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Autonomous Innovations in the Rural Communities of Developing Countries I—A Narrative Analysis of Innovations and Synergies for Integrated Natural Resource Management

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Abstract: Vulnerable sectors of the population living in poverty in developing countries are highly dependent on renewable natural resources for their livelihoods and daily lives. Sustainable resource management, improving the well-being of vulnerable people, and building resilience to shocks are global challenges. This study analyzed the outcomes of various autonomous innovations by the people themselves and the enablers of these innovations in the communities of developing countries. This analysis of 20 autonomous innovations from six countries revealed that these innovations produced outcomes that simultaneously improved multiple indicators of human well-being, including "basic materials for a good life", "safety", "health", and "good social relations". The process of promoting public values, such as education, health improvement, and landscape conservation as a by-product of collective actions was an important enabler of these innovations, as well as the innovator's proactive attitude toward continuous improvement. Public values and supporting ecosystem services were emphasized from the early stages of collective actions, to realize synergies toward integrated natural resource management. It is also important to achieve conditions in which collective actions could be practiced autonomously and adaptively. These results revealed the great potential of autonomous innovations emerging among socially vulnerable groups and the important mechanisms for promoting autonomous innovations for the transformation of social-ecological systems toward sustainable futures.

Keywords: social-ecological system; transformation; transdisciplinary; enabler; innovator; vulnerable people; human well-being; collective action; by-product

1. Introduction

1.1. Background

Socially vulnerable people living in conditions of poverty in developing countries are highly dependent on natural resources for their livelihoods and daily needs. The lives and livelihoods of these vulnerable people are embedded in complex social-ecological systems with a high degree of uncertainty, and improving their well-being is a global challenge [1–3]. Building the resilience of people living in poverty to various shocks, such as the global COVID-19 pandemic since 2020, is an urgent issue [4]. The combination of

various types of shocks and stresses, including climate change and ecosystem degradation, has caused new problems and exacerbated the existing ones in unexpected ways, making it particularly important to enhance their resilience [5,6]. For people living in poverty, it is also important to ensure their access to essential resources [7]. Countries, regions, or communities vulnerable to shocks and stresses often lack the resources necessary to create technical and social innovations to mitigate these challenges [8,9]. Governments and private organizations have been implementing various approaches to support socially vulnerable people. However, not much attention has been paid to the innovative practices emerging among socially vulnerable people themselves to create social systems and technologies, as well as the mechanisms to support these practices [7].

In our previous studies, we have found various innovations created by people in local communities in developing countries [10]. The emergence of these autonomous innovations by the socially vulnerable people themselves can have a significant impact on the sustainable management of natural resources and the improvement of their well-being. The establishment of mechanisms to effectively support autonomous innovations emerging among socially vulnerable people is expected to achieve the sustainable and integrated management of natural resources, improve the quality of life (QOL) and human well-being, as well as enhance resilience.

1.2. The Conceptual Framework of Autonomous Innovation

In 1934, Joseph Schumpeter proposed the concept of "innovation", especially in terms of its importance for entrepreneurs [11,12]. Innovation theory has developed into various studies elucidating its principles and the factors of its occurrence. Today, this genealogy of innovation theory is called "traditional innovation" [11]. Recently, research has been conducted into exploring the principles and procedures for socially vulnerable people to create innovations on their own. For example, Radjou et al. (2012) [9] and Chataway et al. (2013) [13] have proposed different approaches to innovation creation for people in low-income situations. This lineage of innovation theory is called "autonomous innovation" [13].

The concept of autonomous innovation includes "grassroots innovation" and "bottom-up innovation", which respond to local conditions and other factors and are created or actioned by citizens and community groups. Farmers and other grassroots actors can lead the emergence of innovations without external support [14–17]. The concept of "frugal innovation" was proposed as an approach that encourages a response to limited resources, based on the needs and circumstances of low-income citizens [18,19]. Various traditional approaches that have been practiced for years have been highlighted as having common characteristics [20]. However, even though concepts and case studies have accumulated regarding autonomous innovation, we have not been able to identify attempts to analyze the enablers of innovation and their impacts on integrated natural resource management by isolating specific cases of autonomous innovations emerging from poor and socially vulnerable people [21].

1.3. Autonomous Innovation and the Transformation of Social-Ecological Systems

Not only the lives and livelihoods of the socially vulnerable people living under poverty conditions in developing countries but also the autonomous innovations that they generate are embedded in complex social-ecological systems with high uncertainties. People under poverty conditions are particularly dependent on various natural resources, which also behave in complex ways. To improve people's lives and well-being and increase resilience through autonomous innovation, the innovation in question must have the potential to bring about the transformation of social-ecological systems [21]. Therefore, we define "autonomous innovation" as "collective actions emerging from local practitioners with the potential to transform social-ecological systems, and the mechanisms that support them". Transformation here refers to "a process of change that fundamentally alters interactions and feedback processes between society and the environment" [22,23].

1.4. Autonomous Innovation in Integrated Natural Resource Management

To facilitate the transformation of social-ecological systems, it is necessary to manage various natural resources synthetically, based on the interaction of multiple resource management systems. An ecosystem approach that focuses on the ecosystems supporting diverse resources is important for managing the various resources embedded in complex social-ecological systems through autonomous innovations [24,25]. The concept of "integrated natural resource management" has evolved in the context of ecosystem approaches, such as sustainable land use and watershed management [26]. This concept includes the perspective of social-ecological systems as complex systems that interact with human society [27,28]. When attempting to manage various natural resources synthetically, we need to be aware of the trade-offs and synergies within the systems [29–31]. Autonomous innovation leading to integrated natural resource management should minimize trade-offs and encourage synergies. Trade-offs and synergies are mutually exclusive. Thus, in the case of innovations where synergies are realized and transformation of social-ecological systems is facilitated, the risk of trade-offs is assumed to be minimal. However, reports of innovations where potential trade-offs do not manifest, and synergies are realized across multiple resources, are limited [7]. Therefore, in this paper, we focus on the mechanisms of the emergence of synergies in autonomous innovations that promote integrated natural resource management. The definition of "synergy" used in this study is "a combination of different actions or elements strengthening each other, leading to a result that is greater than the sum of their individual impacts" [32].

1.5. Research Questions

In this paper, we analyzed the outcomes and enablers of autonomous innovations emerging among socially vulnerable people under poverty conditions in developing countries, as well as cases of integrated natural resource management through the synergy of multiple management practices. By answering the following research questions, we examined the mechanisms of transformation of social-ecological systems triggered by autonomous innovation that lead to integrated natural resource management.

(1) What outcomes in terms of natural resource management and human well-being do the autonomous innovations emerging among socially vulnerable people achieve?
(2) What are the enablers that promote the emergence of autonomous innovations?
(3) What are the factors responsible for the emergence of synergy in innovation toward integrated resource management?

2. Materials and Methods

2.1. Target Countries/Regions and Research Period

We conducted transdisciplinary research from October 2015 to February 2020 in six countries according to the OECD (the Organization for Economic Co-operation and Development) classifications of least developed countries (Malawi), lower-middle-income countries and territories (Indonesia and the Philippines), and upper-middle-income countries and territories (Fiji, Turkey, and Thailand) [33]. The 12 communities studied included four in Malawi, three in Indonesia, one in the Philippines, one in Fiji, two in Thailand, and one in Turkey. These are the farming and fishing villages and rural small cities where the co-authors of this paper and our collaborators in this research have been deeply involved over time. The study sites were selected to allow for the exploration of autonomous innovation in the agricultural, water, fisheries, and tourism resources used by socially vulnerable people with diverse income levels and cultural backgrounds.

2.2. Methodology of Identifying Innovations

To explore autonomous innovations, we have developed a transdisciplinary research methodology called "Dialogic Deliberation in Living Spheres" (DIDLIS) [7]. This methodology is based on repeated dialogs and deliberations, conducted by scientists who are deeply involved in the local communities on a long-term basis, with diverse people classified as

socially vulnerable, working in an equal partnership from a perspective very close to their daily lives. We identified those autonomous innovations and innovators (actors who are central to the emergence and operation of autonomous innovations) that were emerging in each community. Narratives on the emergence process and the outcomes of innovations and the remaining challenges were created in close collaboration with innovators for each autonomous innovation that was identified in this way. Thus, the narratives were co-created through collective thinking between scientists and local innovators in the transdisciplinary processes, and all contents of the narratives were shared between the scientists and innovators in the communities.

2.3. Building a Database of Autonomous Innovations

We have organized the 20 autonomous innovation narratives into an "autonomous innovation toolbox" (see the Supplementary Materials). This is a simple database in which the researcher is responsible for categorizing and organizing the narratives regarding the innovations and their outcomes. The contents of the narratives in the database are the co-created products between researchers and innovators, with shared ownership among them. The toolbox is unique in that it specifies the motivations of innovators, the process of emergence of these innovations, the remaining challenges, and indices of human well-being improved by the innovations. We determined the structure of the toolbox to allow for analysis of the characteristics of outcomes brought about by the autonomous innovations and enablers of innovations. In designing the toolbox, we referred to the "Fisheries Management ToolBox", a database of bottom-up fisheries management practices used by fishers in Japan [34,35].

2.4. Analysis of the Outcomes of Autonomous Innovation

To analyze research question (1), the outcomes of innovations and the remaining challenges were organized using data from the toolbox.

The outcomes of each innovation were evaluated on four scales: contribution to resource management, contribution to human well-being, sustainability of innovation, and creation of enforceable local rules. For the contribution to human well-being, we used the four indices proposed in the Millennium Ecosystem Assessment: "basic materials for a good life", "safety (resilience and physical safety)", "health", and "good social relations" [36].

2.5. Analysis of Enablers of the Emergence of Autonomous Innovation

To analyze research question (2), basic information about the region, the resources targeted by innovations, the background of innovation emergence, and detailed contents of innovations were organized as factors that may promote the emergence of innovations.

We hypothesized that the emergence of innovations may also be related to the characteristics of innovators, the scales of collective actions, and external factors. We summarized innovator attributes, gender, and motivation as the characteristics of innovators. We used the spatial scales of activities and the number of participants at the core of the action as factors related to the scales of collective actions. We summarized the presence or absence of regional development support at the start of innovation emergence and the distribution of products to international markets as external factors.

2.6. Comparison of "Single Type" and "Integrated Type" to Identify Factors Related to Synergy Emergence

We could identify six autonomous innovations among 20 that not only contributed to the management of a single resource but also managed multiple resources simultaneously in an integrated manner. Such cases are assumed to minimize the trade-offs among different management practices and generate synergies. It is also expected that the integrated management of multiple resources will contribute to the improvement of resilience of vulnerable people and to the transformation of social-ecological systems. Therefore, we

categorized autonomous innovations into the "single type" and "integrated type", based on the target resources.

We defined a "single type" as an autonomous innovation in which no impact on resources other than the original target resource has occurred or could occur but that remains in the potential stage. The "integrated type" is defined as a situation in which an innovation generates synergies and produces an impact on more than one natural resource. Natural resources in these analyses include basic resources such as landscapes and ecosystems but exclude cultural and human resources.

Based on the data in the toolbox, the contribution to integrated resource management was analyzed to answer Research Question (3). We compared single and integrated types according to target resources, potential trade-offs, and the content of synergies.

3. Results and Discussion

3.1. Outcomes and the Remaining Challenges of Autonomous Innovations

Table 1 provides a list of the narratives of 20 autonomous innovations in the autonomous innovation toolbox (see also the Supplementary Materials) that are used for the analyses in this study.

Table 2A summarizes the outcomes of autonomous innovations contained in the narratives. Table 2B shows the number of innovations producing the outcomes categorized in Table 2A.

Most innovations made contributions to sustainable resource management (Table 2A). Regarding the contribution to human well-being, almost all the innovations contributed to "basic materials for a good life", "improvement of resilience", and "good social relations", while a few innovations made contributions to "physical safety" and "health".

An important feature of all autonomous innovations is their contribution to multiple indices of human well-being (Table 2A). For example, innovation number 13, "Seasonal fishing bans around Mbenji Island by traditional chiefs and communities" was triggered by the motivation of securing the safety of the fishers. In the process of implementing various collective actions, the well-being indices of "physical safety" were improved, as well as "contribution to resource management" (in this case, fisheries resource management), "basic materials for a good life", and "good social relations". These simultaneous contributions to multiple indicators of human well-being suggested the possibility that the improvement of diverse aspects of well-being was promoted as a by-product of efforts to improve the component of well-being that motivated the innovators in the first place. This point is discussed in more detail in Section 3.2.

Regarding the sustainability of innovations, we found that autonomous innovations could emerge in less than 10 years, and the longest ones continued for more than 30 years (Table 2A). All four cases that had created enforceable local rules were medium- to long-term and ongoing. In contrast, none of the short-term cases created local rules. This suggested that the long-term continuation of innovation leads to increased effectiveness through the creation of enforcement systems.

Table 3A shows the summary of the remaining challenges of autonomous innovations, and Table 3B shows the number of innovations that correspond to the categories of the remaining challenges extracted from Table 3A.

Table 1. List of autonomous innovations from six countries.

No.	The Name of Innovation	Country	Area	Target Resource
1	Community-based marine tourism	Indonesia	Gorontalo	Tourism Fisheries
2	Improving the quality of cacao raw materials and high value-added distribution		Polewali	Agriculture
3	Improving cacao farm management			Agriculture
4	Multi-species cultivation on cacao farmland			Agriculture, Ecosystem
5	Collaborative network construction	Indonesia	Jeneberang	Agriculture
6	Development and practice of irrigation channel management mechanisms			Water
7	Improvement of the rice planting method through international exchange	Philippines	Ifugao	Agriculture
8	Latex production association by small-scale natural rubber farmers	Thailand	Songkhla	Agriculture
9	Diversification of production activities of natural rubber plantations		Rayon	Agriculture, Ecosystem
10	Reorganization and utilization of traditional salt-making techniques	Fiji	Wai	Tourism
11	Small-scale aquaculture and multi-species cultivation	Malawi	Nkhotakota	Agriculture, Fisheries
12	Traditional smoking and value-added distribution		Chia lagoon	Fisheries
13	Seasonal fishing bans around Mbenji Island by traditional chiefs and communities		Salima	Fisheries
14	Implementation of dry-season agriculture by small-scale irrigation		Chembe	Agriculture
15	Direct sale of fresh fish to urban consumers		Chembe	Fisheries
16	Formation and operation of a tour guide association by local residents		Chembe	Tourism
17	Cape Maclear Cleanup project and recycling center		Chembe	Tourism, Landscape
18	Organic farming by small-scale irrigation linked to educational activities (Sinthana)		Chembe	Agriculture, Tourism
19	Efforts by fishers to create satoumi-type fishing grounds (Chirundu)		Chembe	Fisheries
20	Cultivation and sale of pickled salad melons requiring a small amount of irrigation water	Turkey	Karapinar	Agriculture

Table 2. (A) Summary of the outcomes of autonomous innovations; (B) The number of autonomous innovations achieving outcomes, as categorized in the left columns.

(A)

No.	Outcomes of Autonomous Innovations							
		Contributions to Human Well-Being					Sustainability of Innovations Long: 30 Years or More Medium: 10 to 30 Years Short: Less Than 10 Years	Creating Enforceable Local Rules
	Contribution to Resource Management	Basic Materials for a Good Life	Safety		Health	Good Social Relations		
			Improvement of Resilience	Physical Safety				
1	✓	✓	✓			✓	Medium	
2	✓	✓	✓			✓	Short	
3	✓	✓	✓			✓	Short	
4	✓	✓	✓		✓	✓	Short	
5	✓	✓				✓	Long	✓(Agreement: Manual)
6	✓	✓	✓			✓	Medium	
7	✓	✓	✓	✓		✓	Short	
8	✓	✓	✓			✓	Medium	✓(Quality control)
9	✓	✓	✓			✓	Long	
10	✓	✓	✓		✓	✓	Medium	
11		✓	✓				Medium	
12	✓	✓	✓	✓		✓	Medium	
13	✓	✓	✓	✓		✓	Long	✓ (Committee Enforcement)
14	✓	✓				✓	Medium	
15	✓	✓	✓			✓	Medium	
16		✓	✓			✓	Medium	✓ (Mutual aid mechanism)
17	✓	✓	✓		✓	✓	Short	
18	✓	✓	✓		✓	✓	Medium	
19	✓	✓	✓			✓	Short	
20	✓	✓	✓			✓	Medium	

(B)

Outcomes			Number of Innovations
Contribution to resource management			18
Contributions to human well-being	Basic Materials for a good life		20
	Safety	improving resilience	18
		physical safety	3
	Health		4
	Good social relations		19
Sustainability of innovations	Long		3
	Middle		11
	Short		6
Creating enforceable local rules	Yes		4
	No		16

Table 3. (A) Summary of the remaining challenges of autonomous innovations; (B) The number of autonomous innovations, with the remaining challenges in the left column.

(A)	
No.	**Remaining Challenges**
1	Resource management, network strengthening, ensuring compliance with the rules
2	Agricultural land management, generation change (improvement of resilience)
3	Management improvement, organizational strengthening
4	Resilience improvement
5	Scale expansion, network strengthening
6	Scale expansion, organizational strengthening
7	Landscape conservation, scale expansion
8	Improving resilience, consideration for the vulnerable
9	Profit improvement, ecosystem management
10	Management improvement, network strengthening
11	Management improvement, organizational strengthening
12	Resource management (fishery), resource management (forest), support for the vulnerable
13	Improving profits and ensuring compliance with the rules
14	Profit improvement, technology improvement, conflict resolution
15	Resource management and resilience improvement
16	Quality improvement, conflict resolution
17	Profit improvement, landscape conservation, change of consciousness
18	Scale expansion, technology improvement, network strengthening
19	Resource management, support of the vulnerable, improvement of profits
20	Technology improvement, changes in perceptions

(B)	
Remaining Challenges	**Number of Innovations**
Resource management	5
Environmental management (Agricultural land management, landscape conservation, ecosystem management)	4
Management (profit improvement, scale expansion)	12
Strengthen organization and network	7
Technical development, quality improvement	4
Conflict resolution	2
Improvement of resilience	4
Change of perceptions	2
Caring for the vulnerable	3
Ensuring compliance with the rules	2

The remaining challenges were classified into 10 categories (Table 3B). It was clear that even with the emergence of innovations, a wide variety of remaining challenges in social-ecological systems were recognized. "Management (profit improvement, scale expansion)" and "Strengthen organization and network" were the challenges that remained in many cases.

These results in the outcomes of innovations (Table 2B) and remaining challenges (Table 3B) have many implications for understanding the factors responsible for the emergence of autonomous innovations. In the next section and beyond, we will use these results as a basis for examining the enablers of autonomous innovations and the mechanisms of synergy emergence.

3.2. Factors and Enablers of the Emergence of Autonomous Innovations

Table 4A shows a summary of the factors that are assumed to relate to the emergence of autonomous innovations, and Table 4B summarizes the number of innovations corresponding to these possible factors.

Table 4. (A) Summary of factors related to the emergence of autonomous innovations (QOL: quality of life); (B) The number of autonomous innovations corresponding to the factors related to the emergence of innovations, as categorized in the left columns.

(A)							
No.	**Factors Relating to the Emergence of Autonomous Innovations**						
	Innovator Attributes	**Gender of the Innovator**	**Innovator Motivations**	**External Development Support at the Start**	**Spatial Scale of Activities**	**Number of Participants at the Center of the Action**	**Distribution of Products to International Markets**
1	Secondary resource users (sightseeing)	Male	Livelihood improvement		Medium	Small	✓
2	Agricultural improvement organization, secondary resource users (processing and distribution)	Male	Livelihood stability	✓(inside / outside the area)	Large	Medium	✓
3	Producers (farmers), agricultural improvement organizations	Male	Livelihood improvement	✓(inside/outside the area)	Medium	Medium	✓
4	Producer (farmer)	Male	Livelihood stability, Ecosystem management	✓(inside/outside the area)	Medium	Small	✓
5	QOL improvement organization (outside the area)	Female	Health improvement	✓(outside the area)	Medium	Large	
6	Producers (farmers), government, QOL improvement organizations (outside the region)	Male/Female	Livelihood improvement	✓(outside the area)	Medium	Large	
7	Producer (farmer)	Male	Livelihood improvement	✓(outside the area)	Small	Small	
8	Producers (farmers), livelihood associations	Male	Livelihood improvement, Social status improvement		Medium	Medium	✓
9	Producer (farmer)	Female/Male	Livelihood stability		Medium	Small	✓
10	Secondary resource users (processing and distribution), environmental protection groups (outside the region)	Female	Cultural inheritance, Livelihood improvement	✓(outside the area)	Medium	Small	

Table 4. *Cont.*

(A)							
No.	**Factors Relating to the Emergence of Autonomous Innovations**						
	Innovator Attributes	**Gender of the Innovator**	**Innovator Motivations**	**External Development Support at the Start**	**Spatial Scale of Activities**	**Number of Participants at the Center of the Action**	**Distribution of Products to International Markets**
11	Producer (farmer)	Male	Curiosity		Small	Small	
12	Secondary resource users (processing and distribution), agricultural improvement organizations	Male	Safety, Livelihood improvement	✓(inside/outside the area)	Medium	Medium	
13	Producers (fisheries), traditional leaders, regional committees	Male	Safety		Large	Large	
14	Producer (farmer)	Male	Livelihood improvement		Small	Small	
15	Secondary resource users (processing and distribution)	Male	Livelihood improvement, Friendship		Medium	Small	
16	Secondary resource users (tourism), livelihood associations	Male	Improving social status and livelihoods		Medium	Medium	
17	Secondary resource users (tourism), livelihood associations	Male	Landscape conservation, Livelihood improvement		Small	Small	
18	Community education organizations	Male	Education, Health improvement	✓(outside the area)	Small	Small	
19	Producers (fisheries), regional committees	Female/Male	Livelihood improvement, Ecosystem management	✓(inside/outside the area)	Small	Small	
20	Producer (farmer)	Male	Livelihood improvement		Medium	Small	

(B)		
Factors Relating to the Emergence of Autonomous Innovations		**Number of Innovations**
Innovator attributes	Producer	11
	Secondary resource users	7
	Agricultural improvement organization	3
	QOL improvement organization	2
	Government	1
	Environmental protection groups	1
	Traditional leader	1
	Regional committee	2
	Livelihood association	3
	Community education organizations	1
Gender of the innovator	Male	18
	Female	5
Innovator motivations	Livelihood improvement	13
	Livelihood stability	3
	Ecosystem management	2
	Education	1
	Health improvement	2
	Landscape conservation	1
	Safety	2
	Improving social status	2

Table 4. *Cont.*

(A)							
No.	**Factors Relating to the Emergence of Autonomous Innovations**						
	Innovator Attributes	**Gender of the Innovator**	**Innovator Motivations**	**External Development Support at the Start**	**Spatial Scale of Activities**	**Number of Participants at the Center of the Action**	**Distribution of Products to International Markets**
			Cultural inheritance			1	
			Friendship			1	
			Curiosity			1	
External development support at the start				Yes		10	
				No		10	
Spatial scale of activities					Large	2	
					Middle	12	
					Small	6	
Number of participants at the center of the action						Large	3
						Middle	5
						Small	12
Distribution of products to the international market							6

The spatial scales of the activities and the number of participants at the center of the action were estimated from the narratives. The spatial scales of activities are categorized as large (multiple communities in wide areas), medium (multiple communities in limited areas), and small (single communities). If external connections are observed through the supply chain and tourism, scales covering a single community are considered to be medium. The number of participants at the center of the action is categorized into large (about 100 or more), medium (about 50–100) and small (less than about 50).

Innovator attributes were broadly classified into ten groups (Table 4B). "Producers" accounted for the largest number of innovators, followed by "secondary resource users". The gender of innovators was mostly male. The most common motivation of the innovators was "livelihood improvement", which was closely related to the "basic materials for a good life" index of human well-being.

In the case of the presence or absence of development support at the start of the emergence of innovations, support was provided in 10 cases, with 5 cases from outside the region, and 5 cases from both within and outside the region. The scales and numbers of participants in the innovations were diverse, ranging from a very small number of participants within a community to a scale covering a much broader area, with many participants.

Based on these results, the following two enablers were derived, which play an important role in the emergence of autonomous innovations.

I. Emergence of By-products from Collective Actions

In the innovators' motivations, "livelihood improvement" was found in most cases, suggesting that motivations closer to everyday life triggered innovations (Table 4B). However, some motivations with high public value, such as "ecosystem management", "education", and "health improvement", were also found, as well as motivations that focused on human relationships, such as "improving social status" and "friendship". The motivation "curiosity" did not fit anywhere in the indices of human well-being. Thus, the motivations of innovators are extremely diverse, and innovations can emerge from various motivational triggers.

However, as indicated in Section 3.2, many of the autonomous innovations contributed to "basic materials for a good life", "improvement of resilience" and "good social relations" in the well-being indices. If the main motivation of innovators is "livelihood improvement", it is easy to assume that innovations produce outcomes to improve the "basic materials for a good life". However, many innovations also contributed to "sustainable resource management" and "good social relations". Although they were few, some innovations contributed

to "physical safety" and "health". Even though the collective actions may initially stem from motivations that are closer to the daily lives of innovators, innovation can produce diverse outcomes as by-products, including those connected with public values. Collective actions with public values will also contribute to "good social relations" through the increased awareness of social ties and trust among participants. These observations indicate important processes in the emergence and dissemination of autonomous innovations. The production of by-products in collective actions that differ from the original motivations are one of the important enablers of the emergence of autonomous innovations. With these by-products, autonomous innovations can improve the various aspects of human well-being in parallel and promote the transformation of social-ecological systems.

II. Innovator's Proactive Attitude

Many innovations were found to have continued challenges in the categories of "management (profit improvement, scale expansion)" and "strengthen organization and network". Innovations with these remaining challenges had "sustainable resource management", "basic materials for a good life", "improvement of resilience", and "good social relations" as their outcomes at the same time.

Profit improvement and scale expansion are the basis for the "basic materials for a good life" and the "improvement of resilience". The achievement of "good social relations", is necessary to strengthen organizations and networks. These observations indicated that in the process of the emergence and implementation of autonomous innovations, innovators recognize the "outcomes" of innovations as "challenges".

This recognition seems to reflect the innovator's attitude of not being satisfied with short-term outcomes and constantly striving for improvement. This proactive attitude is another important enabler of the emergence of autonomous innovations. Furthermore, the solution to the remaining challenges can provide new motivations for innovators, and the emergence of collective actions triggered by new motivations can lead to new autonomous innovations.

3.3. Factors Responsible for Synergy Emergence in Integrated Natural Resource Management

Table 5A summarizes the details of six cases of synergies observed among 20 autonomous innovations. The target resources, potential trade-offs, and contents of synergies were extracted from the toolbox. Table 5B shows the number of innovations that fall into the single type and integrated type categories with respect to factors that may promote the emergence of innovations. Regarding the potential trade-offs, there were no trade-offs manifested in the practices of the integrated type, and the risk of trade-offs could be minimal.

Table 5. (A) Details of synergies emerging in autonomous innovations targeting different resources; (B) Comparison of single and integrated types of autonomous innovations on the factors related to the emergence of innovations.

(A)			
No.	**Details of Synergies Emerging among Different Resource Management Practices**		
	Target Resources	**Potential Trade-offs (Not Manifested)**	**Content of Synergies**
1	Tourism, Fisheries	Tourism and fisheries	Growing awareness of conservation by revitalizing coral reef tourism contributes to improving the condition of marine ecosystems and fishery resources and further enhancing the attractiveness of tourism resources.

Table 5. *Cont.*

(A)			
No.	**Details of Synergies Emerging among Different Resource Management Practices**		
	Target Resources	**Potential Trade-offs (Not Manifested)**	**Content of Synergies**
4	Agriculture, Ecosystem	Profitability and ecosystem function	Multi-species cultivation on cacao plantations improves agricultural profitability and at the same time improves agricultural land ecosystem functions
9	Agriculture, Ecosystem	Stabilization of management and improvement of ecosystem functions	The introduction of various crops in rubber plantations realizes stable management and improvement of agricultural land ecosystem functions.
11	Agriculture, Fisheries	Distribution of water resources for agriculture and aquaculture	The combination of agriculture and aquaculture by using abundant water resources achieves improved resilience by diversifying products.
17	Tourism, Landscape	Attractiveness of tourism resources and living environment	Recycling activities promote the reduction of waste on the shores of lakes and in villages, contributing to the attractiveness of tourism resources and the improvement of landscapes and living environments.
18	Agriculture, Tourism	Sales and purchase of local products and expanding organic farming	Active purchase and usage of local agricultural products by tourism lodges contributes to improving lodge services and expanding and revitalizing sales channels for organic farming.

(B)			
Factors Relating to the Emergence of Autonomous Innovations		**"Single Type" (14 Cases)**	**"Integrated Type" (6 Cases)**
Innovator attributes	Producer	8	3
	Secondary resource users	5	2
	Agricultural improvement organization	3	0
	QOL improvement organization	2	0
	Government	1	0
	Environmental protection groups	1	0
	Traditional leader	1	0
	Regional committee	2	0
	Livelihood association	2	1
	Community education organizations	0	1
Gender of the innovator	Male	12	6
	Female	4	1

Table 5. *Cont.*

(B)			
Factors Relating to the Emergence of Autonomous Innovations		**"Single Type" (14 Cases)**	**"Integrated Type" (6 Cases)**
Innovator Motivation	Livelihood improvement	11	2
	Livelihood stability	1	2
	Ecosystem management	1	1
	Education	0	1
	Health improvement	1	1
	Landscape conservation	0	1
	Safety	2	0
	Improving social status	2	0
	Cultural inheritance	1	0
	Friendship	1	0
	Curiosity	0	1
External development support at the start	Yes	8	2
	No	6	4
Spatial scale of activities	Large	2	0
	Middle	9	3
	Small	3	3
Number of participants at the center of the action	Large	3	0
	Middle	5	0
	Small	6	6
Distribution of products to the international markets		3	3

Six autonomous innovations from three countries achieving integrated resource management with synergies are shown with their potential trade-offs and the content of synergies in Table 5A. Innovations that did not achieve synergies were omitted. The numbers at the leftmost column are the innovation numbers in Table 1.

The factors related to the emergence of autonomous innovations were compared between the single-type and integrated-type innovations. There was no marked difference between the two types for most of the factors summarized in Table 5B. However, regarding innovators' motivations, 11 cases of the single type were motivated by "livelihood improvement", compared with two cases of the integrated type. A total of four cases of the integrated type were motivated by "ecosystem management", "education", "health improvement", and "landscape conservation", compared with two of the single type. Regarding the spatial scale of activities, three cases in the single type were small-scale, while two cases were medium to large-scale. In terms of the integrated type, there were no cases of large-scale activities, and three cases each were on medium- and small scales. The number of participants in the single type ranged from small to large, but all cases in the integrated type were small. The two types also showed differences in their outcomes. Table 2A shows four innovations, categorized into the single type (numbers 5, 8, 13, and 16) and creating enforceable local rules, out of the 14 cases, while none of the six cases in the integrated type did so.

From these results, the following three enablers were identified that play an important role in synergy creation for integrated natural resource management.

I. Emphasis on Public Values

"Ecosystem management", "education", "health improvement", and "landscape conservation" in Table 5B are motivations that place more emphasis on public values. The innovators who were responsible for the emergence of integrated-type innovations were likely to focus more on these highly public values from the early stages of collective actions.

The realization of public values through collective actions across multiple resources created synergies among practices for managing different natural resources in parallel. For example, number 18 (organic farming by small-scale irrigation, linked to educational activities by Sinthana project), an innovation in Chembe, Malawi, realized synergies through collective actions motivated by "education" and "health improvement". Organic farming contributed to the public value of the health of children who were the target of education and produced synergies with tourism industries through the effective use of its organic products as a tourism resource. In the case of number 4, "multi-species cultivation on cacao farmland " in Polewali, Indonesia, the collective actions triggered by the highly public motivation of proper management of the agroecosystem improved the ecosystem function of the farmland through the cultivation of various crops. The collective actions with public values also improved the stability and resilience of agricultural production and the health of the farmers. An enabler contributing to synergy creation in integrated natural resource management is the emphasis on public values by innovators to create collective actions in the early stages.

In the outcomes of innovations, one single-type innovation (number 10) compared to three (numbers 4, 17, and 18) in the integrated type contributed to the "health" index of human well-being (Table 2A), which had a high public value. Thus, the public values contained in the motivation of innovators are also manifested in the outcomes assessed by the indices of human well-being.

II. Self-sustained and Adaptive Collective Actions

The spatial scale of activities and numbers of participants at the core of actions in the integrated type were smaller than with the single type (Table 5B). There were no examples of creating enforceable local rules in the integrated type (Table 2A). Creating enforceable local rules may be incompatible with synergy creation in the integrated type.

These results suggest that self-sustained and adaptive decision-making and actions are more suitable for synergy creation in integrated natural resource management, rather than management by enforceable rules. Collective actions on a relatively small spatial scale and participants have a limited number of stakeholders, making decision-making easier and more adaptive. The potential of self-sustained, flexible, and adaptive collective actions is an important enabler for synergy emergence in integrated natural resource management.

III. The Improvement of Supporting Services

In four cases of the integrated type, the synergies included improvements in supporting services, one of the four categories of ecosystem services [36]. In the remaining two cases, the synergies were based on the existence of rich supporting services. Thus, supporting services may form the basis for synergy generation in integrated natural resource management.

Number 1 (community-based marine tourism) emerged in Gorontalo, Indonesia; the synergy between the tourism and fishing industries was promoted by the supporting services provided by the rich coral reefs. In the case of number 11 (small-scale aquaculture and multi-species cultivation) in Nkhotakota, Malawi, the supporting services of abundant water resources were the basis for synergies between agriculture and small-scale aquaculture.

Number 17 (the Cape Maclear Cleanup project and recycling center) in Chembe, Malawi, enhanced the synergy between the improvement of the landscape, supporting the living environment and the attractiveness of tourism resources, through recycling waste. Synergy was created through the supporting services provided by the improved landscape.

Number 18 (organic farming by small-scale irrigation linked to educational activities)m in the same community, improved the supporting services of agroecosystems through the revitalization of organic farming. Through organic farming, the supporting services of

agroecosystems were improved to promote synergy between the expansion of organic agricultural production and the use of the products by the tourism industry.

Number 4 (multi-species cultivation on cacao farmland) in Polewali, Indonesia, and number 9 (the diversification of production activities in natural rubber plantations) in Rayong, Thailand, were based on the management of agricultural lands, and the enhancement of ecosystem functions and services were synergistically connected to the improvement of agricultural profitability and management stability.

These results suggest that collective actions, including the usage or improvement of supporting services, are important enablers for synergy emergence.

4. Conclusions

These autonomous innovations had the outcomes of promoting sustainable resource management and contributing to the improvement of multiple aspects of human well-being. All the autonomous innovations analyzed herewith were characterized by their simultaneous contribution to the improvement of multiple aspects of human well-being, suggesting that outcomes different from the innovator's original motivations have emerged as by-products.

Innovations that started from the innovator's motivations closer to daily life, such as improving or stabilizing their lives and livelihoods, generated highly public outcomes as by-products. The creation of diverse by-products of collective actions promotes the emergence of autonomous innovations as an important enabler. The proactive attitude of innovators, who are not satisfied with the short-term outcomes, is another enabler of autonomous innovations that improve resource sustainability and human well-being including resilience toward the transformation of social-ecological systems. Even though various remaining challenges were recognized in all innovations, these challenges do not undermine the positive impacts of innovations and seem to open new opportunities for the emergence of further innovations through the proactive attitudes of innovators.

Although the number of cases achieving synergies was limited, the emergence of synergy in integrated natural resource management was closely related to the emphasis on public values, self-sustained and adaptive collective actions, and the improvement of supporting services. Public value-oriented collective actions are deemed to be important enablers of synergy emergence in integrated natural resource management. The conditions to promote self-sustained and adaptive collective actions are also considered important. Collective actions, including the usage of rich supporting services or their improvement, are considered another important enabler.

These results provide an important basis for understanding the mechanisms of the emergence of autonomous innovations among socially vulnerable people in developing countries that can trigger the transformation of social-ecological systems in sustainable and equitable directions. They also contribute significantly to our understanding of the mechanisms by which autonomous innovations can create synergies among multiple resource management practices to enhance resilience. We hope that these results will contribute to mobilizing the transformation of social-ecological systems by socially vulnerable people toward the sustainable futures.

To this end, the value of the emergence of innovations by socially vulnerable people around the world should be widely recognized. Although the quantitative analysis in this paper does not provide strong empirical bases for the direct transferability of innovations to other regions, the practitioners in the various regions will obtain important suggestions to their own actions through this study. Therefore, these innovations and innovators must be effectively supported at all levels, from local to global, to actively promote autonomous innovations that can lead to the transformation of social-ecological systems. Policies and interventions should be designed based on the conditions that will enable the enhancement of public values and supporting services as a by-product of collective actions. The creation of such conditions will expand the opportunities for innovators with a proactive attitude to play a self-sustained and adaptive role that will pave the way for improving sustainability

and human well-being, strengthening resilience, and transforming social-ecological systems. Further comprehensive analysis of the mechanisms of the emergence of autonomous innovations explored in this study is warranted.

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