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# Resilience as an Adaptation Strategy of Agroecosystems in the light of Climate Change

Quiroz-Guerrero, Ismael[1]; Pérez-Vázquez, Arturo[1*]; Landeros-Sánchez Cesáreo[1]; Gallardo-López Felipe[1]; Velasco-Velasco, Joel[1]; Benítez-Badillo Griselda[1]

[1]Colegio de Postgraduados, Veracruz Campus. Carretera Federal Xalapa-Veracruz km 88.5, Tepetates, Manlio Fabio Altamirano, Veracruz, Mexico. C. P. 91963. [2]Colegio de Postgraduados, Córdoba Campus. Carretera Córdoba-Veracruz km 348, Manuel León, Amatlán de los Reyes, Veracruz, Mexico. C. P. 94946.

***Corresponding author**: parturo@colpos.mx

## ABSTRACT

**Objective**: To analyze the resilience concept as a property of agroecosystems to face potential climate change scenarios.

**Methodology**: The literature related to concepts such as resilience, vulnerability, climate change scenarios and resilience in agroecosystems was analyzed.

**Results**: Resilience is an upcoming property and it is part of the trajectory of agroecosystems and it is also closely related to the capacity of adaptation and self-learning.

**Limits**: Weak elements should be strengthened and feedback for the agroecosystem controller should be fostered in order to increase adaptation capacities.

**Conclusions**: The promotion of agroecosystem resilience should start from the integration of indicators in environmental dimensions, governance, risk assessment, knowledge and education, risk management and vulnerability reduction, disaster preparation and response.

Keywords: Exposure, natural disasters, temperature.

## INTRODUCTION

Natural disasters have been experienced throughout history in different human civilizations. In Mexico, the oldest disaster reports go back to pre-Hispanic times, which were recorded in codices (Therrell *et al*., 2004). The impact of natural disasters on society is significant to the degree of making it prone to collapse, as it happened in lowland Mayan cities, where the cause for their collapse could have been due to the incapacity of the government system to maintain social and cultural balance in the light of a great draught caused by strong climate changes and an intense solar cycle (De la Garza, 2018). Due to natural disasters from 1998 to 2017 in poor countries, 130 individuals out of one million inhabitants have died as opposed to rich countries where only 18 out of one million individuals die. This means that citizens of poor countries are more exposed to natural disasters and that the likelihood of dying in these nations is seven times greater compared to persons inhabiting rich countries. Human losses happen frequently in environments exposed to natural dangers and problems caused by man, such as poverty, lack of ecosystems, protectors and institutional incapacity to prepare for and respond to extreme natural phenomena (Wallemacq & House, 2018).

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As for Mexico, in the last 30 years the yearly average of natural disasters has increased to more than twice. According to CENAPRED (2014), the catastrophes that have increased more are weather events (tropical storms, winter storms, droughts and tornadoes), water events (flash floods, tidal waves and landslides) and weather events (heatwaves, frosts, forest fires and droughts). Between 2000 and 2014, the country showed losses accounting for US$2 147 million caused by disasters of natural origin (CENAPRED, 2015). In poor and emergent economies, a natural disaster also means greater attachment to the financial poverty of their citizens, due to material losses amplified by the effects of natural phenomena. With anticipated changes in the global climate system and the vulnerability of systems, it is possible that the frequency and impact of extreme events will increase in the future. As a result of climate change, it is likely that coastal cities will be affected by the increase in sea levels. As for natural systems (ecosystems) and agricultural production systems (agroecosystems), the increase of temperature and the decrease in rain will affect their current distribution and productivity (IPCC, 2015). Within the agroecosystem context, it is important to ensure the production of foodstuffs for humanity, reason why the development of robust agroecosystems with high resilience capacity, that allow minimizing losses caused by extreme weather phenomena is necessary. The aim of this study was to analyze the resilience concept as a property of agroecosystems to face potential climate change scenarios.

## MATERIALS AND METHODS

A literature review was made with the keyword "resilience"; the association thereof with the words "vulnerability", "agroecosystems" and "climate change" was used as selection criterion in academic search engines (SciELO, Redalyc, Google Scholar, ISI Web) and the CENAPRED database. Then the clearing of results followed. Once the articles that addressed resilience as an emergent property of agroecosystems were identified, concepts and methods were reviewed and identified. Municipal vulnerability and resilience data found in the CENAPRED database were analyzed through the Qgis software, version 3.6.

## RESULTS AND DISCUSSION

### Vulnerability

Within the context of agroecosystems, vulnerability may be defined as the susceptibility or tendency that the exposed systems have to being affected or damaged by the effect of a disturbing phenomenon. In general terms, two types of vulnerability may be distinguished: physical and social. The quantification of the former is more feasible. For example, in the number of resistant plants against the forces of wind produced by hurricanes,

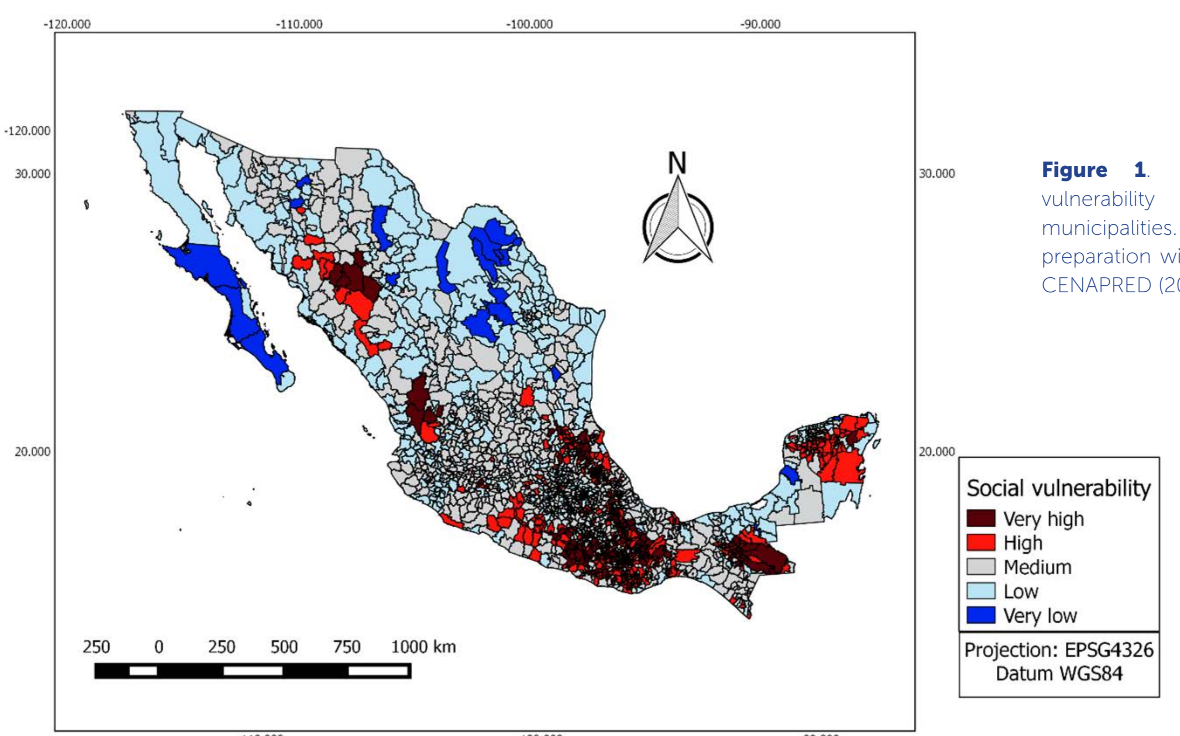


**Figure 1**. National social vulnerability classification of municipalities. Source: Self preparation with information of CENAPRED (2015).

which is different to the latter, which should be appraised in quality and which is relative, as it is related to economic, educational, and cultural aspects and the degree of preparation of persons (Zepeda *et al*., 2014). For Mexico, most of the municipalities classified as "high" and "very high" social vulnerability are located in the southeast (Figure 1) and associated to marginalization and "high" and "very high" poverty (CONAPO, 2013).

**Table 1**. General characteristics of scenarios used to study climate change (IPPC, 2015).

| Scenarios | Description |
|---|---|
| A1 | A quick economic growth and introduction of new, more efficient technology. |
| A2 | A socially heterogeneous world with emphasis in family values and local traditions. |
| B1 | A world with de-materialization and introduction of clean technologies. |
| B2 | A world with emphasis on local solutions for economic and environmental sustainability. |

It is likely that agroecosystems distributed in municipalities with greater vulnerability are also vulnerable to the effects of climate change. The European Environment Agency (EEA, 2004) defines vulnerability as "the fact that citizens may be subjects of negative effects of climate change; either as individuals, members of a community, citizens of a country or part of humanity in general." The Intergovernmental Panel on Climate Change (IPCC, 2015) defines vulnerability as the "degree at which a system is susceptible or incapable of facing adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of character, magnitude and rapidness of climate change and the variation at which a system exposes its sensitiveness and adaptation capacity."

## Climate Change and its Scenarios

Climate change scenarios are a plausible and often simplified representation of the future climate, based on a set of weather relations which are constructed to be used in the research of potential consequences of human-generated climate change and that serve as an input for impact simulation (IPCC, 2015). Climate change scenarios are not weather forecasts, as each scenario is an alternative to how the future weather may behave depending on anthropogenic emissions of greenhouse gases (GEI). These emissions depend mainly on the size of the population, economic activity, lifestyle, use of energy, land use patterns, technology and climate policy. Due to the foregoing, the scenarios allow decision-makers to face potential future conditions and analyze the availability and usefulness of options to face an unknown future; they also allow implementing mitigation measures in the present to avoid an undesired future (INECC, 2017).

Table 1 shows four emission scenarios that have been published in the Special Report on Emissions Scenarios) developed by economists and social science researchers for the third assessment report of IPCC (2015).

## The Impact of Climate Change in Agroecosystems

The increase in global temperature (Table 2) will increase the frequency of extreme weather phenomena that will have direct and indirect effects on ecosystems, biodiversity, the productivity of crops, livestock breeding, forestry, fishing and aquaculture in the years to come (IPCC, 2015). Projected impacts vary in different adaptation, crop and regional scenarios. Around 10% of projections for the 2030-2049 period show gains of more than 10% in the performance of crops and performance losses above 25%, compared to what occurred by the end of the 20th century. The most severe impact risk increases after 2050 and it depends on the warming level.

There is also a risk of violent conflict derived from the deterioration of subsistence means, which depend on agricultural and grazing resources. Water access will be lesser for poor persons in rural and urban areas due to the scarcity and greater competition for the obtainment of such resource. Due to the above, under a context of increase in temperature and decrease in rain, the southeastern states of Mexico that currently show a greater population in poverty, among which Veracruz (Figure 2) stands out as it has a greater cultivated agricultural

**Table 2**. Mean global temperature increase between 2081-2100 (IPCC, 2015), based on different scenarios.

| Scenario | Increase in temperature (°C) |
|---|---|
| RCP 2.6 | 0.3 – 1.7 |
| RCP 4.5 | 1.1 – 2.6 |
| RCP 6.0 | 1.4 – 3.1 |
| RCP 8.5 | 2.6 – 4.8 |

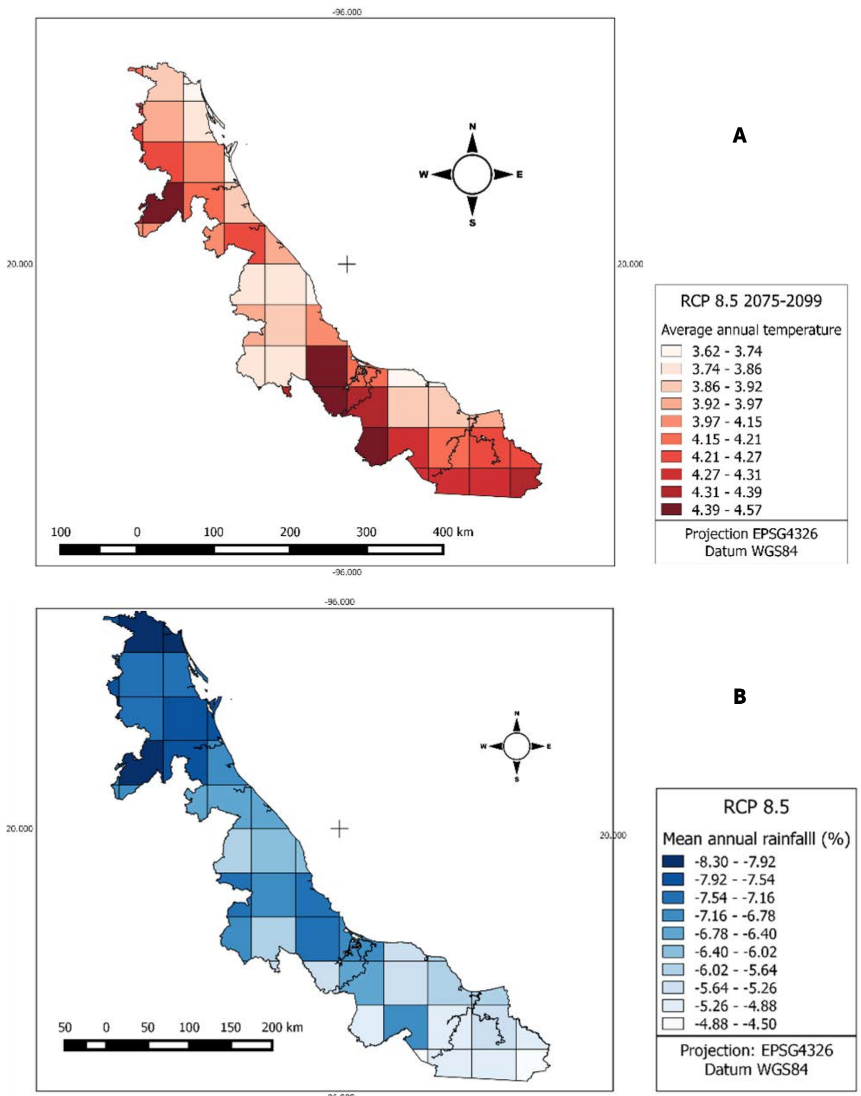


**Figure 2**. Veracruz state area, according to scenario 8.5, during the 2075-2099 period: A) Increase of mean annual temperature B) Decrease of mean annual temperature. Self preparation with information of INECC (2017).

area, may be considered to be at risk of conflict (CONEVAL, 2018; SIAP, 2020).

Thus, it is foreseen that the more vulnerable areas face great impacts with respect to food security, infrastructure and agricultural income, including changes in food and non-food crops around the world (IPCC, 2015).

### ¿What is Agroecosystem Resilience?

The word resilience comes from the latin *resi-lire* and it was used initially by physicists to describe the stability of materials and their resistance to external impacts (Davoudi *et al*., 2012; Reid & Botterill, 2013). In the 1960s, with the growth of systemic thinking, the concept was used in ecology, and its definition underlines the recovery and return to an initial state of an ecosystem after an impact (Masterson *et al*., 2014). Currently, the term resilience is used in areas such as psychology, geography, psychiatry, public health and economics, to mention a few. A resilient system is that which has a capacity to absorb or withstand impacts and its ability to maintain or return to its original structure, shape, functions or qualitative state (Miller *et al*., 2010). For the purpose of this work, the resilient agroecosystem is considered to be a set of social, economic, technological, and environmental components, the robustness, feedback and adaptation capacity of which allows the expression of resilience as an emergent property (Figure 3) (Masterson *et al*., 2014). Due to the foregoing, in agroecosystem design, farmers and technicians should establish characteristics that foster the reduction of future vulnerabilities through adaptation and innovation strategies to ensure that agroecosystems do not return the level before the impact, due to the fact that the risk of suffering the same damage would exist in case that a similar extreme event occurred. This is why a disturbance should be an opportunity for gaining experience through feedback and increasing agroecosystem robustness (Helfgott, 2018).

There are important factors for the development of agroecosystem resilience, one of which is the ability of farmers to access and use their capital (natural, financial and human) better after an extreme natural phenomenon, which would allow them to improve the economic, political and civil state and begin their accelerated recovery (Alfani *et al*., 2015). Other important factors of resilience dimensions are autonomy, food security, adequate nutrition levels, health, and education, to mention a few, as well as the versatility of modifying their system's structure, as required, in light of disaster scenarios (Akter and Mallick, 2013). In Mexico, the National Disaster Prevention Center assessed resilience at a municipal level, depending on the adaptability capacity before disruptive phenomena; it determined that the greater part of municipalities with "low" and "very low" resilience are in southeast Mexico (Figure 4). These municipalities also show low values

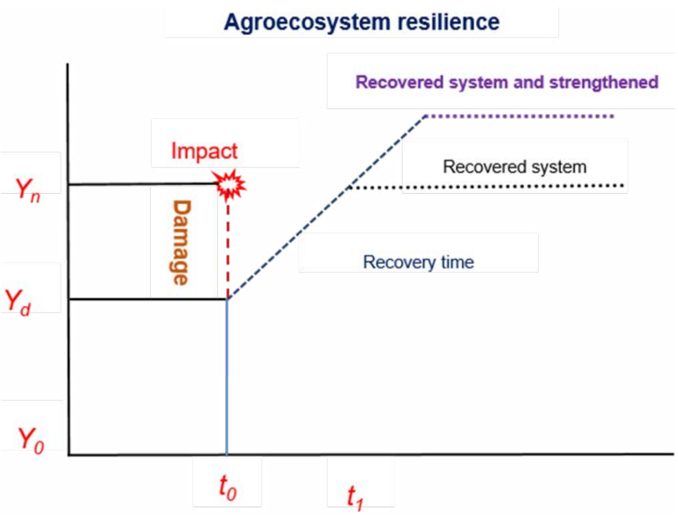


**Figure 3**. Dimensions of a resilient agroecosystem. $t_1$ = system recovered at a before-impact level; $t_2$ = recovery level greater than before-impact; $Y_n$ = normal integrated agroecosystem performance level; $Y_d$ = normal performance reduction level; $Y_0$ = level with total performance cost; $t_0$ = the impact occurs and decreases normal performance (Modified from Rose, 2009).

in terms of governance, risk assessment, knowledge and education, risk management and reduction in vulnerability and preparation and response to disasters (CENAPRED, 2015).

## Key Elements for the Development of Resilient Agroecosystems

Resilience is related to what may be done by the agroecosystem by itself and how its capacities may be strengthened. Focuses on research-action and social learning turn out to be useful in the analysis of agroecosystem resilience, due to the fact that they allow the conceptualization of the necessary stages for attaining resilience (Table 3). The use of virtual tools, such as modeling based on complex agents and scenarios, allows knowing the behavior of systems under several conditions, in a timescale and with different actors (Masterson et al., 2014; U. S. Climate Resilience, 2016). The multi-factorial nature of the resilience concept predisposes the consideration of a wide diversification of variables to be measured within the agroecosystem. According to Twigg & Bunge (2007), variables may be grouped into five major areas or dimensions in which agroecosystem resilience may be measured: 1) governance, 2) risk assessment, 3) knowledge and education, 4) risk management and vulnerability reduction, and 5) preparation for and response to disasters.

The resilience analysis in the context of agroecosystems allows the conceptualization of the producer as a system of conscience, due to the fact that this intervenes in the access to the external world of communication. It is important that the producer promote learning or adaptation before disasters in order to strengthen prevention and decrease vulnerability, impact and damage of an extreme weather event; this would accelerate the recovery of the system until the attainment of resilience (Cabell and Oelofse, 2012; Casanova et al., 2015).

Another outstanding focus is the social-ecological one (Figure 5), which considers that resilience is a component

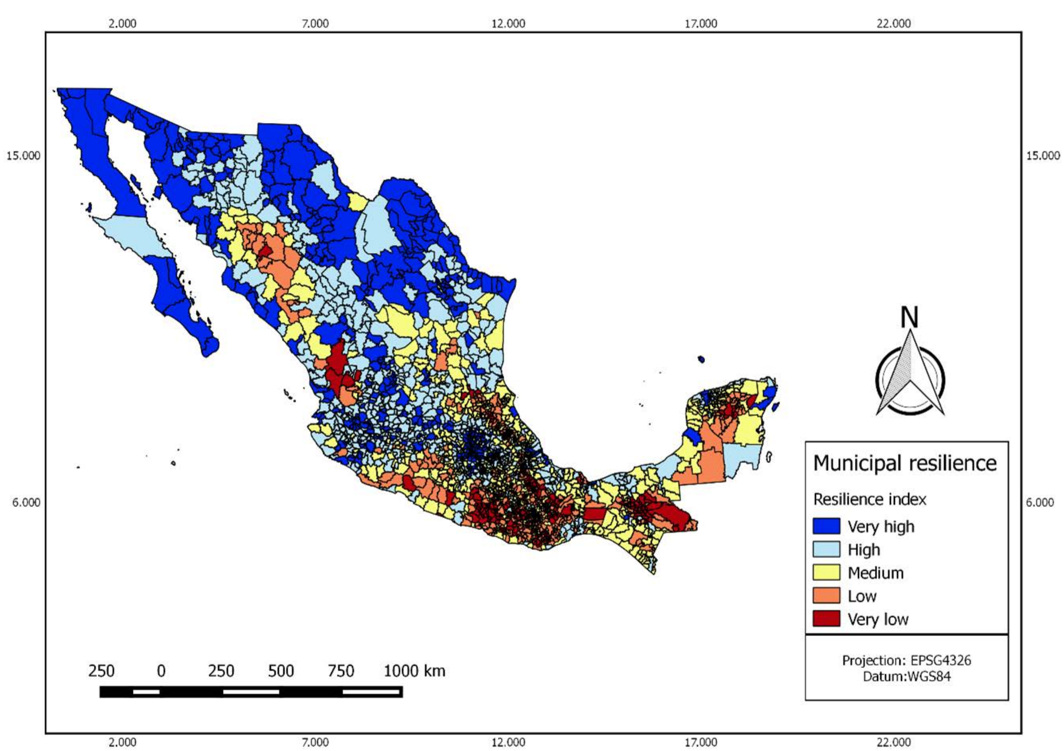


**Figure 4**. National municipal resilience index classification. Self preparation with information of CENAPRED (2015).

**Table 3**. Recommendations for attaining resilience in communities and their infrastructure (U. S. Climate Resilience, 2016).

| Recommendations | Description |
|---|---|
| 1) Explore climate threats | Organizes a group, explores regional climate threats and considers whether that which is appraised is threatened by weather. |
| 2) Assessment of vulnerabilities and risks | Determines which properties exposed to a likely damage or that may be lost by the impact of climate events. |
| 3) Research options | Performs some brainstorming on potential solutions and does research on what has been done by other groups. Underlines options in a list, where the stakeholders agree. |
| 4) Prioritization of actions | Consolidates actions and determines the better sequence to protect most properties. Organizes resources so as to focus them on greater risks. |
| 5) Action-taking | Implements the plan and monitors results. Modifies the focus as much as necessary. |

in the trajectory of agroecosystems based on cyclic adaptability through constant feedback (Walker, 2004). From this focus, there are indicators such as social end ecological self-organization, connectiveness with other systems, rapid response, optimal redundancy, temporary and spatial heterogeneity, self-learning, global autonomy and local interdependence, documentation of past experiences, economic profitability and the constant training of human capital that allow developing an adaptation capacity and the respective redundancy in the expression of agroecosystem resilience (Cabell & Oelofse, 2012; Folke, 2016).

## CONCLUSIONS

Both in social-ecological systems and agroecosystems, resilience shows a multi-dimensional and complex nature that allows regenerating in case of suffering damages to their structure. Agroecosystems show environmental, social, economic, technological and communications components that are key in the adaptation stage before changes originated by external disturbances. Making the structure of agroecosystems robust redounds in the decrease of vulnerability and allows developing resilient agroecosystems that remain before and after the impact of climate change to continue with the production of foodstuffs and fibers for the wellbeing of humanity.

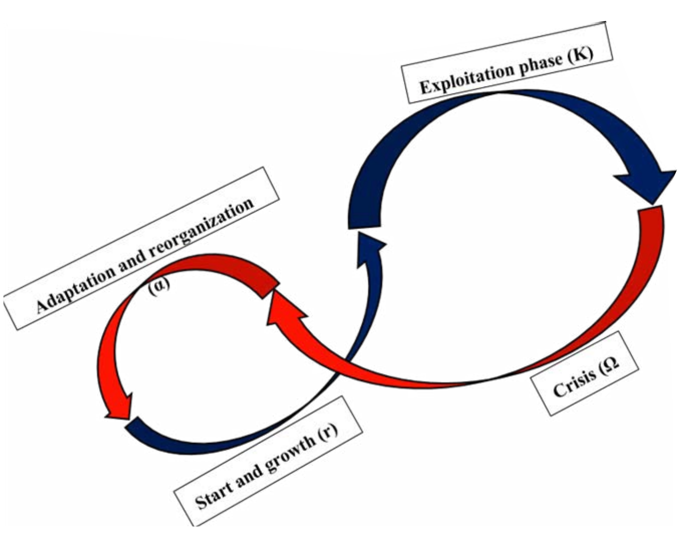


**Figure 5**. Components integrating the cyclic resilience process from the social-ecological focus (Walker, 2004).

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