論文審査の結果の要旨

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Sustainability is the new prevailing paradigm of the 21st century where local and global decisions are based upon concerning the viability of co-dependent human and nature constructs. Nonetheless, the idealism of sustainability remains pluralistic and contested. On the other hand, the emerging concept of resilience is sought to define sustainability in terms of persistence whether by withstanding or adapting to perturbations. However, as much as resilience has become an essential discourse in sustainability of interlinked nature and human-built systems, it has also gained the trait of ambiguity. This paper contributes to the resilience debate by providing an objective measure of resilience and systemic network characteristics essential for sustainability and to the study in sustainability science. Although there are proposals of the use of network approach in assessing interconnected social and ecological sustainability, empirical evidence is still lacking to support progress. The ecological information-based approach, which is a form of network analysis that measures robustness as a trade-off between resilience and efficiency, is applied on the Philippine brackish pond sector as an example of interlinked social, economic and ecological systems to gain understanding of systemic persistence.

Resilience adds a dimension to sustainability that indicates persistence over time in the presence of adversity and uncertainty. The use of the term resilience can be traced back to the field of physics and material sciences and diffused to other fields such as psychology, engineering and other trans-disciplinary fields. The more contemporary and prevailing concept of resilience comes from the field of ecology. It has been defined as a capacity to absorb shocks and still retain essential properties to persist. Ecological resilience is not just a matter of bouncing back to an original state or configuration, but the ability to adapt to change. Having diverse interpretations of resilience would hinder further development of the concept. A quantitative measure of resilience may provide a foundation for accumulating and creating new knowledge that is relevant to the academe, policy makers and communities. The challenge therefore is developing an approach of quantification to complement qualitative descriptions of resilience.

The main culture species in the Philippine brackish pond sector is the milkfish. The milkfish brackish pond social-ecological system is composed of two major components. The first is the prime system which is the brackish water pond areas. Milkfish are farmed in earthen ponds relying on natural resources and services such as water, land and the natural micro fauna and flora in the culture areas. The second component is the source of milkfish fry for stocking in the ponds. Before the development of hatchery systems, milkfish fry is gathered in the coastal areas by fisher folks. The milkfish fry social-ecological system is an ancillary sector of the over-all brackish pond milkfish social-ecological system. The milkfish fry and the milkfish production systems are expressed into networks. The milkfish fry social-ecological network is composed of the fry source and the various dealers that facilitate the delivery of fry to the grow-out ponds which is also a social ecological system. The milkfish production social-ecological network also has dealers that facilitate the delivery of the culture product to the market. These networks have been reconstructed at the national, main island and regional scales and the ecological information-based approach is used to measure robustness (sustainability), resilience and efficiency. There seven network structures for the milkfish fry system. Four fry networks are at the regional scale and three at the national. The two networks at the national scale or interregional and inter-island trade of milkfish. There are three main island scale and one national scale networks constructed for the milkfish pond production system. There are a total of eleven systems.

Previous studies on ecological systems have determined that self-organizing ecological systems allocate efficiency and resilience to optimize robustness. A system is said to be sustainable if it has enough efficiency to compete in sequestering resources and yet resilient to novel disturbances. Our results show that the network structures of the milkfish system occupy a wider range of efficiency and resilience levels as compared to ecological systems. Our results also indicate that the milkfish networks occupy a wider range of efficiency and resilience allocation as well as robustness levels. The milkfish fry networks at the national scale have the highest resilience and lowest robustness levels. Here I argue that self-organizing ecological systems are effective in managing the allocation of efficiency and resilience in optimizing robustness than human managed systems as the milkfish network does approach boundary limits determined from ecological systems. The interregional and inter-island trading of milkfish fry had the highest resilience and lowest robustness values, the system could benefit from more efficient trading routes in order to increase robustness. The inter trading of milkfish fry is highly redundant that the system is suffering from too much inefficiency. The milkfish networks were also compared to 6 global economic trade networks. The inter-trade of milkfish fry behaves similarly with the economic networks of having high resilience and low robustness levels. The similarity of economic and the inter-trade fry networks perhaps is due to the network construction which does not highlight the delivery component of the system but instead is comprised of point to point exchange of resources and materials. The application of the ecological information-based approach perhaps has its limits of applicability to trading networks that does not highlight special functions of delivery.

The national milkfish-fry resource delivery has also high resilience and low robustness level that it approaches the boundary of the hypothetical limit for optimized robustness. The network structure of that facilitates delivery of fry from the fry-grounds to the pond production areas is highly redundant and multiple pathways render the system inefficient. However, the milkfish fry distribution network at the regional scale has high levels of robustness and tending towards more efficiency relative to the national fry system. This shows that robust sub-systems do not necessarily render a higher scale system sustainable. This is very much counter to our belief that in order to sustain higher scale systems, it is important to guarantee the sustainability of lower level systems. However, in natural systems such as a forest, constant renewal of sub-component continuously occurs to maintain the overall health of the entire system. In the case of the milkfish fry system, it is necessary to have both highly resilient and highly efficient regional networks to render the entire system more robust. The efficient regions would contribute to the efficiency needed by the national system and resilient regional network could offer redundant pathways in time of perturbations. Having low level of efficiency, the national fry social-ecological system would likely suffer from competition rather than disturbances to the system.

Hatchery systems were established in the 1990s to artificially propagate milkfish fry for stocking into grow-out brackish ponds. It was a concerted effort between the government, research institutions as well as the private sector to meet the demand for stocking material for the expanding growth of milkfish production. Milkfish hatchery directly competed with the milkfish fry gathering system. The milkfish fry social-ecological system had very little efficiency that it could not compete with the hatchery system in supplying fry to the grow-out areas. This transition from wild fry gathering to hatchery bred fry may be considered as a renewal of system component to maintain the overall system of milkfish production. This is a very important insight of how self-organizing renew sub-components in order to maintain the overall structure of the industry.

In the case of the milkfish production social-ecological systems, the four production networks is observed to behave similar to ecological systems where there is allocation of system residence efficiency and resilience that optimizes sustainability. The production network systems at the national and main island scale seem to occupy its own narrow distribution of resilience and efficiency that optimizes robustness. This could be the potential limit for the milkfish industry, the boundary of persistence. The national milkfish production system does not vary greatly from the main island milkfish systems. One reason is perhaps is that the scale difference between the main island and national level is quite small as compare to the scale difference of the national and regional levels in the case of the milkfish fry. The smaller the scale difference, the more likely the system would behave the same. Ecological systems have the tendency to increase efficiency in the absence of disturbances; it is the natural tendency towards growth and development. At three main islands are at different stages of growth and development. The more developed island has higher levels of resilience. This is counter to the ecological concept of ascendency or increasing efficiency. As the main islands grow and develop the milkfish industry, the less efficient it is becoming. Luzon is the main island where milkfish production was initially practiced before spreading to Visayas, then finally to Mindanao. Luzon has the greatest production and Mindanao the least. Ceteris paribus, as these islands develop their milkfish sector, there is an increasing trend of resilience. Luzon has the highest resilience and Mindanao the lowest. It could be argued that restructuring of the network system to increase resilience to support the flow of material as it increases. This is consistent with the ecological concept of resilience where newly perturbed systems increase resilience as it starts to grow and accumulate resources. This would suggest that resource networks that are developed has higher production and requires higher levels of resilience. The different components of the milkfish social-ecological system has been analyzed at different scales and found to have similar characteristics to ecological systems in terms of the general systemic variables of robustness, resilience and efficiency.

The ecological information based approach is also applied on temporal analysis of the milkfish and tiger prawn social-ecological systems from 1970 to 2001. Results show that resilience is a good indicator for the vulnerability of systems. Prior to rapid decline in production of both milkfish and tiger prawn, a decrease in resilience levels could be observed. The causes of decrease in production for milkfish includes market competition of milkfish coming from fish pen production in lakes; shift in fish farming from milkfish to tiger prawn. Disturbances for the tiger prawn includes outbreak of disease and drop in market demand. The measure of resilience is not aimed for any specific disturbance such as what has been mentioned. It is the concept of increasing diversity. Having stated the various disturbances, the measure still responds well to determine if the system is becoming vulnerable to disturbance that may be coming from the social, ecological or economic domains. The main lesson in this research is that social-ecological network systems have traits similar to ecological systems. Many are familiar with the concept of efficiency, but in attaining systemic sustainability, resilience should also be considered. The approach can assist policy makers and practitioners in making informed decisions in maintaining sustainability by deciding over the trade-off between efficiency and resilience of social-ecological systems described as a network.

This dissertation hereby has been approved for fulfilling the requirement for the degree of Ph.D. in Sustainability Science. (1,833 words)