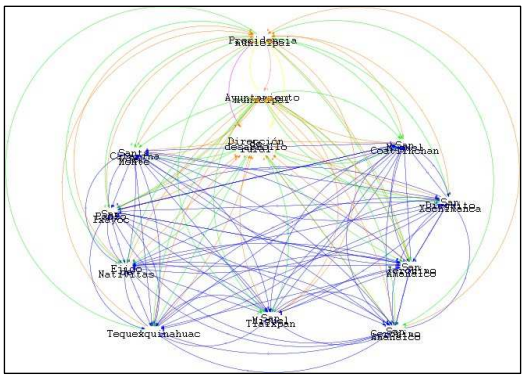

Figure 4.- Interactions at the municipal/local level of organization

Types of interaction:		
Color	**Description**	**Quantity**
Blue	Persuasion, reference, experts	72
Orange	Reward, athority, persuasión, experts	18
Green	Authority, regulation, persuasion, experts, reward	18
Pink	Persuasion, authority, reward	1
Yellow	Experts, persuasion	4
Purple	Authority, reward	1

Distributed control: At this scale of organization, the distribution of control over the condition of the forest system studied becomes evident, the agents corresponding to ejidos and community share through their management plans, (which are linked by interactions through multiple levels of organization , PROBOSQUE and CONAFOR) this "control". Remembering that the forest system covers an area larger than that delimited for this study and therefore the influence of other actors at the local scale is omitted.
Being present in the context for the analysis, different perspectives begin to emerge that allow this framework of reference to be operationalized to generate inputs that allow better decision making.

For the particular case of this study, forestry activities are those interactions that local agents have with the system and that are directly related to the condition of the forest. A follow-up for this study would be, with the permission of the corresponding authorities, to generate the databases with the variables considered important for comprehensive forest management and particularly, to operationalize adaptive management. Some important variables are: forest volume, n* of plant species, n* of faunal species, presence of fungi and classification, relative abundance index, number of forest stands, area assigned to forest exploitation, area assigned to conservation, activities non-timber exploitation, among others.

Distributed control can be operationalized at this scale of organization through these activities and indicators, however, this communication also has multiple levels of organization and requires multiple channels. Ex.- The information shared by the ejidos regarding their forest management plans will be every end of the month, however, the meetings of the different fire brigades of the ejidos will be weekly, many times these will have an impact on the meetings of each ejido and later in the monthly general meetings. In this way we could even reach a level of individual organization, however, to maintain operationality it is better to stay within "official", pre-established relationships and better than with normative references.
In such a way that distributed control can be considered a strategic plan that requires multiple stages for its implementation. From the generation of a joint vision, the setting of goals, activities, implementation, monitoring of processes, among others.

Connectivity: At this scale of organization that we call local, this connectivity is reflected with respect to forest management in the previously indicated indicators. Even when communication channels do not exist, the consequences that are generated in the system due to the decision of a particular agent can be abstracted through different variables. In this sense, information channels allow greater awareness and response capacity to situations arising from the lack of coherence between the different management plans and/or any problem that arises that requires the intervention of two or more agents, due to because the phenomena that occur in the system will have consequences for the actors, even when the event is not within their territory, e.g.-Movement of soil masses can affect the dynamics where it happened and in other areas that depended on those conditions.

To operationalize this abstraction, it is worth reviewing and comparing forest management plans, in such a way that there is a perspective both at the stakeholder level (localities) and at a general level with respect to the part of forest land use within municipal limits. using variables and particularly indicators that allow the system to be monitored from the researchers' perspective.

Co-evolution: This aspect goes after the identification of the variables and indicators that allow us to abstract the connectivity and distributed control of the actors over the system. The change over time of these variables will allow us, from both an academic and functional perspective, to determine attraction regimes, behavioral patterns reflected in the ranges of values of the variables, records of changes in the values of those ranges. If public policies are implemented, begin to see changes in values, interesting to observe the influence of the actors among themselves through these variables.

It is then understood that to operationalize this concept you must have multiple inputs, in this sense it becomes key to find an optimal way, either through digital interfaces or using stationery materials, to be able to visualize the information at the agent scale and at the system scale. If databases, files, maps, graphs were generated, being able to view them during the decision-making, monitoring, evaluation, etc. processes... It presents an enormous advantage and a more functional use of these concepts for planning.

States far from equilibrium: With a subsequent study, the identification of the possible conditions of the system would allow determining a domain regime related to forest structure and management. Through the activities and social structure recorded, one can begin to

understand the feedback that exists between the agents, in particular, relate the changes and internal dynamics of the agents that are also in states far from equilibrium, with the possible conditions in which they occur. find the forest. In relation to the panarchy concept, through other studies, the different phases of the system can be identified in relation to the forest management of this system, both at the agent scale and at the forest level in general. In this way, also identify or propose the establishment of learning mechanisms that allow the new configurations of "fast" variables of the systems to really contribute knowledge and experience to the "slow" variables.

Path dependence: In this scale of organization, the ecological variables are part of the scale, so they are directly affected through the activities of the agents present. In this sense, a more functional use of the concept is through a process where the reference framework is first defined to establish the condition of the forest system and the desired condition, in such a way that by registering the activities of the agents and Based on their results, it can be identified which activities or mechanisms allow the functions to be better fulfilled and the desired conditions reached. The exercise can be carried out using frameworks such as the SDGs, the agroecological approach, or even frameworks with more political than technical or academic ideals, the latter being very difficult to separate. In such a way that again, the monitoring of processes, the registration of activities and the use of that information will generate greater capacity for evolutionary resilience of the system, this implies that the appropriate people have access to the information, so that decision making considers also temporal changes, both institutional, which is the focus of this work, and ecological changes, thus adapting forest management activities and strategies to social and ecological changes, maintaining the desired condition of the system, in this case, continuous forestry exploitation.

Conclusions

The constant collection of information relevant to the problem framework or emerging property of socioecosystems (multiscalar, multidimensional and multiagent monitoring systems) is critical to using socioecosystems as complex adaptive systems as a conceptual planning tool. Converting this information into knowledge for the agents involved is the next part of the procedure to really be able to use these concepts. The frames of reference to describe the interactions between actors must vary according to the emergent property or problem framework that has been established as a basis for the study; the context in which they were applied must also be considered when applying predefined concepts. previously defined and applied, seeking to ensure that they are conditions similar to those to be applied and understanding them within a particular pre-established context.

The network of actors involved in managing the forest system within the municipality of Texcoco de Mora includes multiple feedback mechanisms between agents, internal mechanisms of the agents and different qualitative speeds. This gives rise to a regulatory framework that regulates activities but leaves, particularly at the local organizational level, few coordination mechanisms in relation to the internal administrative changes of the agents, which generates an imposition of possibilities in forest management by agents at the federal level but little coordination at the local level on the same issue

Using the software to create the models, we can establish variables in these Vensim models (interactions), determine according to the variable and the behavioral rules and attributes of the agents whether it is contributing in a negative or positive way, in this way, quantify feedback mechanisms for the variables that are required, even for different topics where these same agents are related. To operationalize the concepts of socio-ecosystems as complex adaptive systems, a technically clear process is necessary, from the conceptualization of the problems or emerging properties to the products that are generated during and therefore the procedures necessary for the elaboration of these products. particularly the variables that determine the attributes of the actors and the rules of action.

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